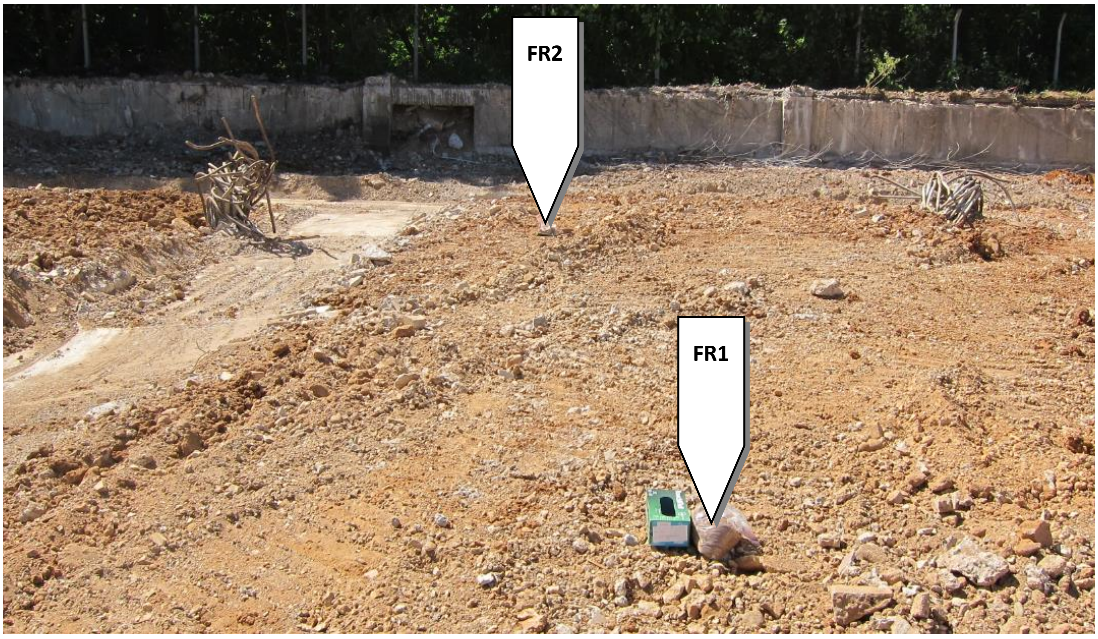
k_0	-18.236
minus k_0 therefore k_1	18.236
therefore alpha	0.01
p_1	0.99
Estimate against H0 being true	99%
Is p_1>95%	TRUE

The conclusion is that there is a very high degree of confidence H0 is rejected *i.e.* the true mean concentration is less than the critical concentration.

8.5 Firing Range Assessment

The base of the below ground firing range (described in *Section 2.4.3*) was subject to composite sampling and chemical analysis during the John F Hunt removal process (June 2018). It is important to note that the samples were obtained from approximately 2 metre below the current site surface at the base of the previous basement/firing range (*Photograph 8-1*).



Photograph 8-1: *Firing range sample points (FR01 and FR02)*

8.5.1 Soil Chemical Data

The two samples FR1 and FR2 were scheduled for laboratory analysis (*Table 8-3*). The first stage of initial assessment was to screen out those compounds that were not recorded above the laboratory analytical method detection limits (MDLs). These are provided below and have not been considered further:

- Total Cyanide (MDL 1 mg/kg);
- Total Phenols (MDL 1 mg/kg);
- Selected Polyaromatic Hydrocarbons (PAHs) (*i.e.* Acenaphthylene and Dibenz(a,h)anthracene – Individual MDL 0.05 mg/kg);
- Cadmium (MDL 0.2 mg/kg), Chromium (hexavalent) (MDL 4 mg/kg), Mercury (0.3 mg/kg) and Selenium (1 mg/kg);
- Monoaromatics (*i.e.* Benzene, Toluene, Ethylbenzene, p & m-xylene, o-xylene, MTBE (Methyl Tertiary Butyl Ether - Individual MDL 1 µg/kg)
- TPH-CWG - Aliphatic >C5 - C6 (MDL 0.001 mg/kg);
- TPH-CWG - Aliphatic >C6 – C8 (MDL 0.001 mg/kg);
- TPH-CWG - Aliphatic >C8 – C10 (MDL 0.001 mg/kg);
- TPH-CWG - Aromatic >C5 – C7 (MDL 0.001 mg/kg);
- TPH-CWG - Aromatic >C7 – C8 (MDL 0.001 mg/kg);
- TPH-CWG - Aromatic >C8 – C10 (MDL 0.001 mg/kg);
- All VOCs (MDL 1 µg/kg) including dichloromethane (MDL 100 µg/kg);
- All SVOCs (MDL variable) except for selected PAHs *i.e.* Naphthalene, Acenaphthene, Dibenzofuran, Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Indeno(1,2,3-cd)pyrene, Benzo(ghi)perylene;
- PCBs (PCB Congener 28, PCB Congener 52, PCB Congener 101, PCB Congener 118, PCB Congener 138, PCB Congener 153 and PCB Congener 180) (Individual MDL 0.001 mg/kg); and
- PCB (total) (MDL 0.007 mg/kg).

In-line with the Tier 1 assessment criteria (*Section 8.3.2*) neither of the two samples exceeded any of the stated screening thresholds. The analytical results are provided in *Annex D*.

However, Asbestos (Chrysotile Loose Fibrous Debris) was detected in one of the two samples (FR1). As this basement structure was subject to an asbestos removal process, prior to demolition, it is conceivable that some limited fibre release could have occurred. It is important to note that the samples were obtained from approximately 2 metre below the current site surface (*i.e.* well below the proposed finish floor level of the planned development).

9 Contaminant Characterisation

9.1 Introduction

This section aims to characterise the nature of the potential contaminants, identify potential source areas and define the contaminant distribution, to prioritise the contaminants of concern and key risk drivers in terms of potential impacts on the local water environment.

The assessment of the nature and distribution of contamination in the soils and groundwater beneath the site is based on the information presented within previous assessments completed by Delta-Simons and the recent investigations completed by EAME.

9.2 Nature and Distribution of Soil Organic Contamination

9.2.1 Inorganic Contaminants

In general concentrations of inorganic contaminants (including heavy metals) were recorded at low levels. However, slightly elevated concentrations of Arsenic were found to be ubiquitous in the shallow soil horizon (approximately 0.5-4.0m bgl). This has been assessed and discussed within *Section 8*.

9.2.2 Organic Contaminants

As outlined, volatile organic compound (VOC) profiling was undertaken using a Photo-ionisation Detector (PID) during both the borehole and windowless sampler investigations. In general, PID readings were low (<5ppm) but elevated readings (>40ppm) were recorded in BH01-17 (approx. 3.5m-11.0m bgl) and BH02-17 (approx. 4.5m-8.0m bgl). The VOC profiling suggests that localised residual petroleum hydrocarbon contamination is present in the soils beneath the former tank farm/remediation area.

Elevated PID readings were also recorded in all borehole locations at depths of c. 25-26m but this is not considered to be reflective of conditions within the unsaturated zone soils and is discussed in more detail in the Non-Aqueous Phase Liquid (NAPL) section below.

The results of the chemical analysis on samples of soil from the site (EAME 2017) are generally consistent with the VOC profiling and suggest that residual organic contaminant impact is primarily in the former remediation area. However, elevated concentrations of petroleum hydrocarbons were also recorded in shallow soils in WS01-17 (c. 770mg/kg TPH, 0.40m bgl) and WS02-17 (c. 1,440mg/kg TPH, 0.40m bgl). Location WS01-17 is near a possible (but not confirmed) underground fuel storage tanks (USTs) and WS02-17 is located between the former wash down area and the former boiler house and above ground fuel storage tanks (AST).

A summary of the soil contaminant distribution (*i.e.* exceedences of Tier 1 screening values) is provided in *Annex D – Figure D1*.

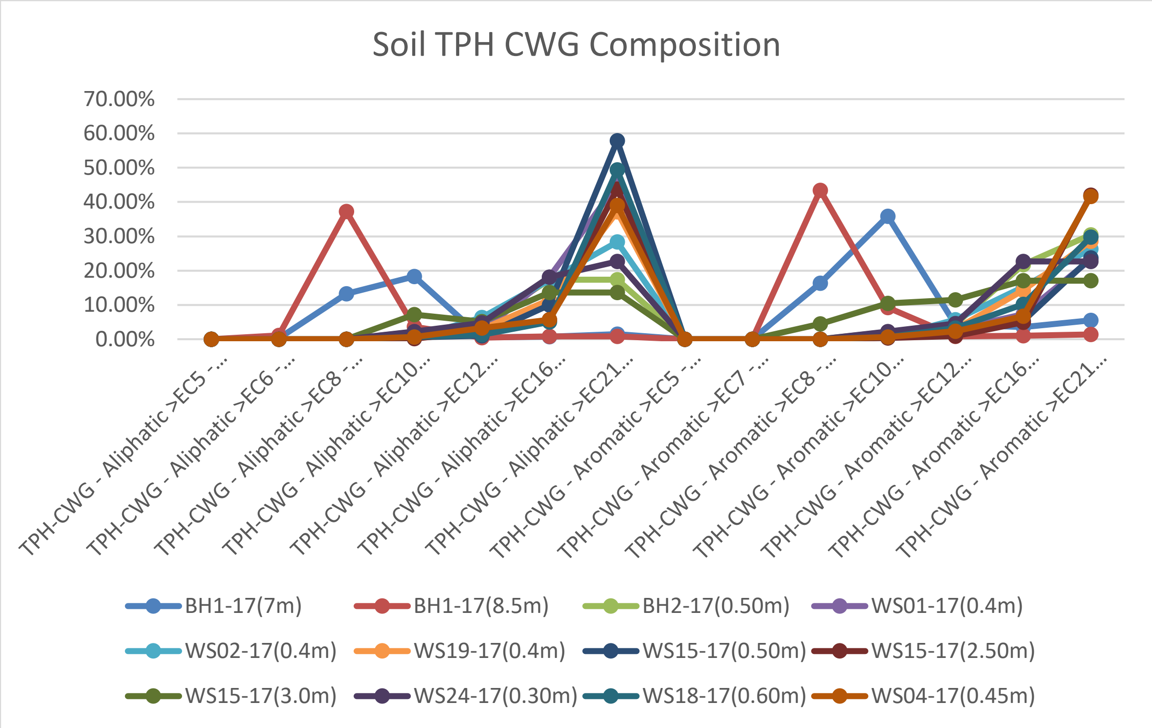


Figure 9-1: *Soil TPH results from the site (EAME 2017)*

The dominant TPH fractions in the soils are the C21-35 aliphatic fraction and to a lesser extent the C21-35 aromatic fraction. However, it is notable that in the soils sampled from BH01-17 (7.0m and 8.50m) the composition appears to be different with the C8-12 aliphatic fractions and C8-12 aromatic fractions dominant.

This is likely to be reflective of the different sources and depths. The samples from BH01-17 were collected from depths of 7.00m and 8.50m bgl respectively and are within the former tank farm/remediation area and are reflective of more mobile residual TPH fractions.

Conversely the other soil samples are all from shallow depths (typically <1.0m) and the dominant TPH fractions are heavy end, low solubility compounds that are less likely to mobilise and migrate vertically via the unsaturated zone soils.

9.3 Non-Aqueous Phase Liquid (NAPL)

The Delta-Simons DQRA report (2005) records the presence of a thin layer (0.05m) of Light NAPL (LNAPL) on the groundwater and subsequent analysis was undertaken on two samples of LNAPL and also an LNAPL saturated soil sample collected from the saturated chalk (below groundwater level c. 26.0m bgl). Delta-Simons state that the analysis shows the contamination from the soil samples comprises predominantly C8-C11 alkane range and the LNAPL comprises 'White Spirit' with the highest concentrations in the 'C7-C12 range.'

During the recent site investigation works undertaken by EAME no LNAPL was observed during the site investigation works but PID profiling highlighted elevated levels of volatile organic compounds at depths of between 22.5m and 25m bgl, which is approximately coincidental with the groundwater level within the putty chalk and is considered to be reflective of organic contamination within the groundwater rather than a physical LNAPL layer.

During return monitoring (March 2018) a trace thickness of LNAPL (c. 1 mm) was recorded in BH01-17, which is located within the former remediation area. The UKAS laboratory (i2 Analytical Ltd) confirmed that the sample obtained from BH01-17 (March 2018) had 'no product or emulsion' present within the sample. In addition, comparison of the recorded petroleum hydrocarbon concentrations sampled from BH01-17 with pure phase solubilities for individual carbon fractions suggests that concentrations are > solubility and therefore may be indicative of the presence of LNAPL.

9.4 Nature and Distribution of Groundwater Contamination

9.4.1 Inorganic Contaminants

In general, inorganic contaminants (including heavy metals) were recorded at low concentrations and the results suggest that there has been minimal leaching via the unsaturated zone soils and that impacts to the underlying groundwater are negligible.

9.4.2 Organic Contaminants

An appraisal of the analytical results of the groundwater samples (EAME 2017) suggests that the highest residual concentrations have been recorded in the former tank farm/remediation area. However, elevated TPH concentrations are also recorded in the other monitoring wells and in general suggest that concentrations gradually decrease from the source area (BH01-17) to the south eastern site boundary (BH302s & BH06d-17).

The exceptions are BH05-17d and BH302d which have recorded concentrations below the limit of detection for the laboratory method applied (<LOD).

A summary of the groundwater contaminant distribution (C8-10 & C10-16 Aromatics) is provided in *Figure 9-2* and *Figure 9-3*.

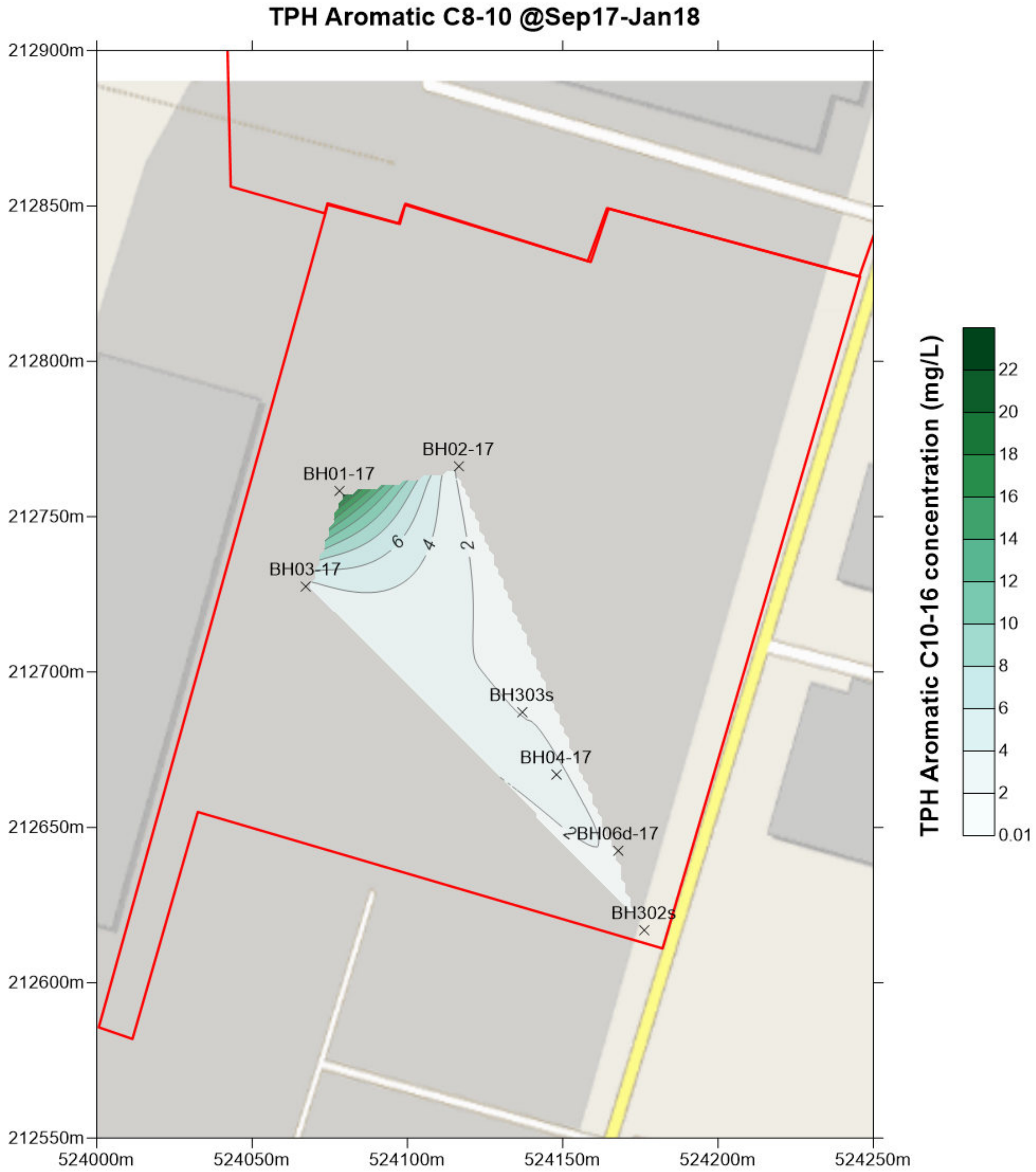


Figure 9-2: *Groundwater contaminant distribution (C8-10 Aromatics)*

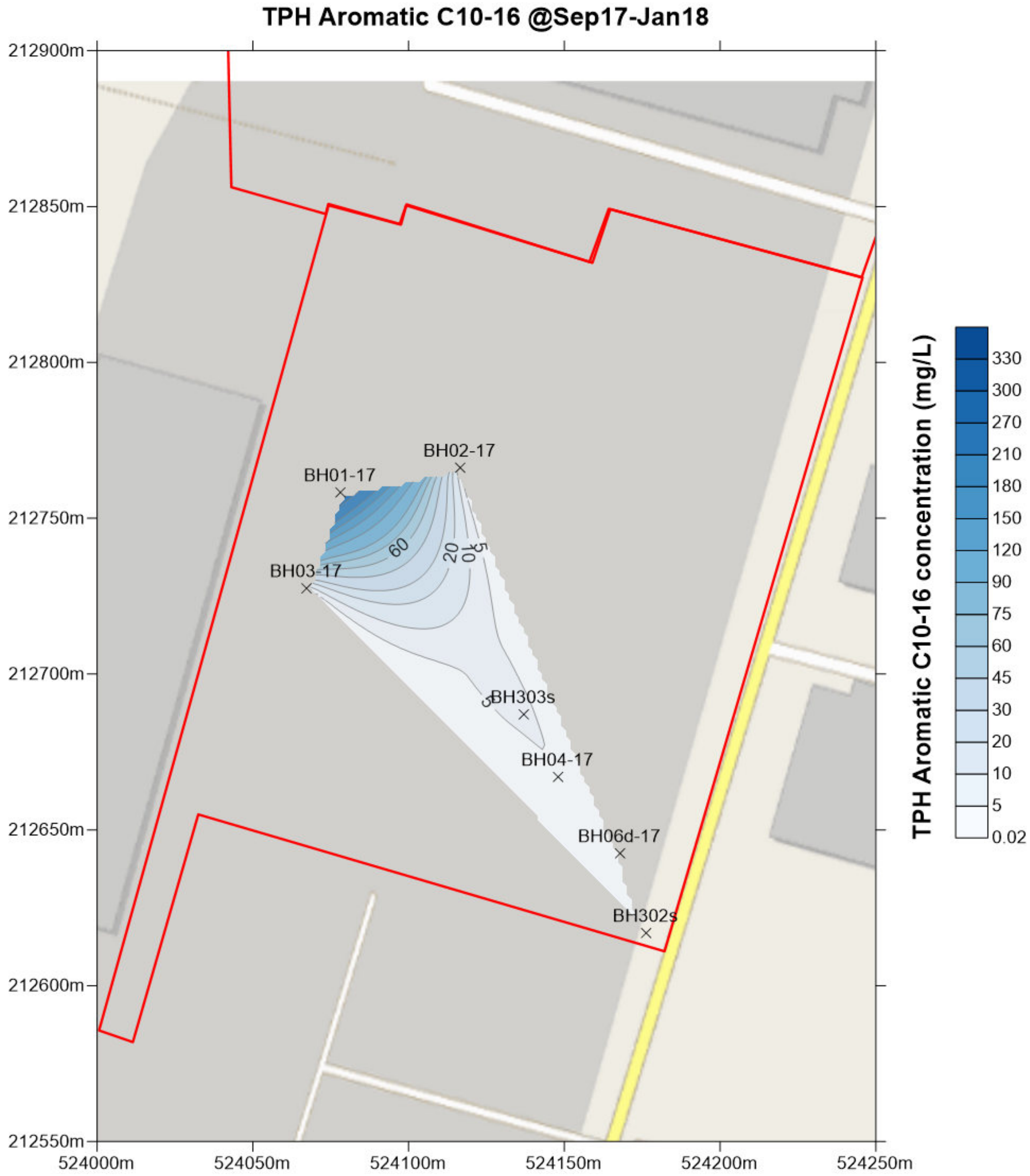


Figure 9-3: *Groundwater contaminant distribution (C10-16 Aromatics)*

The groundwater TPH composition, based on the results of the chemical analysis on samples from the site (EAME 2017), is outlined in *Figure 9-4*. The results and characteristics suggest that the C8-10 and C10-12 aromatic fractions are mobile and are migrating via groundwater.

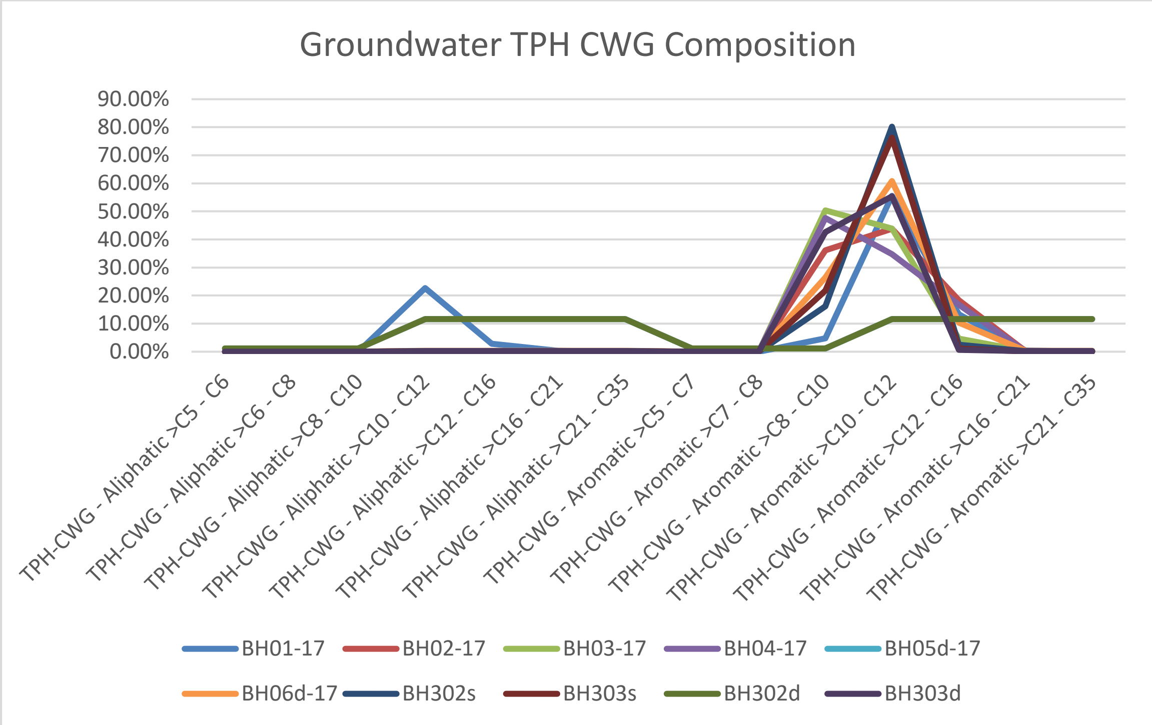


Figure 9-4: *Groundwater TPH composition (EAME, 2017)*

In terms of the petroleum hydrocarbon characteristics the groundwater samples differ from those in the soils, with the dominant fractions being the C8-10 and C10-12 aromatic fractions. In monitoring well BH01-17 (and to a lesser extent BH302d) there is also a slight peak in the C10-12 aliphatic fraction but this is not visible in the monitoring wells that extend toward the south eastern site boundary.

9.4.3 Dichloromethane

Elevated concentrations of Dichloromethane (DCM) were recorded in groundwater samples collected from monitoring wells BH01-17, BH02-17, DS01 and BH39 which are near the former tank farm/remediation area.

In all other monitoring wells sampled concentrations of DCM were <LOD suggesting that it is a static residual legacy concentration, not actively migrating via groundwater.

9.5 Risk Characterisation

In accordance with current best practise guidance, petroleum hydrocarbons are classified as hazardous substances.

Table 5.1 within the CL:AIRE document Petroleum Hydrocarbons in Groundwater: Guidance on assessing petroleum hydrocarbons using existing hydrogeological risk assessment methodologies (2017) provides a ranking of potential risk to groundwater and groundwater-dependent receptors based primarily on the solubility and the organic carbon to water partition coefficient (Koc).

When considering the information within this document as well as the contaminant concentrations, distribution and risk ranking parameters (solubility and KOC) it is evident that Benzene and Toluene pose greater risk to the water environment. However, these have been recorded <LOD or at relatively low concentrations in the groundwater beneath the site.

Appraisal of the groundwater analytical results suggests that the greatest impact is beneath the former tank farm area (BH01-17) with the highest concentrations recorded in the following petroleum hydrocarbon fractions:

- C8-C16 Aliphatics (124,000 µg/l);
- C8-C10 Aromatics (23,000 µg/l);
- C10-C16 Aromatics (335,000 µg/l);

The concentrations of the C8-C10 aromatic fraction that have been recorded in BH01-17 are similar to the sum concentration of 23,000 µg/l of the following individual aromatic compounds, as outlined within *Table 9-1*.

Table 9-1: *Aromatic concentrations BH01-17*

Compound	Recorded Concentration (µg/l)
Ethylbenzene	223
p & m-Xylene	1,570
o-Xylene	2,120
Isopropylbenzene	376
n-Propylbenzene	1,410
1,3,5-Trimethylbenzene	4,420
1,2,4-Trimethylbenzene	13,200
sec-Butylbenzene	118
p-Isopropyltoluene	579
Total	24,016 µg/l

On this basis and considering the recorded elevated concentrations in other groundwater monitoring wells, the C8-10 aromatic fraction has been considered as a key risk driver.

Although the C8-C16 aliphatic fraction has been recorded at elevated concentrations in BH01-17 it is generally <LOD in other monitoring wells and is considered to have low risk ranking with the solubility of these compounds is <1mg/l. On this basis the C8-C16 aliphatic fraction is not considered to be a key risk driver.

The highest petroleum hydrocarbon concentrations have generally been recorded in the C10-16 aromatic fraction, which (according to the CL:AIRE guidance) includes high mobility compounds such as Xylenes and Naphthalene. These have been recorded at high concentrations beneath the former tank farm area (BH01-17, 1,840ug/l). On this basis the C10-16 aromatic fraction is considered to be a key risk driver.

The analytical results suggest that Dichloromethane in groundwater is restricted to the former tank farm / remediation area. However, due to its known historical presence at the site and potential toxicity and mobility it is also considered as a key risk driver.

In summary, the following contaminants are considered the key risk drivers at the site:

- C8-C10 Aromatics;
- C10-C16 Aromatics; and
- Dichloromethane (DCM).

10 Hydrogeological Conceptual Site Model

10.1 Introduction

The information within previous assessments completed by Delta-Simons along with the data from the recent investigation completed by EAME and summarised in the earlier sections of this report has been used to formulate a Hydrogeological Conceptual Site Model (HCSM) that has been used as the basis for the subsequent Hydrogeological Detailed Quantitative Risk Assessment presented below.

A cross section and schematic representation of the HCSM is outlined in *Figure 10-1*.

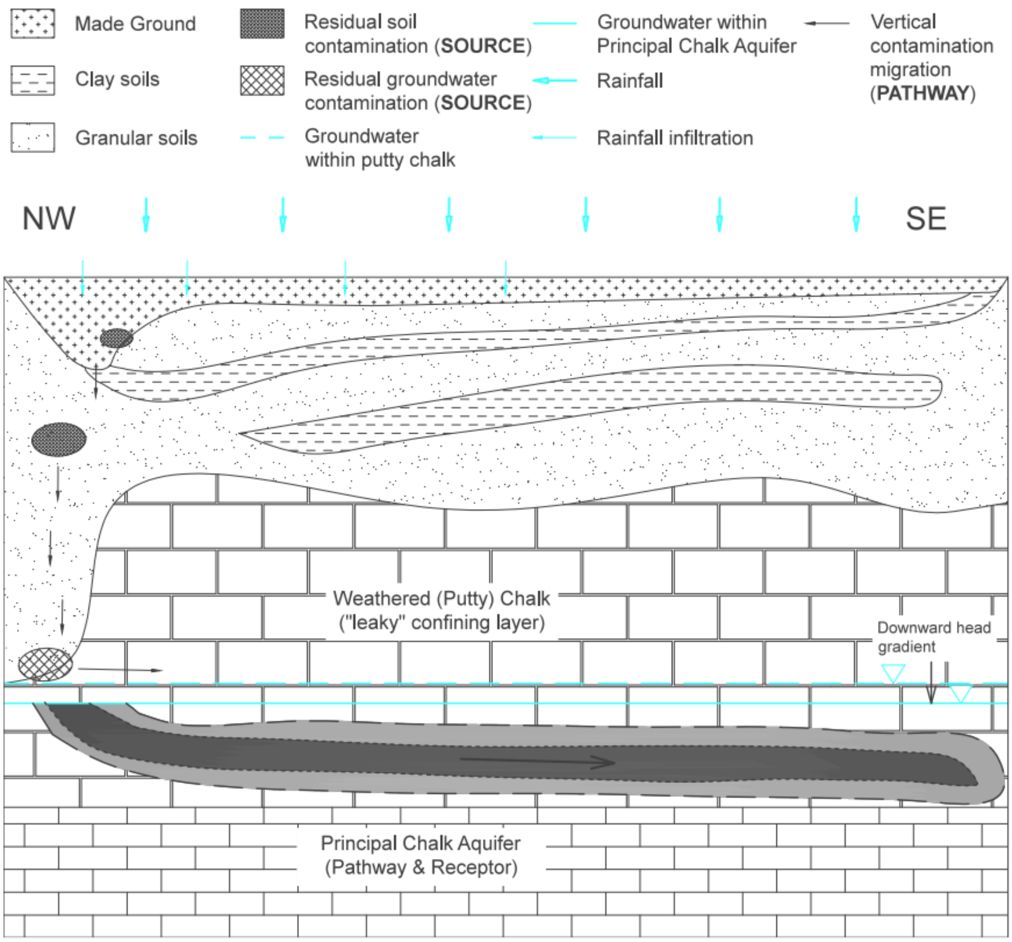


Figure 10-1: *Cross section and schematic representation of the HCSM*

10.2 Hydrometric Data

The nearest known surface water bodies are the River Lea and River Mimram, located approximately 2-km WSW and 4-km ESE respectively. Information within the UK Hydrometric register for the River Mimram (Panshanger Park gauging station) indicates that the mean annual rainfall, run-off and loses for this gauging station are 655 mm, 126 mm and 529 mm respectively.

In addition, the catchment geology for the gauging station is similar to that of the gauging station (*i.e.* chalk overlain by glacial deposits) and so it is considered reasonable to assume that the Base Flow Index (BFI) of 0.93 would be similar.

10.3 Recharge

Based on the current understanding of the on-site conditions, the HCSM predicts that recharge across the site will vary according to the ground cover and unsaturated zone geology.

At present the ground surface cover across the site is estimated to comprise approximately 60% hardcover and 40% soft surface cover. Following development, the site is anticipated to comprise similar proportions, but within the HCSM a conservative approach has been adopted and proportions of 70% hardcover and 30% soft cover have been considered.

In the areas of soft ground cover, rainfall infiltration will be controlled by the Soil Moisture Deficit and rates of evapotranspiration. In areas of hard cover rates of run-off will be relatively high and rainfall infiltration will be limited to localised cracks in hard standing and inputs from artificial mechanisms such as leaking drains (assumed to be 80% efficient).

It is likely that following development, infiltration via leakage will decrease as the quality of the hard cover and drainage networks will improve.

It is considered likely that direct rainfall recharge of groundwater beneath the site is relatively low and it is anticipated that this recharge mechanism will only be significant in the winter months.

There is potential for recharge of the groundwater beneath the site via off-site areas where soft ground cover is present, such as the rear gardens associated with residential housing and areas of green space around Coronation Fountain to the west and north west. However, this would be limited by the extent (outcrop), geological heterogeneities and hydraulic continuity of the superficial deposits.

This hydrometric data presented above has been used to estimate the rainfall infiltration over the site following development to be 1.22E-04m/d which is similar to the value of 34.9 mm/y applied by Delta-Simons during previous groundwater modelling works.

The data is provided in the General Hydraulic Parameterisation calculation workbook presented in *Annex E*.

10.4 Groundwater Conditions

The data within the previous assessments completed by Delta-Simons along with the data from the recent investigation completed by EAME have been used to appraise the groundwater conditions beneath the site.

10.4.1 Aquifer Properties

Reference to information on the BGS online viewer indicates that chalk aquifer beneath the site is a, 'Principal aquifer in UK up to 450 m thick and yielding 50 to 100 l/s from large diameter boreholes and up to 300 l/s from adited systems. Hard to very hard, good quality water.'

Reference to the Environment Agency (EA) document The Physical Properties of Major Aquifers in England and Wales (Allen, DJ et al 1997) indicates that the hydrogeology of the chalk in the region of the site varies according to topographical setting with the highest transmissivity values (>1000m^2/d) recorded in the dry valley areas and with transmissivity values several orders of magnitude lower (c. 50m^2/d) encountered in the topographically higher interfluve areas. As outlined the site is in a relatively high lying area between two river valleys (River Lea and River Mimram) area and on this basis would be anticipated to have a transmissivity at the lower end of the published range (*i.e.* c. 50-200m^2/d).

Assuming that the most transmissive section of the chalk is the top 20 metres then this would suggest a hydraulic conductivity in the range of 2.5 m/d to 10 m/d.

Reference to the previous groundwater risk assessment reports completed by Delta-Simons indicates that hydraulic testing undertaken by URS Dames and Moore and QDS on the shallow and deeper sections of the chalk aquifer in two boreholes (BH302 & BH303). The hydraulic testing resulted in the following estimates of hydraulic conductivity (*Table 10-1*).

Table 10-1: *Aquifer hydraulic conductivity*

Test Type	Aquifer Section	Estimated Hydraulic Conductivity (m/d)
Packer/Lugeon Test	Shallow Deep	0.33 2.07
Pumping Test	Shallow	0.22

Based on the recorded groundwater levels beneath the site the lower hydraulic conductivity (K) values could have justifiably been applied. However, in order to ensure conservatism and consistency with the HCSM (which conservatively assumes potential migration of contaminants into the deeper groundwater) the higher K value has applied in the modelling.

10.4.2 Groundwater Flow

Review of the SPZ data on the EA website indicates that regional groundwater flow in the chalk is to the south east which is supported by the Hydrogeology Map of England and Wales (ref. BGS 1:625,000 1977) for the area, which confirms that the site lies between the 60m and 0m AOD groundwater elevation contours.

The recent EAME ground investigation works included the construction of multi-level groundwater monitoring wells with screened sections in both the more weathered 'putty' Chalk and the underlying Principal Chalk Aquifers.

The groundwater level data from the most recent monitoring undertake on the wells installed during the EAME ground investigation is summarised in *Table 10-2*.

Table 10-2: *Groundwater level data*

Monitoring Well	Drilled Depth (m bgl)	Screened Depth (m bgl)	Recorded GW Strike Level (m bgl)	Rest Water Level (m AOD)
BH01-17	28.00	21-28	23.50	22.04 (62.853)
BH02-17	28.50	21.5-28.5	24.90	22.66 (62.807)
BH03-17	28.00	21-28	23.50	22.27 (62.922)
BH04-17	28.00	21-28	22.50	23.20 (62.081)
BH05-17	41.00	35-41	23.50	22.75 (62.566)
BH06-17	38.00	33-38	23.00	22.62 (62.361)

The monitoring data suggest that groundwater within the chalk is confined and that in general there is an upward head gradient. However, comparison of rest water levels in the monitoring wells installed at shallower and deeper depths (*e.g.* BH03-17 and BH05-17) suggests that there are two groundwater bodies within the chalk and that there is a downward head gradient between the shallow and deeper groundwater within the chalk.

A similar trend is observed in the monitoring wells previously installed *i.e.* BH302s/BH302d and BH303s/BH303d.

This is not uncommon in the chalk where an upper layer of weathered 'putty chalk' develops and acts as a leaky confining layer between shallow groundwater contained in the putty chalk itself and the deeper groundwater within the Principal Chalk Aquifer.

The recent groundwater monitoring data (Jan 2018) has been used to produce groundwater contour plots considering the shallow groundwater in the putty chalk (*Figure 10-2*) and the deeper groundwater within the Principal Chalk Aquifer (*Figure 10-3*). There is some variation in the groundwater contour plots for the shallow and deeper groundwater but in general they are consistent with the regional trend and suggest that groundwater flow is in a south easterly direction.

10.4.3 Fluctuation in Groundwater Elevation

Review of groundwater level data for existing monitoring wells from the period July 2005 to March 2014 suggests that fluctuation in groundwater level varies between approximately 1.0 m to 2.5 m, with an average fluctuation range of 1.45m. In the context of regional variations in the groundwater level within the chalk the observed fluctuations are considered to be reasonably small and suggest that any 'smear zone' is relatively narrow.

<u>Hydraulic Gradient</u>

The hydraulic gradient has been estimated based on the site-specific groundwater monitoring data and also considers the input value used in the previous groundwater risk assessment completed by Delta Simons. As discussed above, variations in the groundwater level are relatively small and the hydraulic gradient doesn't vary significantly. As such and in keeping with the steady state modelling approach an average value has been applied that is considered appropriate and reflective of aquifer conditions.

10.4.4 Groundwater – Surface Water Interactions

As outlined the BFI for the nearest gauging station is 0.93, which suggests that in this catchment groundwater provides a significant contribution to surface water flow. However, the nearest known surface water courses are >1.5 km from the site and thus potential for interaction of groundwater in the Principal Chalk Aquifer beneath the site and known surface water courses is considered to be minimal.

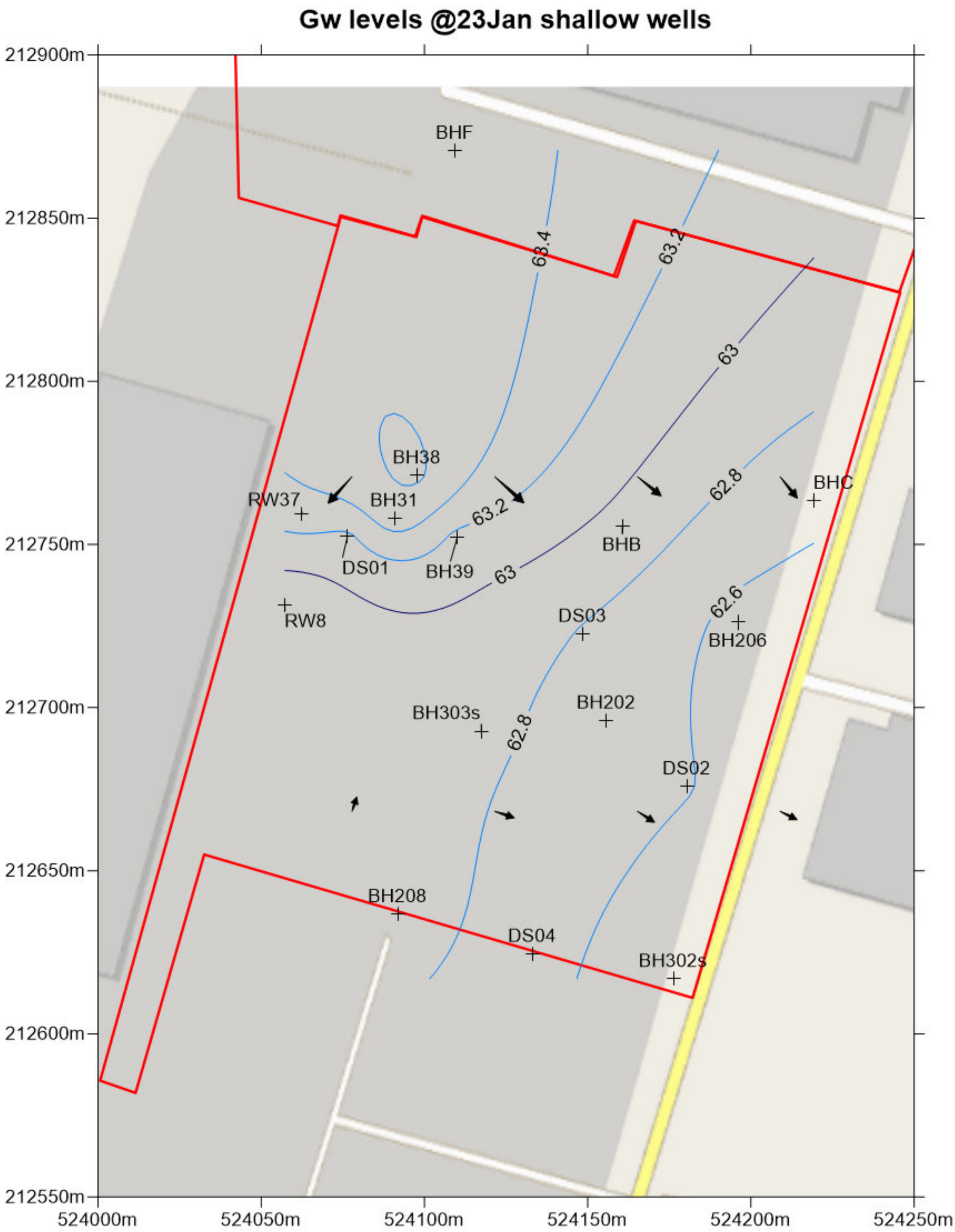


Figure 10-2: *Groundwater levels within the shallow wells*

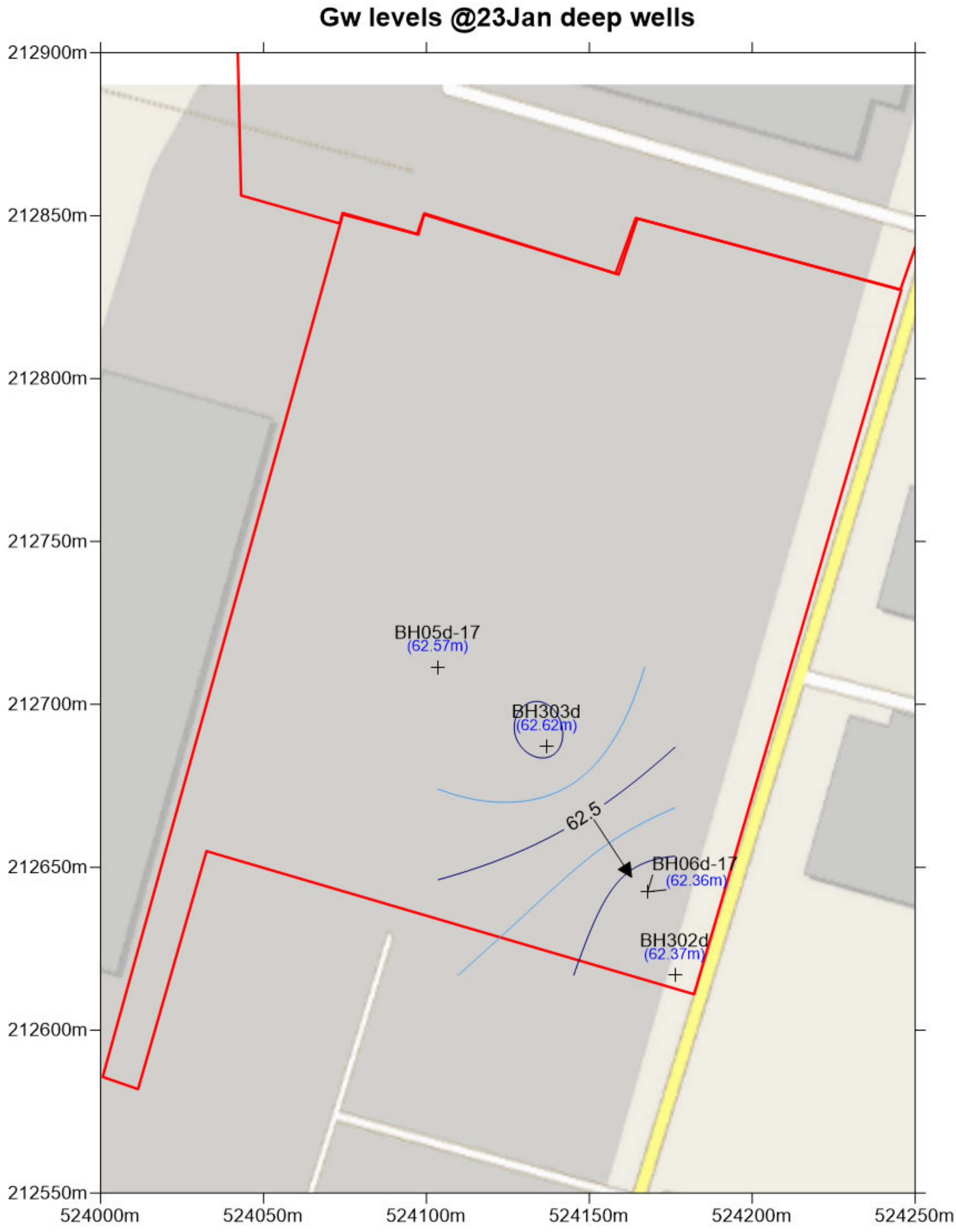


Figure 10-3: *Groundwater levels within the deep wells*

10.5 Potential Pollutant Linkages

Within the HCSM it has been assumed that residual contamination in the former tank farm/remediation area is the source of the petroleum hydrocarbon contamination and that this has migrated via the unsaturated zone soils into the groundwater within the putty chalk beneath the site.

As outlined, in the Contaminant Characterisation section there is some variation in the concentrations of petroleum hydrocarbons recorded in the deeper monitoring wells *i.e.* concentrations in BH05-17d and BH302d have recorded concentrations below the limit of detection for the laboratory method applied (<LOD). However, within the HCSM it has been assumed that there is potential for petroleum hydrocarbon contaminant migration via the putty chalk into the underlying Principal Chalk Aquifer.

11 Hydrogeological Detailed Quantitative Risk Assessment

11.1 Introduction

The following section presents the findings of a Hydrogeological Detailed Quantitative Risk Assessment (DQRA), which has been used as a tool to help determine the potential risks to the local water environment and to support future remedial (betterment) works.

Further details of the methodology, rationale and model input parameters are presented in *Annex E*.

11.2 Assessment Strategy

In completing the DQRA the following documents have been referenced in order to ensure that current best practice, policy and guidance has been adhered to:

- Groundwater Protection: Principles & Practice (GP3). Environment Agency (August 2013) and guidance on the Gov.uk website (14th March 2017) relating to groundwater risk assessments.
- Remedial Targets Methodology: Hydrogeological Risk Assessment for Land Contamination. Environment Agency (2006);
- CL:AIRE (2017). Petroleum Hydrocarbons in Groundwater: Guidance on assessing petroleum hydrocarbons using existing hydrogeological risk assessment methodologies.
- Water Framework Directive (Directive 2000/60/EC) and associated UK Technical Advisory Group documents;
- World Health Organisation (WHO) Guidelines for Drinking Water Quality, Fourth Edition, Volume 1;
- The River Basin Districts Typology, Standards and Groundwater Threshold Values (Water Framework Directive) (England and Wales) Directions 2010; and
- The Water Framework Directive (Standards and Classification) Directions (England and Wales) 2015.

In accordance with current best practice guidance (GP3), the ‘prevent and limit’ approach has been adopted for the assessment, such that:

- Where pollutants have not yet entered the groundwater, all necessary and reasonable measures must be taken to;

- Prevent the input of hazardous substances into groundwater.
- Minimize entry of other (non-hazardous) pollutants into groundwater so as to avoid pollution and deterioration of the status of groundwater bodies or sustained, upward trends in pollutant concentrations.

- Where hazardous substances or non-hazardous pollutants have already entered the groundwater, the priority is to;
  - Minimise further entry of hazardous substances and non-hazardous pollutants into groundwater.
  - Take necessary and reasonable measures to limit the pollution of groundwater or impact on the status of the groundwater body from the future expansion of a contaminant 'plume', if necessary by actively reducing its extent.

As outlined in the Contaminant Characterisation section, petroleum hydrocarbons are considered to be hazardous substances and the previous phases of investigation have shown that they have already entered the groundwater in the Chalk Aquifer beneath the site. Therefore, the priority is to ensure that further entry is minimised and limit the pollution of groundwater.

11.3 Receptors

When considering the groundwater beneath the site in the context of the guidance within GP3, the regional importance of the Principal Chalk Aquifer as a resource and the fact that the site lies within an EA defined SPZ have been given consideration. On this basis the Principal Chalk Aquifer in the context of off-site groundwater quality has been considered the receptor.

11.3.1 Compliance Points & Plume Definition

In selecting appropriate compliance points the main point of reference has been GP3.

Within GP3 a plume is defined as, *'the area within which the existing groundwater is contaminated to a level that exceeds the relevant environmental standard that would apply to any likely or feasible future use of groundwater.'*

Considering the information presented above and the guidance within GP3, a compliance point distance of 50 m has been applied to ensure limiting impacts to off-site groundwater quality.

11.4 Assessment Methodology

The DQRA has been completed in accordance with the Remedial Targets Methodology: Hydrogeological Risk Assessment for Land Contamination (Environment Agency, 2006). In addition, the methodology used in the EA approved ConSim (v 2.5) modelling package has also been considered.

A summary of the level of assessment within each tier of the Remedial Targets Methodology is provided in *Annex F*.

11.4.1 Assessment Level

In accordance with the Remedial Targets Methodology and considering the site environmental setting and the HCSM, it is considered necessary to undertake a Level 3 assessment as the identified contaminants have already entered groundwater. This is in order that potential impacts at the compliance point can be estimated and that derived remedial targets consider the contaminant concentrations in both the soil and groundwater. Similarly, a Level 3 Assessment has been completed within the EA approved ConSim (v 2.5) modelling package.

11.5 Effective Solubility

As outlined, appraisal of the groundwater analytical results for petroleum hydrocarbon species suggests that for several of the TPH fractions are recorded at concentrations greater than their theoretical pure phase solubility.

In this case it is important to provide an estimate of the true concentrations of individual TPH fractions within the hydrocarbon mixture so that potential risks from particular contaminants are not over estimated and also to ensure that the key risk drivers identified remain valid.

The effective solubility of the individual TPH fraction within the petroleum hydrocarbon mixture has been completed by applying Raoults Law. The effective solubility worksheets used to complete the calculation are provided in *Annex E*.

11.6 Modelling of Contaminant Fate and Transport

11.6.1 General

For the assessment of key risk drivers, the EA's Remedial Targets Worksheets (Release 3.2) has primarily been utilised. A summary of the software package and how it functions, along with specific input parameters are provided in *Annex E*.

The Remedial Targets Worksheets (RTW) were selected because the key risk drivers have been identified in the soil and groundwater beneath the site. With this in mind it was considered that the back-calculation methods of the RTW would be appropriate as they would allow appraisal of both soil and groundwater concentrations in the context of the environmental setting and proposed site redevelopment.

In addition, the EA approved ConSim (v 2.5) modelling package has been utilised to specifically assess the potential for residual soil contamination in the former tank farm / remediation area to pose an ongoing risk to the underlying groundwater.

ConSim is a probabilistic model that requires the input of aquifer specific parameters such as hydraulic conductivity, contaminant specific parameters such as half-life and partitioning which can be both aquifer and contaminant specific. A range of values (or single values) can be input for each parameter to enable uncertainty to be acknowledged and the model uses *monte carlo* analysis to randomly select input parameters from the specified range input.

11.6.2 Model Calibration and Validation

Within the RTW a general water balance is applied at Level 3 (Soil) such that if the flux in does not equal the flux out the hydraulic gradient is auto adjusted to create an overall water balance. If the hydraulic gradient is adjusted over an order of magnitude this will usually suggest that one of the input parameters may be inaccurate. Experience has shown that the most sensitive and difficult parameter to predict is the calculated infiltration rate.

Reference to the worksheets within the model constructed indicates that the hydraulic gradient is slightly higher but very similar in Level 3 Soil (0.0069) to the value input in Level 2 Soil (0.0064). This suggests that the infiltration rate derived is an accurate representation and that the water balance within the model is valid.

11.6.3 Marker/Surrogate Approach

Petroleum Hydrocarbons (TPH) typically comprise complex mixtures of aliphatic and aromatic hydrocarbons, as demonstrated in the results of the chemical analysis completed on samples of soil and groundwater on the subject site. This complicates the assessment of environmental risk, since the compound mixtures contain components with varying physicochemical and toxicological properties.

Specific physicochemical and toxicological data is not available for many of the individual components of petroleum hydrocarbons and hence fractions have been characterised from the available data in the literature following the Total Petroleum Hydrocarbon Criteria Working Group, 1998 methodology (TPHCWG). These fractions are based on physico-chemical properties and also on data from phase partitioning models.

Of the 250 individual compounds identified in petroleum by the TPHCWG, toxicity data were only available for 95. Of these the TPHCWG concluded that there was sufficient data to develop toxicity criteria for only 25. Subsequently, it has been identified that a marker/surrogate approach is the best available method for assessing risks from hydrocarbons, where a representative individual compound from the TPH mixture is used for fate and transport modelling.

C8-10 Aromatic Fraction

As outlined, within the C8-10 aromatic fraction the highest concentrations are associated with Trimethylbenzene and on this basis a very conservative approach has been adopted with the physio-chemical properties of Trimethylbenzene being used as a surrogate in considering the risks associated with the entire fraction. In addition, the WQS for Trimethylbenzene has been applied.

C10-16 Aromatic Fraction

As outlined, the highest groundwater concentrations were recorded in monitoring well BH01-17 and approximately 70% of the total concentration is recorded within the C10-16 aromatic fraction. A conservative approach has been adopted with the physio-chemical properties of a Naphthalene/methylnaphthalene being used as a marker/surrogate compound in considering the risks associated with the entire fraction.

11.6.4 Summary of Results – RTW

The results of the Level 3 Assessment completed using the RTW are summarised in *Table 11-1*, with the Remedial Targets Worksheets provided in *Annex F*.

Table 11-1: *Level 3 Assessment*

Contaminant	Maximum Concentration		WQS (mg/l)	Predicted Concentration at Compliance Point (mg/l)		Remedial Target	
	Soil (mg/kg)	Groundwater (mg/l)		Level 3 Soil	Level 3 Groundwater	Soil (mg/kg)	Groundwater (mg/l)
Xylenes (sum)	1.10 (BH01-17, 7.5m)	3.69E+00	5.00E-01(1)	4.72E-03	2.92E+00	1.17E+02	**6.32E-01**
C8-C10 Aromatics	420 (BH01-17, 7.5m&8.0m)	3.64E+00 (2)		7.47E-02	5.75E-01	**3.88E+02**	**5.60E-01**
C10-C16 Aromatics	1030 (BH01-17, 7.5m)	1.57E+01 (2)	9.00E-02(1)	1.59E+00	1.16E+01	**5.85E+01**	**1.22E-01**
DCM	<LOD	1.40E+01	2.00E-02(1)	N/A	7.22E+00	N/A	**3.88E-02**

Notes:

(1) WHO Guidelines

(2) Corrected to effective solubility.

(3) RED CELLS - Recorded concentration greater than derived remedial target.

11.6.5 Sensitivity Analysis – RTW

In order to account for the inherent uncertainty associated with the input parameters used within the model constructed and assess the effects on the model resulting from changes in parameters values, sensitivity analysis has been completed.

The sensitivity of infiltration rate has in effect been appraised by comparing the Level 2 Soil and Level 3 Soil water balance correction.

In addition to this, the hydraulic conductivity has been selected (due to the inherent variability in this parameter) and the also the fraction of organic carbon in the unsaturated zone soils (due to the variability in the soil horizon).

The sensitivity analysis has been applied to the C8-10 aromatic fraction, as this is a key risk driver that has been recorded at elevated concentrations in both the soil and groundwater beneath the site.

11.6.6 Hydraulic Conductivity

A packer/lugeon test was undertaken by URS Dames & Moore in 2000 (Ref. R2779/38842-019-401/WH). They completed multiple tests in two boreholes (BH302 & BH303) at differing depth horizons as summarised within a later Delta Simons report:

"The hydraulic conductivities determined by URS Dames and Moore for the upper section of the chalk and the deeper section of the chalk (beneath a layer of flint) were 0.330 m/day and 2.07 m/day, respectively."

And:

"A range of hydraulic conductivities have been identified at the Site, which have been utilised in the modelling to assess the sensitivity of this parameter. The recent K value calculated by QDS during a pilot test (Pump Test Report Project No. 3254-01, August 2005) and the Dames and Moore (Final Factual Report, July 2000) value calculated for the shallow Upper Chalk (of 0.330 m/day based upon an average of four values at depths of between 26.6 m and 43.3 m in BH302 and four values at depths of between 28.5 m and 43.25 m in BH303.) are fairly consistent. The K value for the deeper chalk (beneath a layer of flint) is taken from the Dames and Moore report and is 2.07 m/day (based upon an average of 46.2 m to 48.8 m in BH302 and 41.9 m to 44.5 m in BH303)."

Based on the groundwater levels recorded beneath the site we could have justifiably applied the lower K values, but in order to ensure conservatism and consistency with the HCSM (which conservatively assumes potential migration of contaminants into the deeper groundwater) the higher K value was applied in the modelling.

The sensitivity of the model to changes in the hydraulic conductivity was completed, as it is a key parameter in contaminant fate and transport modelling and also because of the inherent variability of the hydraulic conductivity, which typically varies over orders of magnitude.

The results of the sensitivity analysis are provided in *Table 11-2*.

Table 11-2: *Sensitivity Analysis*

Hydraulic Conductivity (m/d)	WQS (mg/l)	Predicted Concentration at Compliance Point (mg/l)	Remedial Target	
			Soil (mg/kg)	Groundwater (mg/l)
5.00E-01	2.00E-02	1.17E-02	8.40E+02	6.22E+00
2.07E+00		5.75E-01	1.12E+02	1.27E-01
1.00E+01		2.35E+00	1.33E+02	3.10E-02

Sensitivity analysis undertaken on hydraulic conductivity suggests it has an effect on both the soil and groundwater remedial targets.

The most notable effect is the variation in the soil remedial target which decreases between the lowest and middle hydraulic conductivity but then increases slightly when the hydraulic conductivity increases between the middle and highest values input. This is likely to be a consequence of increase in dilution within the aquifer and it provides a level of surety that if the hydraulic conductivity is higher than estimated within the main model it will not have an adverse impact on off-site groundwater quality.

11.6.7 Fraction of Organic Carbon

The sensitivity of the model to changes in the FoC has been completed due to the variation in the geological sequence beneath the site and the subsequent variation in the parameter.

Table 11-3: *FOC*

FOC	WQS (mg/l)	Predicted Concentration at Compliance Point (mg/l)	Soil Remedial Target (mg/kg)
2.63E-03	2.00E-02	7.47E-02	1.12E+02
2.63E-02		7.47E-02	1.12E+02
2.63E-01		7.47E-02	1.12E+02

Sensitivity analysis undertaken on fraction of organic carbon suggest it has no effect on predicted the soil remedial targets.

11.6.8 Effective Porosity

The sensitivity of the model to changes in the effective porosity has been completed as it is a key parameter in contaminant fate and transport modelling, particularly in chalk where fracture flow dominates.

Table 11-4: *Effective Porosity*

Effective Porosity	WQS (mg/l)	Predicted Concentration at Compliance Point (mg/l)	Remedial Target	
			Soil (mg/kg)	Groundwater (mg/l)
0.015	5.00E-01	3.25E+00	3.88E+02	5.60E-01
0.30		5.75E-01	1.12E+02	1.27E-01

The results of the sensitivity analysis using the RTW suggest that changes in effective porosity have an effect on the soil and groundwater remedial targets, resulting in an order of magnitude difference in predicted concentration at compliance point. However, it is also notable that although the derived remedial targets alter due to changes in this parameter they remain within the same order of magnitude.

11.6.9 Summary of Results – ConSim

The results of the modelling completed using the RTW suggest that there is potential for impact resulting from residual soil and groundwater contamination in the area beneath the former tank farm/remediation area. The results, in particular the soils, do not appear to be consistent with the empirical site data that suggests the contaminated soil does not extend beyond the upper 7 m of the unsaturated zone soils. In addition, the site data suggests that there is a decrease in groundwater concentrations down hydraulic gradient of the former tank farm/remediation area.

On this basis further assessment has been undertaken using ConSim to specifically assess the potential for residual soil contamination in the former tank farm/remediation area to pose an ongoing risk to the off-site groundwater quality. ConSim is limited with the number of contaminants included within its database and does not include TPH fractions. As such Xylene has been used from the Consim database but the concentrations applied relate to the highest soil concentrations recorded for the C8-10 aromatic fraction. In the ConSim model this concentration has been applied over a 0.5-1.5m thickness which based on the available date is considered conservative and appropriate.

The results of the Level 3 Assessment for the C8-10 aromatic fraction (Xylene) completed using ConSim are summarised below, with the outputs provided in *Annex E*.

Table 11-5: *Level 3 ConSim Summary*

Contaminant	Maximum Soil Concentration (mg/kg)	WQS (mg/l)	Predicted Concentration (95% of values) 1000 years (mg/l)		
			Entering GW	Source Receptor	Site Boundary
C8-10 Aromatic	420	5.00E-01 (1)	8.77	**9.00E-02**	**5.00E-02**
Notes: 1 *WHO guidelines*					

We would highlight that the modelling predictions via ConSim are more consistent with the empirical site data, which suggest that concentrations of key risk drivers significantly reduce down hydraulic gradient of the source area.

11.6.10 Sensitivity Analysis – ConSim

ConSim automatically generates sensitivity analysis for the following:

- Unsaturated zone travel time;
- Receptor travel time;
- Concentration at the source (various time slices);
- Concentration at the base of the unsaturated zone (various time slices);
- Concentration at the receptor (various time slices).

The sensitivity analysis results vary between -1 and +1, with a value of 1 indicating a perfect linear positive correlation between the input value and the result and a result of -1 indicates a perfect negative linear correlation between the input and the result.

For this assessment, the concentrations at the base of the unsaturated zone and at the receptor for the 1000-year time slice were appraised.

When appraising the concentrations at the base of the unsaturated zone, the strongest correlation was a negative correlation (-0.422) with the fraction of organic carbon in unsaturated zone. When appraising the concentrations at the receptor, the strongest correlation was again a negative correlation (-0.373) with the fraction of organic carbon in unsaturated zone.

The results suggest that model is sensitive to changes in *foc* and that decreases in its value would result in increases in the recorded concentration at the base of the unsaturated zone (*i.e.* entering groundwater) and at the source receptor (*i.e.* the receptor automatically generated by ConSim immediately down hydraulic gradient of the source). However, the correlations are not particularly strong and the *foc* values input are based on a site-specific dataset for soils sampled at differing depths (including the saturated chalk) across the site.

11.6.11 Discussion of Results

The results of the DQRA using the RTW suggest that residual soil and groundwater concentrations in the C10-C16 aromatic fractions (key risk drivers) could result in some small-scale impact on groundwater quality at a 50 m compliance point and potential off-site groundwater quality.

However, additional modelling using ConSim was undertaken to specifically assess the potential for residual soil contamination in the former tank farm / remediation area to pose an ongoing risk to the off-site groundwater quality. This modelling suggests that potential impacts from residual soil contamination would be minimal *i.e.* slightly above but the same order of magnitude as relevant WQS.

The modelling undertaken suggests that residual concentrations of Dichloromethane in the groundwater beneath the site would not impact off-site groundwater quality.

11.6.12 Model Conservatism

In addition to the conservatism inherent within the contaminant fate and transport model constructed, additional conservatism has been added as follows:

- Both the ConSim and RTW models constructed were run in steady state, considering an infinite breakthrough time with no declining source term;
- In both the ConSim and RTW models, degradation has only been considered within the dissolved phase, both in the UZ and in the groundwater;
- Within the RTW the compliance point distance has been set to 50 m, despite the location of the maximum concentrations being >50m up hydraulic gradient of the site boundary.

- Water Quality Standards applied have considered the most stringent values for individual compounds within hydrocarbon fractions despite the sum of those concentrations being significantly higher than those recorded for the individual compounds.

12 Monitored Natural Attenuation

12.1 Introduction

The assessment of the potential for natural attenuation processes within the dissolved phase in the groundwater beneath the site has been undertaken in accordance with the Environment Agency's R&D Publication 95: Guidance on the Assessment and Monitoring of Natural Attenuation of Contaminants in Groundwater (2000).

Application of natural attenuation requires demonstration that naturally occurring physical, chemical and biological processes are occurring at a rate that:

- protects the wider environment; and
- achieves remedial objectives within a reasonable time-frame.

Demonstration is achieved by monitoring the system to confirm the attenuation processes. Monitored Natural Attenuation (MNA) refers to such monitoring undertaken where (for instance) monitoring and mitigation can be considered as a remedial option. The guidance document sets out the following four stage assessment process that should be followed to provide evidence of MNA performance:

- **Stage 1:** Screening procedures to assess the viability of natural attenuation;
- **Stage 2:** Procedures to demonstrate current attenuation properties;
- **Stage 3:** Procedures to evaluate longer-term attenuation capability; and
- **Stage 4:** Procedures to verify attainment of the agreed remedial objectives.

12.2 Screening Factors

Screening factors for MNA can be subdivided into two categories; contaminant properties and environmental characteristics. Collectively, these factors determine the fate and behaviour of contaminants in aquifer systems. In turn, the fate and behaviour of contamination, together with the toxicological properties, influence the suitability of MNA as a remedial strategy.

Three lines of evidence are available to demonstrate that natural attenuation is occurring at a site, as follows:

- Primary lines of evidence involve the use of historical contaminant data to demonstrate a trend of reduced concentrations down-gradient of the source, along the groundwater flow path;

- Secondary lines of evidence involve measuring changes in chemical and geo-chemical analytical data to prove a loss of contaminant mass; and

- Tertiary lines of evidence use data from laboratory microbiological testing to show that indigenous bacteria are capable of degrading site contaminants. This line of evidence should be used when the first two are inconclusive.

Both primary and secondary lines of evidence have been used to assess whether natural attenuation is ongoing and thus determine the likely effectiveness of MNA as a remedial option, as detailed below.

12.3 Primary Lines of Evidence

Primary lines of evidence have been assessed based on the historical groundwater analytical data over the period October 2008 until September 2017. *Figure 12-1* and *Figure 12-2* illustrate the trend in petroleum hydrocarbon concentrations beneath the site. The data have been presented in two separate plots due to the variations in recorded concentration.

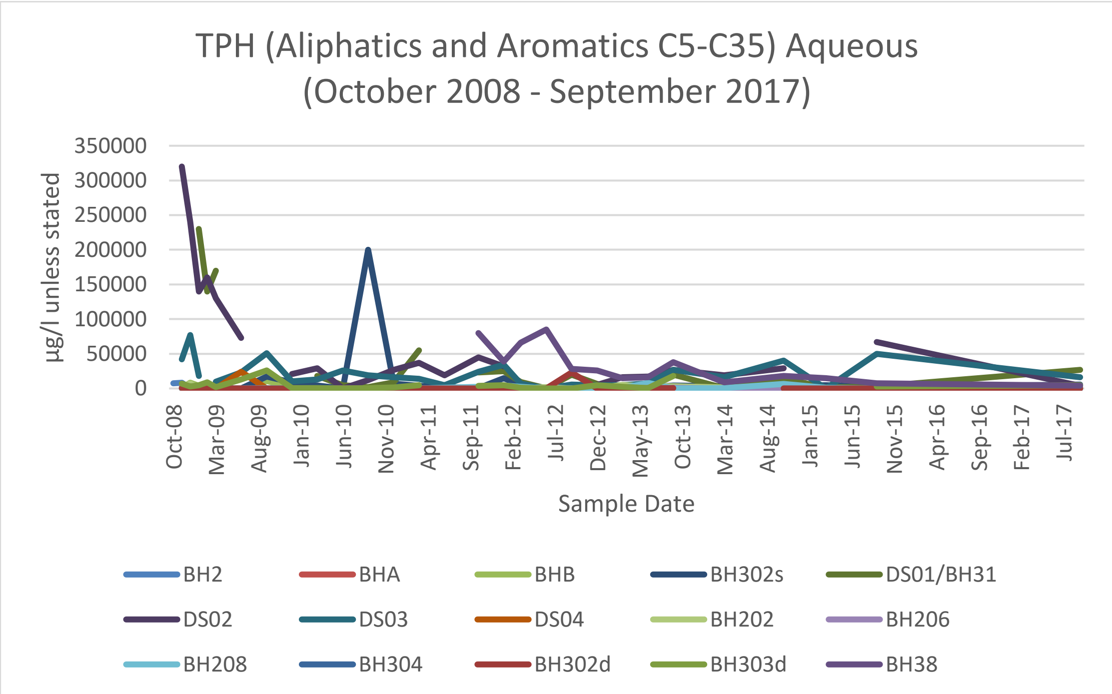


Figure 12-1: *TPH (Aliphatics and Aromatics C5-C35) Aqueous (Oct 2008 - Sept 2017)*

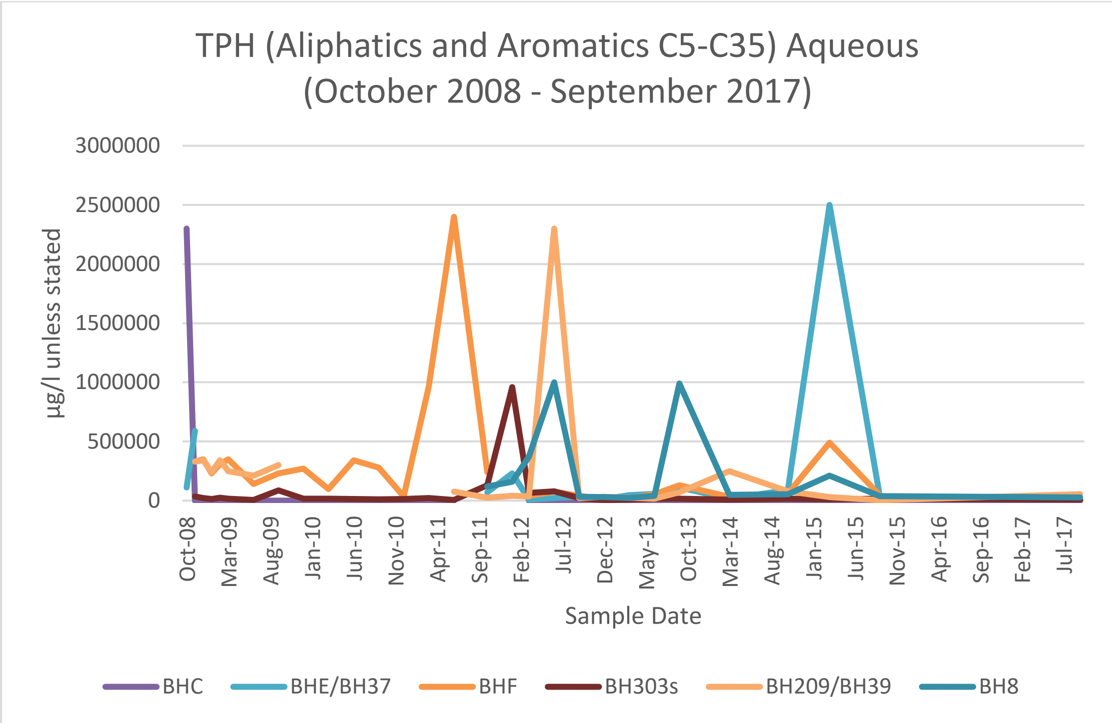


Figure 12-2: *TPH (Aliphatics and Aromatics C5-C35) Aqueous (Oct 2008 - Sept 2017)*

The data suggests that there have been historical fluctuations in the petroleum hydrocarbon concentrations but that in general concentrations have decreased markedly, particularly since October 2015. It is acknowledged that some of this trend is due to the remedial works undertaken. The data are considered to demonstrate a reduction in contaminant mass.

12.4 Secondary Lines of Evidence

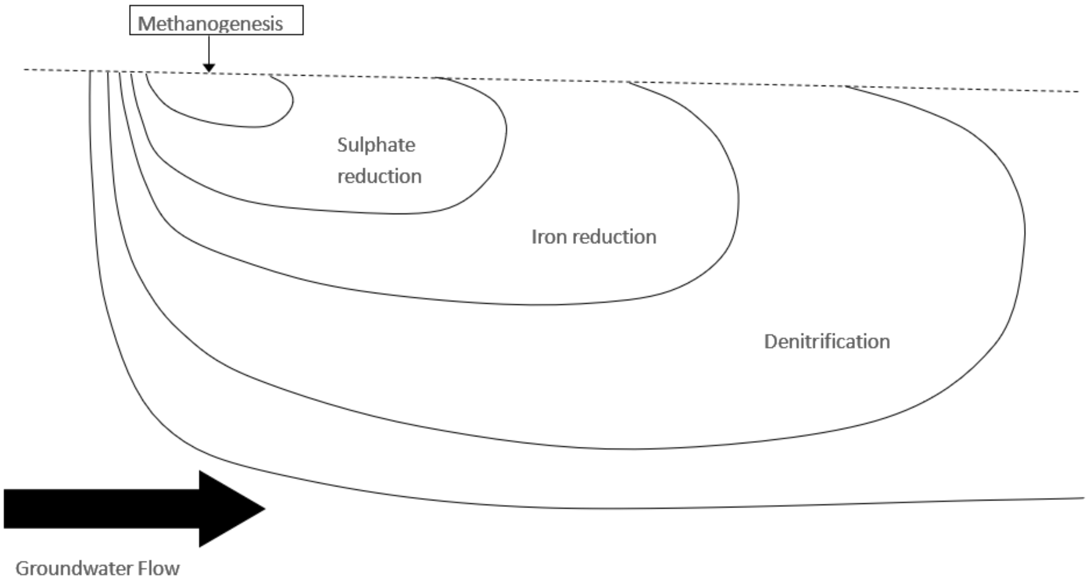
Groundwater samples collected during the EAME ground investigation were analysed for the following MNA indicator parameters (as outlined in EA document R&D P95):

- Dissolved Oxygen;
- Nitrate
- Ferrous & Ferric Iron (Fe II & Fe III);
- Sulphate;
- Chloride; and
- Dissolved Methane.

The concentrations of MNA indicator parameters are provided in *Annex C*.

12.4.1 General Trends

Micro-organisms involved in biodegradation will generally use electron acceptors according to thermodynamic feasibility and in the following order of preference: oxygen, nitrate, iron, sulphate and carbon dioxide. This trend can lead to notable electron acceptor or oxidation/reduction (redox) zones within a dissolved phase plume over time (such as that beneath the subject site) where conditions within the plume centre are anaerobic and at the plume edge conditions are aerobic as illustrated in *Figure 12-3*.



Schematic reproduced from R&D Publication 95 (Figure A1.2)

Figure 12-3: *Conceptual Section of Electron Acceptor (Redox) Zones in Groundwater*

12.4.2 Petroleum Hydrocarbon Degradation

Biodegradation via biological oxidation is the main process involved in the natural attenuation of petroleum hydrocarbon compounds.

The process involves electron donors, electron acceptors and nutrients that are combined by microbial organisms to produce metabolic by products and energy for microbial growth.

In the case of the site and observed contamination the petroleum hydrocarbons will act as the electron donor are broken in the process. Electron acceptors tend to be utilised by microbes in the following order of preference *i.e.* Oxygen; Nitrate; Manganese (IV); Iron (III); Sulphate; & Carbon Dioxide.

As illustrated in *Figure 12-3*, degradation processes can vary in different parts of a contaminant plume such that anaerobic degradation may be occurring in the centre of a plume with aerobic degradation down hydraulic gradient of the plume centre.

12.4.3 Natural Attenuation Parameters

Contour plots displaying the spatial distribution of natural attenuation parameters within the groundwater are provided as *Figure 12-4* and *Figure 12-5*.

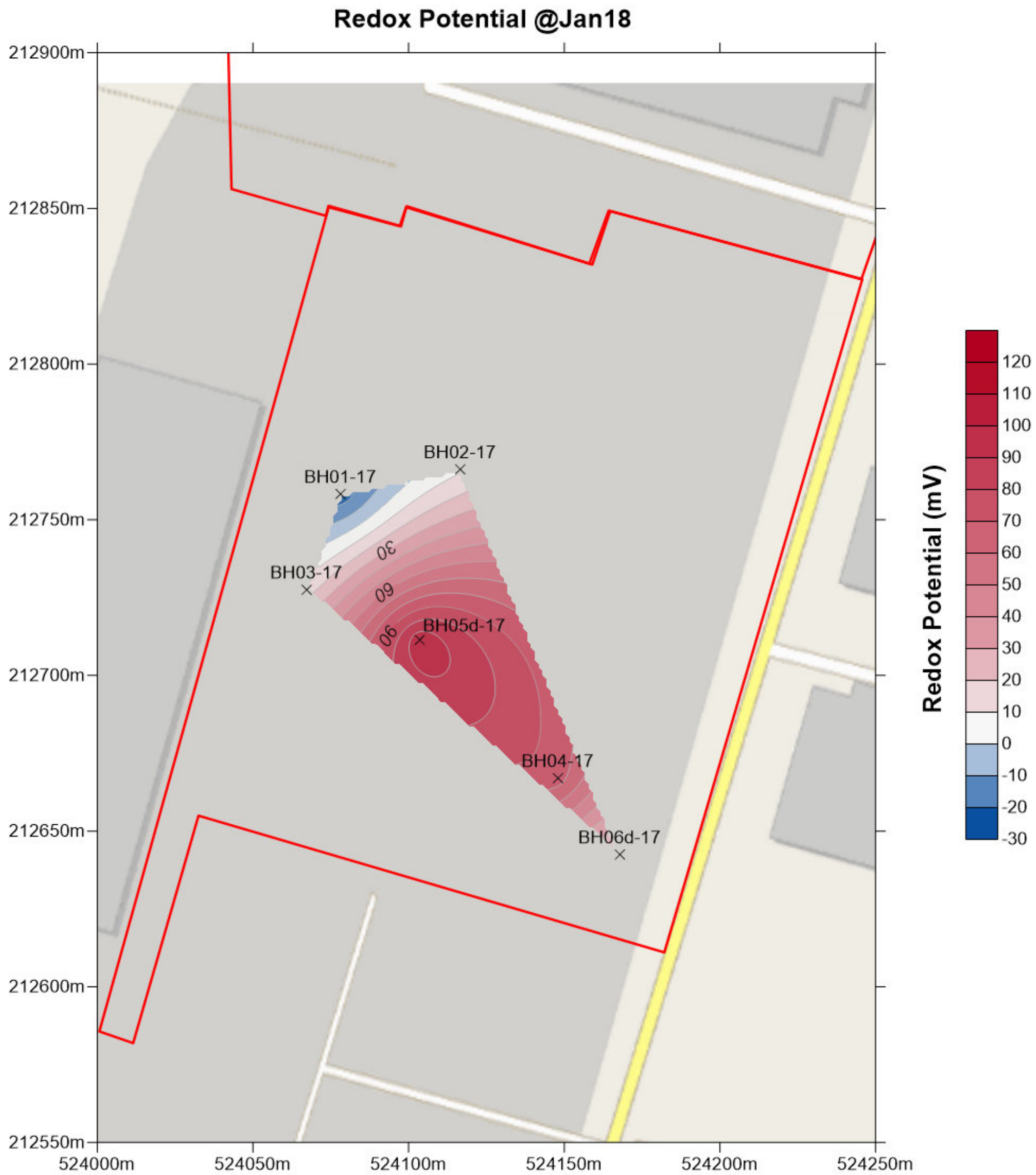


Figure 12-4: *Redox potential in groundwater*

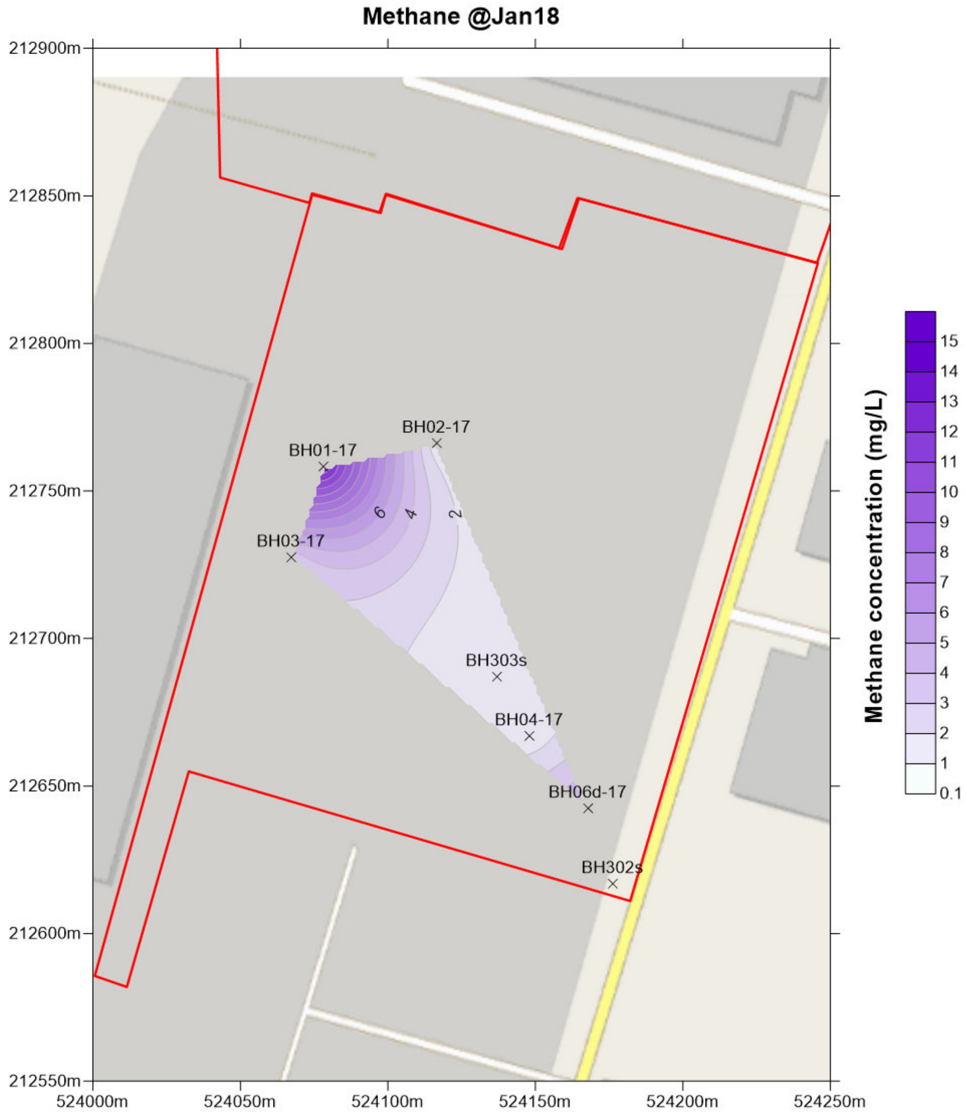


Figure 12-5: *Methane in groundwater*

<u>Dissolved Oxygen (DO) & Redox Potential (Eh):</u> The laboratory analytical results indicate that dissolved oxygen was elevated above 0.5 mg/l in all wells. However, it is very difficult to achieve accurate laboratory analysis of dissolved oxygen that is reflective of the in-situ groundwater condition, as it readily equilibrates to atmospheric concentrations during sampling, sample preparation and analysis.

However, there is a general trend of increasing DO down hydraulic gradient of the highest groundwater contaminant concentration and this is supported by the Eh results which suggest that down hydraulic gradient conditions are aerobic.

Nitrate: Nitrate concentrations are elevated in all monitoring wells. Thermodynamically, nitrate is the next most favourable electron acceptor after oxygen and the results suggest that denitrification during anaerobic degradation is not occurring.

Iron (Fe II): Concentrations of Fe(II) are elevated in monitoring wells BH01-17, BH02-17 and BH03-17 but depleted in monitoring wells BH04-17, BH05-17 and BH06-17. This could suggest that Fe(III) reduction during microbial degradation is occurring but Fe(III) concentrations are not depleted in the corresponding monitoring wells and thus it is unclear if this is an active process.

Sulphate: Sulphate concentrations were elevated in all monitoring wells, suggesting that sulphate reduction is not occurring, and it is not being used as an electron acceptor during biodegradation of organic contaminants.

Dissolved Methane (CH_4): Concentrations of methane were observed to be elevated in all monitoring wells apart from BH05d-17. The highest dissolved methane concentration has been recorded in monitoring well BH01-17 where the highest groundwater contaminant concentrations were recorded.

This could suggest the presence of methanogenic bacteria and in the vicinity of BH01-17 the system has reached the point where methanogenesis is occurring.

12.5 Tertiary Lines of Evidence

Tertiary lines of evidence have not been appraised as part of this assessment.

13 Ground Gas Assessment

13.1 Introduction

Land gas is produced because of the decomposition of organic materials such as paper, vegetation, wood, *etc.* but it may also originate from natural sources, such as coal seams and organic rich soils. The principal components of ground gas are methane and carbon dioxide although trace gases such as hydrogen sulphide and carbon monoxide can also be present. Ground gases can present a hazard to site workers during construction activities (*e.g.* carbon dioxide is heavier than air and may accumulate in voids and methane is flammable), and can enter buildings, thus presenting a hazard to occupants in terms of asphyxiation or explosion. Methane is explosive at concentrations of between 5 and 15%, with 5% being the lower explosive limit (LEL).

Several guidance documents have been produced for new developments on gassing sites. BRE Report 465 (2004) is aimed at providing a framework for planners to ensure 'contaminated land' issues are adequately addressed, including guidance for methane and other ground gases. The framework includes CIRIA's Report 149, which provides further guidance and an initial attempt at characterising gassing sites in terms of volume of gas rather than just concentrations. This was further developed by Wilson and Card's paper in 1999, which provided an approach considering the distribution of gas concentrations and flow rates. For this assessment, reference has been made to the recent CIRIA (665) document, assessing risks poses by hazardous ground gases to building, 2007, which provides the most up to date and comprehensive reference criteria for assessing land gas, by providing advice relevant to existing or planned development and a step-wise approach to risk assessment. The CIRIA guidance has been supplemented using BS 8485:2015 *Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings has been utilised*.

13.2 Development Type

CIRIA C665 identifies two development situations:

- Situation A – Any development other than Situation B *e.g.* factories, shops, commercial, warehouse, schools, cinemas, sports centres, stadiums, high rise housing, housing with basements; and
- Situation B – Low rise building with minimum ventilated under floor (minimum 150 mm).

Situation A has been selected for the assessment.

Under BS8485:2015 the building type proposed would be Type B.

13.3 Determination of Gas Screening Value

The CIRIA C665 document uses both gas concentrations and borehole flow rates to define a characteristic situation for a site based on the limiting borehole gas volume flow for methane and carbon dioxide. This provides a Gas Screening Value (GSV), based on the maximum gas concentrations (methane or carbon dioxide) and flow rates recorded at the site (*i.e.* calculated for each windowless sample under consideration):

- GSV (litres of gas per hour) = max borehole flow rate (l/hr) x max gas concentration (%)

This then enables an appropriate Characteristic Situation to be determined (*Table 13-1*). The GSV should only be considered as a guideline value and not as an absolute threshold.

Table 13-1: *Modified Wilson and Card Classification (adapted from CIRIA Report 665)*

Characteristic Situation (CIRIA R149 & BS 8485:2015	Risk Classification	Gas Screening Value (CH_4 or CO_2 (l/hr))	Additional Factors
CS1	Very low risk	<0.07 l/hr	Typical methane </=1% v/v and/or carbon dioxide </=5% v/v. Otherwise increase to Situation 2.
CS2	Low risk	<0.7 l/hr	Borehole air flow rate not to exceed 70l/hr. Otherwise consider increase to Situation 3.
CS3	Moderate risk	<3.5 l/hr	-
CS4	Moderate to high risk	<15 l/hr	Quantitative risk assessment required to evaluate scope of protective measures
CS5	High risk	<70 l/hr	-
CS6	Very high risk	<70 l/hr	-
Note: Gas Screening Value (GSV): litres of gas/hour is calculated by multiplying the gas concentration (%) by the measured borehole flow rate (l/hr).			

As a worst-case scenario, the C665 maximum Methane and Carbon dioxide concentrations have been used to calculate the individual windowless sample GSVs as well as the site-wide maximum.

13.4 Scope of Required Gas Protection Measures

The characteristic situation defined above can be used to define the general scope of gas protective measures required. The philosophy behind this is that as the risks posed by the presence of methane and carbon dioxide in the ground increase the degree of redundancy within the type of protective system proposed is also increased, so if one method or element of the protection fails for any reason the building is not exposed to unacceptable risk. CIRIA C665 (*Table 13.2*) and BS 8485:2015 differ slightly in the presentation and scope of required protection measures versus the site-specific characteristic situation.

Table 13-2: *Typical Scope of Protective Measures (adapted from CIRIA Report 665)*

Characteristic Situation	Residential building (not those that belong to Situation B)	
	Number of Levels of Protection	Typical Scope of Protection Measures
CS1	None	No special precautions.
CS2	2	Reinforced concrete cast in situ floor slab (suspended, non-suspended or raft) with at least 1200g DPM and under floor venting. Beam and block or pre-cast concrete and minimum 2000g DPM/reinforced gas membrane and underfloor venting. All joints and penetrations sealed.
CS3	2	All types of floor slab as above. All joints and penetrations sealed. Proprietary gas resistant membrane and passively ventilated or positively pressurised underfloor sub-space.
CS4	3	All types of floor slab as above. All joints and penetrations sealed. Proprietary gas resistance membrane and passively ventilated underfloor subspace or positively pressurised underfloor sub-space, oversite capping or blinding and in-ground venting layer.
CS5	4	Reinforced concrete cast in situ floor slab (suspended, non-suspended or raft). All joints and penetrations sealed. Proprietary gas resistant membrane and ventilated or positively pressurised underfloor sub-space, oversite capping and in-ground venting layer and in-ground venting wells or barriers.

Characteristic Situation	Residential building (not those that belong to Situation B)	
	Number of Levels of Protection	Typical Scope of Protection Measures
CS6	5	Not suitable unless gas regime is reduced first, and quantitative risk assessment carried out to assess design of protection measures in conjunction with foundation design.

The gas protection requirements outlined in BS 8495:2015 are based around a point system that varies depending on the Characteristic Situation and building type.

Table 13-3: *Gas Protection Score (BS 8454:2015)*

Characteristic Situation	Minimum Gas Protection Score (Points)			
	High Risk	High Risk	Medium Risk	Low Risk
	Type A Building	Type B Building	Type C Building	Type D Building
CS1	0	0	0	0
CS2	3.5	3.5	2.5	1.5
CS3	4.5	4	3	2.5
CS4	6.5[A]	5.5[A]	4.5	3.5
CS5	_[B]	6.5[A]	5.5	4.5
CS6	_[B]	_[B]	7.5	6.5

Notes:

[A] Residential buildings should not be built on CS4 or higher sites unless the type of construction or site circumstances allow additional levels of protection to be incorporated *e.g.* high-performance ventilation or pathway intervention measures, and an associated sustainable system of management of maintenance of the gas control system, *e.g.* in institutional and/or fully serviced contractual situations.

[B] The gas hazard is too high for this empirical method to be used to define the gas protection measures.

When the minimum gas protection score has been determined for the building, or for each part of the building, then a combination of two or more of the following three types of protection measures should be used to achieve that score *i.e.* structural barrier of the floor slab or basement slab and walls; ventilation measures and a gas resistant membrane.

13.5 Gas Monitoring Equipment and Procedure

Periodic monitoring includes measurement of borehole flow rates, bulk gas concentrations (*i.e.* methane, carbon dioxide and oxygen), trace gas compounds (*i.e.* hydrogen sulphide and carbon monoxide), barometric pressure and temperature. It is best practice that a range of atmospheric conditions are encountered within the monitoring period to cover worst case conditions. Monitoring should ideally include one visit under low pressure (less than 1,000 mbar), one visit under falling atmospheric pressure and one visit under high atmospheric pressure.

13.6 Land Gas Assessment

Three phases of ground gas assessment have been undertaken on the southern site between 2006 and 2018.

Figure 13-1: *Ground gas monitoring (2006 - 2018)*

Google Earth Imaging with the permission of Google – Licensed to Earth and Marine Environmental Consultants Ltd.

13.6.1 Delta-Simons Monitoring (2006)

Delta-Simons undertook a combined Phase I/II assessment of the northern and southern sites in 2006 during which a single round of gas monitoring was undertaken of 3 boreholes on June 1st, 2006 (*Table 13-4*).

Table 13-4: *Delta-Simons (2006) gas monitoring results*

Monitoring Well	Methane (% v/v)	Carbon dioxide (% v/v)	Oxygen (% v/v)	Atmospheric Pressure (mb)
BH1	<0.1	<0.1	21.0	1015
BHE	<0.1	0.1	20.8	1014
BHF	<0.1	<0.1	21.1	1015

Note:

Gas flow, hydrogen sulphide, carbon monoxide was not monitored during the Delta-Simons monitoring event.

13.6.2 Delta-Simons Monitoring (2014)

Delta-Simons undertook a geotechnical assessment of the northern and southern sites in 2014 during which two rounds of gas monitoring were undertaken of 7 boreholes on October 22nd, 2014 (Round 1) and October 29th, 2014 (Round 2).

Table 13-5: *Delta-Simons (2014) gas monitoring results (Round 1)*

Monitoring Well	Flow (Peak/Steady) (l/hr)	Methane (Peak/Steady) (% v/v)	Carbon dioxide (Peak/Steady) (% v/v)	Oxygen (Min/Steady) (% v/v)	Atmospheric Pressure (mb)
BH404	0.0 / 0.0	0.0 / 0.0	0.0 / 0.0	20.3 / 20.3	1013
BH403	0.0 / 0.0	0.0 / 0.0	0.9 / 0.9	8.0 / 8.0	1013
BH401	0.0 / 0.0	0.0 / 0.0	3.2 / 3.2	15.4 / 15.4	1012
BH405	0.0 / 0.0	0.0 / 0.0	4.9 / 4.9	13.2 / 13.2	1013
BH407	-3.0 / -3.0	0.0 / 0.0	3.8 / 3.8	2.2 / 2.2	1014
BH406	0.0 / 0.0	0.0 / 0.0	4.1 / 4.1	7.0 / 7.0	1015
BH402	0.0 / 0.0	0.0 / 0.0	1.1 / 1.1	19.0 / 19.0	1016

Monitoring Well	Flow (Peak/Steady) (l/hr)	Methane (Peak/Steady) (% v/v)	Carbon dioxide (Peak/Steady) (% v/v)	Oxygen (Min/Steady) (% v/v)	Atmospheric Pressure (mb)
Note: Hydrogen sulphide, carbon monoxide and PID was not monitored during the Delta-Simons monitoring event. Sunny, windy, 15.2 °C, windspeed 2.6 m/s. Gas monitor - GFM 436.					

Delta-Simons gas monitoring Round 2 data is outlined within *Table 13-6*.

Table 13-6: *Delta-Simons (2014) gas monitoring results (Round 2)*

Monitoring Well	Flow (Peak/Steady) (l/hr)	Methane (Peak/Steady) (% v/v)	Carbon dioxide (Peak/Steady) (% v/v)	Oxygen (Min/Steady) (% v/v)	Atmospheric Pressure (mb)
BH404	0.1 / 0.1	0.0 / 0.0	0.1 / 0.1	20.3 / 20.3	1008
BH403	0.0 / 0.0	0.0 / 0.0	0.2 / 0.1	20.2 / 20.2	1008
BH401	0.0 / 0.0	0.0 / 0.0	0.5 / 0.4	20.3 / 20.3	1008
BH405	0.0 / 0.0	0.0 / 0.0	0.0 / 0.0	20.6 / 20.6	1008
BH407	Sucked Water				
BH406	0.0 / 0.0	0.1 / 0.1	4.3 / 4.3	6.5 / 6.5	1008
BH402	0.0 / 0.0	0.0 / 0.0	0.0 / 0.0	20.2 / 20.2	1008
Note: Hydrogen sulphide, carbon monoxide and PID was not monitored during the Delta-Simons monitoring event. Dull, windy, 11.4 °C, windspeed 3.7 m/s. Gas monitor - GFM 436.					

13.6.3 EAME Monitoring Round 1 to Round 5 (May 22nd, 2018 – July 2nd, 2018)

EAME undertook a windowless sample assessment of the southern site between 28th November 2017 and 1st December 2017 during which 15 locations were installed for gas monitoring. During the subsequent demolition works 6 of the previously installed locations were lost and/or damaged. EAME undertook five rounds of gas monitoring between 22nd May 2018 and 2nd July 2018.

The equipment used during the monitoring events are outlined within *Table 13-7*.

Table 13-7: *Gas monitoring equipment*

Criteria	PID (Round 1 only)	Landfill Gas Monitor	
Instrument	MiniRae Lite non-ATEX	GFM436 (CH_4, CO_2, O_2, H_2S, LEL)	
Supplied by	Environmental Science and Technology Ltd	Shawcity Ltd	
Serial No.	595-003281	12101 (Round 1)	12727 (Round 2 - 5)
Calibration Date	18/05/2018	26/06/17	10/10/17
Certificate No.	10088	2518	5089

Photograph 13-1: *Gas monitoring on the southern site*

The full results of the monitoring are outlined within *Annex G*.

Although the gas monitoring results obtained only offer a snap shot of conditions at the site the results generally align with the monitoring previously conducted by Delta-Simons in 2006 and 2014. The main findings are outlined below.

Gas flow

The gas flow observations are summarised in *Table 13-8*.

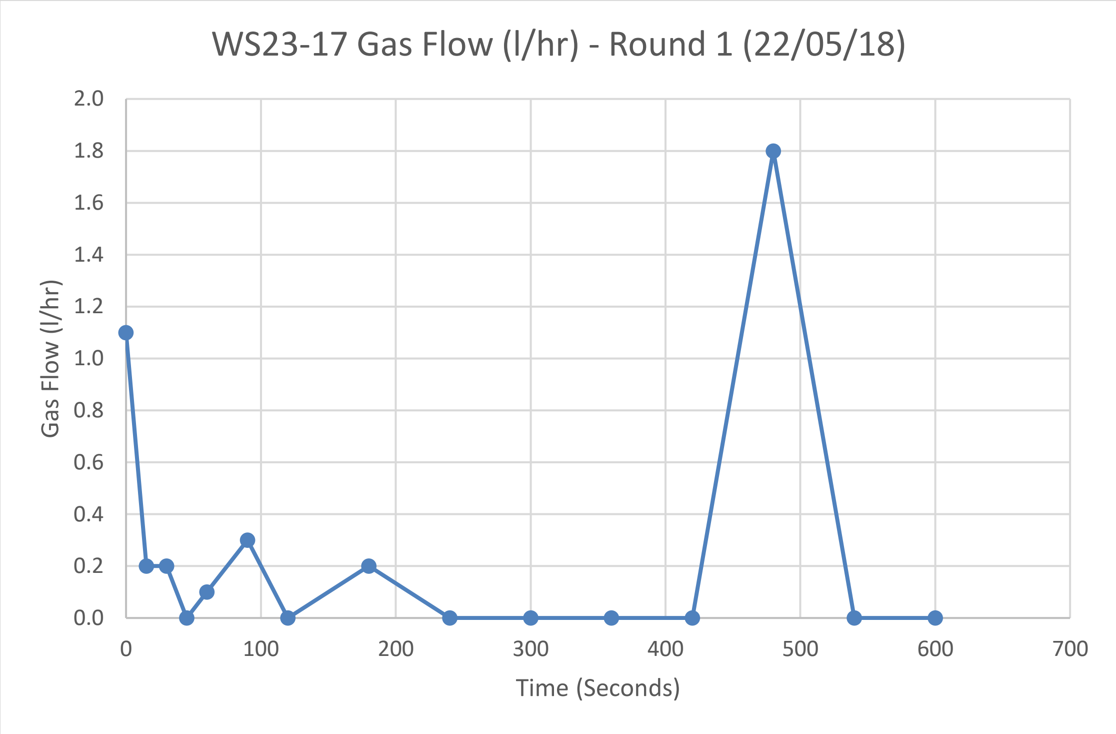
Table 13-8: *Gas flow monitoring - Peak (Southern Site) (l/hr)*

	22/05/2018	21/06/2018	25/06/2018	28/06/2018	02/07/2018
	Round 1	Round 2	Round 3	Round 4	Round 5
WS01-17	0.0				
WS02-17	0.0				
WS08-17	0.0	0.0	0.0	0.0	0.0
WS10-17	0.0				
WS11-17	0.0	0.0	0.0	0.0	0.0
WS15-17	0.0	0.0	0.0	0.0	0.0
WS19-17	0.1	0.0	0.0	0.0	0.0
WS22-17	0.0	0.0	0.0	0.0	0.0
WS23-17	1.8	0.0	0.0	0.0	0.0
Notes: Greyed cells are where wells were damaged/removed due to the slab removal process.					

The key observations are:

- No gas flow was detected in 7 of the 9 Windowless Sample locations during any of the 5 monitoring rounds.
- WS19-17 featured an instantaneous spike of 0.1 l/hr (at 45 seconds only) during monitoring Round 1. No other gas flows were recorded from WS19-17 during any of the next 5 monitoring events.
- WS23-17 featured an instantaneous spike of 1.8 l/hr (at 8 minutes) with an average over the 10-minute monitoring period of 0.3 l/hr (*Figure 13-2*). No other gas flows were recorded from WS23-17 during any of the next 4 monitoring events.

Figure 13-2: *WS23-17 Gas Flow (l/hr) - Round 1 (22/05/18)*



During the 2018 monitoring events (Rounds 1 to 5) 271 individual data points were collected from 9 WS locations across 5 monitoring rounds of which there were 7 gas flow spikes from one windowless sample point (WS23-17). Therefore, based on 6 rounds of gas monitoring (2014 – 2018) there is sufficient evidence to conclude that gas flows at the site are zero.

Methane

The peak methane observations are summarised in *Table 13-9*.

Table 13-9: *Methane Concentrations - Peak (Southern Site) (% v/v)*

	22/05/2018	21/06/2018	25/06/2018	28/06/2018	02/07/2018
	Round 1	Round 2	Round 3	Round 4	Round 5
WS01-17	0.0				
WS02-17	0.0				
WS08-17	0.0	0.0	0.0	0.0	0.0
WS10-17	0.0				
WS11-17	0.0	0.0	0.0	0.0	0.0

	22/05/2018	21/06/2018	25/06/2018	28/06/2018	02/07/2018
	Round 1	Round 2	Round 3	Round 4	Round 5
WS15-17	0.0	0.0	0.0	0.0	0.0
WS19-17	0.0	0.0	0.0	0.0	0.0
WS22-17	0.0	0.0	0.0	0.0	0.0
WS23-17	0.0	0.0	0.0	0.0	0.0
Notes: Greyed cells are where wells were damaged/removed due to the slab removal process.					

No methane was detected in any of the monitoring well monitored between May 2018 – July 2018.

Carbon Dioxide

The peak Carbon dioxide observations are summarised in *Table 13-10*.

Table 13-10: *Carbon dioxide Concentrations - Peak (Southern Site) (% v/v)*

	22/05/2018	21/06/2018	25/06/2018	28/06/2018	02/07/2018
	Round 1	Round 2	Round 3	Round 4	Round 5
WS01-17	4.9				
WS02-17	6.4				
WS08-17	2.8	0.9	2.1	2.7	0.6
WS10-17	4.9				
WS11-17	3.0	4.2	4.0	4.3	4.6
WS15-17	0.1	0.4	0.0	0.0	0.0
WS19-17	0.1	0.0	0.1	0.0	0.0
WS22-17	1.9	0.0	2.3	0.0	0.0
WS23-17	0.6	0.0	0.0	0.0	0.0
Notes: Greyed cells are where wells were damaged/removed due to the slab removal process.					

The maximum Carbon dioxide reading was 6.4% v/v (WS02-17) observed during round 1.

Other Gases

No hydrogen sulphide (H_2S) or carbon monoxide (CO) was detected in any of the locations monitored. Limited vapours from Volatile Organic Compounds (VOCs) were detected with a maximum PID level recorded was 0.5 ppmv (WS01-17).

13.6.4 Ground Gas Risk Assessment

The CIRIA 665/BS 8485: 2015 guidance has been used for comparative purposes. As such, using the modified Wilson and Card Classification (CIRIA C665, 2007), in respect of the current data and the identified GSVs, for the individual monitoring points the site is Characteristic Situation CS1 – Very Low Risk.

The worst-case situation (consideration of site-wide maximums) is as follows:

- Maximum Methane – 0.0 %v/v
- Maximum Carbon dioxide – 6.4 %v/v (WS02-17)
- Maximum flow rate – 0.0 l/hr (based on 6 rounds of monitoring)

This equates to a GSV (0.0 l/hr x 6.4 % v/v/100) = 0.00 l/hr or Characteristic Situation CS1 – Very Low Risk.

Based on the BS 8485:2015 gas protection scores (*Table 13-3*) by CS and building type no gas protection measures would be required.

13.7 Soil Vapour Survey

Between the 28th November 2017 and the 1st December 2017 EAME drilled 21 Windowless Sample locations across the southern site. During the process 63 soil samples were tested by dynamic headspace analysis, for the presence of volatile organic compounds (VOCs) using a Photoionization Detector (PID). The PID screens for a wide range of volatile organic compounds including hydrocarbon compounds and certain chlorinated solvents but does not indicate a specific compound. The measurements obtained by the instrument in parts per million by volume (ppmv) provide a semi-quantitative indication of the concentration of hydrocarbon vapours that are present.

The subsequent plot of the PID readings (*Figure 8-2*) outlined two outliers associated with WS15-17 (3.6-3.7 m bgl and 4.7-4.8 m bgl) which is located within the area of the historic tank farm/remediation area. The two elevated levels were detected immediately below the 3.5 metres of remediated soil that was replaced into the tank farm excavation. As a result, to verify shallow soil vapour conditions, a gridded Soil Vapour Survey (SVS) was undertaken across the former remediation area.

13.8 SVS Procedure

A 5-metre grid was marked out across the remediation area (*Photograph 13-2*).

Photograph 13-2: *Laying out of SVS grid across the remediation area*

Gaps in the grid were due to the placement of a temporary roadway across the site and two large piles of rubble/vegetation (*Figure 13-3*).

The SVS holes were drilled (23/05/18) using a rechargeable Slotted Drive System (SDS) Hilti drill using a 1000 mm x 24 mm drill bit to a depth of between 450 – 550 mm. Upon completion of the hole a plastic conduit plug was inserted. All holes were left for approximately 30 minutes prior to monitoring with the PID and landfill gas monitor (*Table 13-7*).

The weather conditions at the time of monitoring with warm (18°C), cloudy, dry and windy. The atmospheric pressure was 1022 mb.

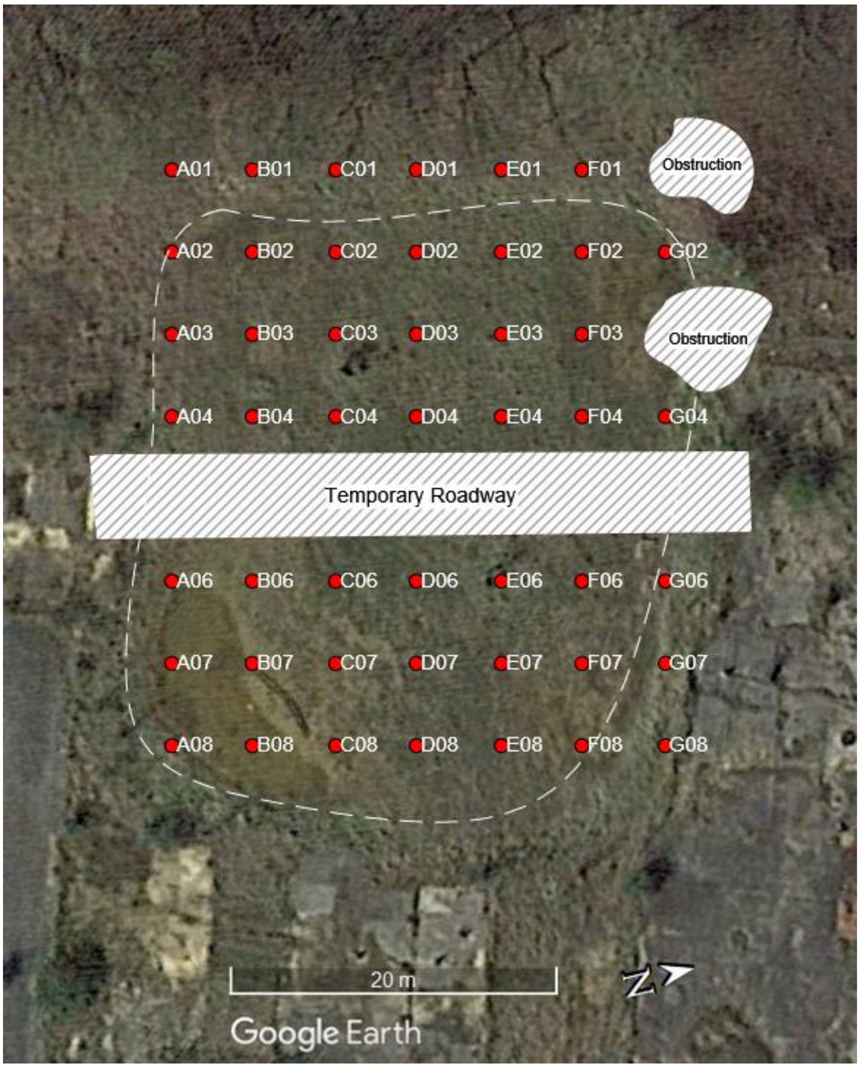


Figure 13-3: *SVS grid (remediation area)*

Google Earth Imaging with the permission of Google – Licensed to Earth and Marine Environmental Consultants Ltd.

13.9 SVS Results

The main findings of the SVS are:

- the maximum Carbon dioxide reading was 0.4% v/v (A6);
- no methane, hydrogen sulphide or carbon monoxide was detected in any of the locations monitored; and
- limited vapours from Volatile Organic Compounds (VOCs) were detected with a maximum PID level recorded was 0.4 ppmv (D7).

No evidence of significant soil vapour was observed in any of the 47 SVS points excavated across the previous remediation area.

14 Qualitative Risk Assessment

14.1 Introduction

Part 2A of the *Environmental Protection Act 1990* ("Part 2A") provides the legislative framework for the contaminated land regime in England, Wales and Scotland. It provides for contaminated land to be identified and dealt with in a risk-based manner. *The Contaminated Land (England) Regulations 2006* set out provisions for procedural matters under Part 2A. The 2006 regulations have recently been modified with the introduction of *The Contaminated Land (England) (Amendment) Regulations 2012*, which came into force on 6th April 2012. This includes an amendment to Regulation 3(c) to take account of the updated definition of "controlled waters" in Section 78A(9) of the Environmental Protection Act 1990.

Section 78A(2) of Part 2A of the EPA 1990 defines contaminated land as "land which appears to the local authority in whose area it is situated to be in such a condition, by reason of substances in, on or under the land, that:

- significant harm is being caused or there is a significant possibility of such harm being caused; or
- pollution of controlled waters is being or is likely to be caused".

Contaminated Land Statutory Guidance published in April 2012 provides for a new four category test which is intended to clarify when land does or does not need to be remediated, where Category 1 is deemed as being high risk and Category 4 as being low risk.

"Significant harm" is defined in the Guidance on risk-based criteria and must be the result of a significant "pollutant linkage". The presence of a pollutant linkage relies on the Source-Pathway-Receptor concept, where all three factors must be present and potentially or actually linked for a potential risk to exist. An initial assessment of pollutant linkage can be made qualitatively (*i.e.* through identifying these factors) and may be assessed using qualitative risk assessment models.

A conceptual model is an essential element of any site-specific environmental risk assessment. In this context, they are often simple representations of the hypothesised relationships between sources, pathways and receptors. For this report, a basic conceptual model has been developed based on the principles of CLR11[18] and interpretation of information gathered during the Phase I review. Thus, this allows the identification of potential pollutant linkages and whether these linkages have the potential to comprise

18 Environment Agency (2004). Contaminated Land Report 11: Model Procedures for the Management of Land Contamination (CLR11)

significant harm and/or pollution of controlled waters in relation to the Site. Based on this interpretation, the implications for potential liability associated with soil or water contamination at the Site can be evaluated.

14.2 Conceptual Site Model

The soil and groundwater conditions on the Site, as identified through the environmental assessment, have been summarised into a Conceptual Site Model (CSM), which defines the key sources, pathways and receptors that have been identified as being relevant to this Site. The CSM concludes with potential pollutant linkages for the Site given the current setting:

- SOURCES – the identification of contaminants within the soils and groundwater that represent potential pollution sources;
- PATHWAYS – the identification of the potential exposure mechanisms and migration pathways from the potential sources; and
- RECEPTORS – the identification of the potential receptors that could be sensitive to harm if exposed to these pollution sources.

Collectively, each of these scenarios would be considered a potential pollutant linkage that may require further assessment.

It is understood that this report is requited to support a proposed planning application for the redevelopment of the Site. Changes to the above proposals will invalidate the following risk assessment (*i.e.* a more sensitive land use has not been considered). A preliminary conceptual model is presented below in accordance with the guidance outlined within CLR11.

14.2.1 Identification of Potential Sources

Based on the information from the desk study, historical maps and published information, a summary of potential contaminant sources is provided. These have been divided into sources resulting from current and historic uses, both on and off-site.

14.2.2 Identification of Potential Exposure Pathways

Exposure pathways are the potential routes and mechanisms by which potential on-site sources could be linked to the identified potential receptors and thereby expose them to potential harm. Only plausible pathways need be considered. The following potential exposure pathways have been identified at the Site (note these do not assume a source is present):

- inhalation (*i.e.* dust and vapours);
- dermal contact (*i.e.* direct contact with contaminated materials);
- ingestion of contaminated soils or groundwater;
- direct contact with buildings and services;
- migration of contaminants via on-site drainage systems;
- vertical/horizontal migration of contaminants (within the soil/groundwater); and
- vertical/horizontal migration of ground gases.

14.2.3 Potential Receptors

Based on the Site's environmental setting and the proposed future end use of the Site, the following potential receptors have been identified:

- groundwater;
- surface water
- construction workers;
- future on-site buildings and services;
- future site users (*i.e.* residential occupiers); and
- third-party land and operations (*i.e.* the possibility of contamination migrating off-site onto third party land via contaminated groundwater, surface water run-off *etc.*).

14.2.4 Potential Pollutant Linkages

For there to be a plausible pollutant linkage there must be a source, receptor and pathway and a feasible linkage between them (a so-called pollutant linkage). Consequently, even where a contaminant is identified, if there is no pathway for the contamination to reach a receptor, or no receptor then there can be no significant risk and remedial actions are not required. Furthermore, even if there is a complete pollutant linkage, it is possible that the contaminant concentration that can pass along the linkage does not represent a significant risk to human health or the environment. Central to this risk assessment process is the development of a 'conceptual model'. This is a descriptive and/or pictorial representation of the area of potential contamination, the surrounding environment and the processes acting on the contaminants by which they can move and encounter receptors (*e.g.* by leaching and migration into groundwater).

Production of a conceptual model requires an assessment of risk to be made. Risk is a combination of the likelihood of an event occurring and the magnitude of its consequences. Therefore, to assess risk both the likelihood and the consequences of an event must be considered. This report adopts the methodology for risk evaluation presented in the guidance document CIRIA C552 Contaminated Land Risk Assessment – A Guide to Good Practice[19].

The method is qualitative and involves the classification of the magnitude of the potential severity or consequence of the risk occurring (*Table 14-1*).

Table 14-1: *Classification of consequence*

Consequence	Definition
Severe	Short term (acute) risk to human health likely to result in 'significant harm' as defined by the Environment Protection Act 1990, Part IIA. Short term risk of (significant) pollution of sensitive water resource. Catastrophic damage to building/property. A short-term risk to a ecosystem, or organism forming part of such ecosystem.
Medium	Chronic damage to human health (significant harm). Pollution of sensitive water resources. A significant change in an ecosystem, or an organism forming part of such an ecosystem.
Mild	Pollution of non-sensitive water resources. Significant damage to crops, buildings, structures and services. Damage to sensitive buildings/structures/services or the environment.
Minor	Harm, although not necessarily significant harm, which may result in a financial loss, or expenditure to resolve. Non-permanent health effects to human health (easily prevented by means such as personal protective clothing *etc.*). Easily repairable effects of damage to buildings, structures and services.

The magnitude of the likelihood or probability of the risk occurring is estimated using (*Table 14-2*).

19 Rudland, D. J., Lancefield, R. M. & Mayell, P. N., (2001). CIRIA C552: Contaminated Land Risk Assessment - A Guide to Good Practice.

Table 14-2: *Classification of probability*

Likelihood	Definition
High	There is a pollution linkage and an event that either appears very likely in the short term and almost inevitable over the long term or there is evidence at the receptor of harm or pollution.
Likely	There is a pollutant linkage and all the elements are present and in the right place, which means that it is probable that an event will occur. Circumstances are such that an event is not inevitable, but possible in the short term and likely over the long term.
Low	There is a pollution linkage and circumstances are possible under which an event could occur. However, it is by no means certain that even over a longer period that such an event would take place and is even less likely in the shorter term.
Unlikely	There is a pollution linkage, but circumstances are such that it is improbable that an event would occur even in the very long term.

Once the likelihood of an event occurring and its severity have been classified, a risk category can be assigned using *Table 14-3*.

Table 14-3: *Risk assessment matrix*

		Consequence			
		Severe	Medium	Mild	Minor
Likelihood of Occurrence	High	Very High	High	Moderate	Moderate/Low
	Likely	High	Moderate	Moderate/Low	Low
	Low	Moderate	Moderate/Low	Low	Very Low
	Unlikely	Moderate/Low	Low	Very Low	Very Low

The description of the classified risks and likely actions required, in accordance with CIRIA C552, are:

- VERY HIGH RISK – There is a high probability that severe harm could arise to a designated receptor from an identified hazard OR, there is evidence that sever harm to a designated receptor is currently happening. This risk (if realised) is likely to result in a substantial liability. Urgent investigation (if not undertaken already) and remediation are likely to be required.

- HIGH RISK – Harm is likely to arise to a designated receptor from an identified hazard. Realisation of the risk is likely to present a substantial liability. Urgent investigation (if not undertaken already) is required and remedial works may be necessary in the short term and are likely over the longer term.

- MODERATE RISK – It is possible that harm could arise to a designated receptor from an identified hazard. However, if it is either relatively unlikely that any such harm would be severe, or if any harm were to occur it is likely that the harm would be relatively mild. Investigation (if not already undertaken) is normally required to clarify the risk and to determine the potential liability. Some remedial works may be required in the longer term.

- LOW RISK – It is possible that harm could arise to a designated receptor from n identified hazard, but it is likely that this harm, if realised, would at worst normally be mild.

- VERY LOW RISK – There is a low possibility that harm could arise to a receptor. In the event of such harm being realised it is not likely to be severe.

EAME has devised a conceptual model based on the information obtained to date through the desk-based study and the proposed end use of the Site. This is detailed in tabular format in *Table 14-4*: Conceptual Site Model (CSM)

and pictorially in *Annex A, Figure A3* and *Figure A4*. It is important to remember that the stated risk assessment only remains valid if the current proposals are implemented.

Table 14-4: *Conceptual Site Model (CSM)*

Source
Zone S01 – Polycell factory (1925 – 1998) – Historic, On-site source Site activities have included a film studio and a Tobacco Company until the site was taken over by Polycell in 1954. Polycell activities included an extensive UST solvent tank farm (13 USTs) and one AST. In addition, the site had a heavy fuel boiler house (with 3 ASTs), 2 USTs (fuel oil), a licensed wastewater soakaway and a below ground firing range. Delta-Simons undertook several phases of intrusive site investigation and long-term groundwater monitoring at the Site between 2003-2016. A long-term strategy was agreed (in conjunction with the Welwyn Hatfield Council and the Environment Agency) to undertake a voluntary groundwater remediation scheme to reduce the associated environmental risks. Delta-Simons investigations at the Site identified localised soil contamination and significant widespread groundwater contamination at depth within the Principal Chalk Aquifer. The source of the contamination was determined to be leakage from the USTs located in the north-west corner of the former Polycell factory (Zone S01).
Zone 02 – Suchard Chocolate Factory (1923 – mid-1970s) – Historic, On-site source Site activities included an electric heater manufacturer (1938) but by the early 1960s it was operated as a confectionary factory. The Site was operated by Suchard as a regional distribution unit and offices until closure in the mid-1970s. No specific sources of contamination have been identified associated with the use of the Site by Suchard's. An area of demolition type material (15 metres x 12 metres) was uncovered during the demolition works. The material included broken cement-based asbestos containing materials (ACMs), Asbestos Insulating Board (AIB) and fibrous lagging. The material has been removed by John F Hunt.
Zone 03 – Cereal Partners Facility (South of Hydeway) (1938 – 1998) – Historic, On-site source From 1878 until 1923, the Site is undeveloped agricultural land. By 1938, part of the Site is used for electric heater manufacturing by Unity Heating (Young, Osmond & Young Ltd.) (central southern area), while a tennis court occupies the north-eastern corner. By 1960, works occupy the southern area of the Site while a factory occupies the northern part of the Site. By 1968, the works in the southern part of the Site are labelled as plastics engineering works, and the factory in the northern part of the Site is labelled as a biscuit factory. In addition, an AST is noted to be associated with the biscuit factory (southern side of building facing the yard area).

Pathway	Receptor	Potential Pollutant Linkage and Significance
Ingestion Inhalation Dermal contact	**HHR01 Human Health** Current Site users	**Likelihood [LOW] x Consequence [MINOR] = VERY LOW**

The property is currently disused (no current users) and there is no public access on to the site. The site is surrounded by fencing or hoardings.

The property was subject to recent demolition and site clearance/turn-over (to two metres below ground level) including removal of two USTs, removal of in-ground ACM demolition material, removal of below ground firing range and cross site ducts.

Minor exceedances of stated soil screening values were found during the site investigation:

- Arsenic – Concentration range of 5.7 – 140 mg/kg with 3 samples more than the 79 mg/kg LQM/CIEH Public Open Spaces (Residential) S4ULs, no Soil Organic Matter stated) screening value.
- Beryllium – Concentration of 0.31 – 3.7 mg/kg with 4 samples more than the 2.2 mg/kg LQM/CIEH Public Open Spaces (Residential) S4ULs, no Soil Organic Matter stated) screening value.
- 1,2,4-Trimethylbenzene – One sample above detection limit (1800 µg/kg) and above the 410 µg/kg C:LAIRE GAC for 1% SOM residential without homegrown produce screening value. It is important to note that the sample was obtained from within the historic remediation zone immediately below the area subject to remediation (*i.e.* WS15 (3.0-3.7m).

According to the BGS Contaminant Distribution in Soil Atlas the Welwyn Garden City area has higher than average 'normal background concentrations' of Arsenic. Statistical tests conclude that there is a very high degree of confidence that the true mean concentration (arsenic and beryllium) is less than the critical S4UL concentration.

Pathway	Receptor	Potential Pollutant Linkage and Significance
Ingestion Inhalation Dermal contact	**HHR02 Human Health** Future construction workers	**Likelihood [LOW] x Consequence [MINOR] =VERY LOW**

The property was subject to recent demolition and site clearance/turn-over (to two metres below ground level) including removal of two USTs, removal of in-ground ACM demolition material, removal of below ground firing range and cross site ducts. As such, the preparation works have been extensive and unexpected areas of potential contamination are not anticipated.

The site investigation did not identify any potentially significant shallow on-site (in ground) sources of contamination beyond that identified in HHR01.

The redevelopment of the Site will involve ground disturbance and removal of some shallow 'Made Ground'. Any localised 'Made Ground' encountered during the redevelopment works should be assessed and removed as required.

Construction mitigations measures would need to include a formal Construction Environmental Management

Pathway	Receptor	Potential Pollutant Linkage and Significance
Plan (CEMP) to minimise potential Environmental impacts. It can be stated that where construction activities involve ground disturbance, appropriate legislative requirements and industry –standard procedures and protocols will be applied such as damping down of soils, cleaning and wetting of roadways, managing stockpiles, dust monitoring, wheel washes, PPE, RPE and hygiene facilities Normal operational hygiene requirements and procedures will be applied. These would be sufficient to break any potential pollution linkages with the below ground materials (if indeed they are present).		

Pathway	Receptor	Potential Pollutant Linkage and Significance
Ingestion Inhalation Dermal contact	**HHR03 Human Health** Future Site users	**Likelihood [LOW] x Consequence [MINOR] = VERY LOW**
The proposed development is residential but there are no individual gardens. All green spaces are shared *i.e.* The weave (a central public area of green space), Podium level residential gardens (recreational space for residents located above ground floor parking), Sensory garden (a publicly accessible space with individual and combined sensory opportunities), Roof gardens (roof level gardens) and a Green edge infrastructure (utilising existing trees and vegetation). The site investigation did not identify any potentially significant on-site (in ground) sources of contamination. Minor exceedances of stated soil screening values were found (HHR01 Human Health). A gridded Soil Vapour Survey (SVS) was undertaken across the entire area previously occupied by the UST tank farm. Limited vapours from Volatile Organic Compounds (VOCs) were detected with a maximum PID level of 0.4 ppmv. It is important to note that the groundwater contamination (described in CWR02) is around 22.5 – 23.5 metres below ground level. Any service pipes should be installed to comply with *Water Supply (Water Fittings) Regulations 1999* and *Water Supply (Water Quality) Regulations 2000*. All materials to be Water Regulations Advisory Scheme (WRAS) approved for use on potable water supplies.		

Pathway	Receptor	Potential Pollutant Linkage and Significance
Migration from impacted soils to surface water	**CWR01 Controlled Waters** Surface Water	**Likelihood [LOW] x Consequence [MINOR] = VERY LOW**
The nearest surface watercourse to the Site is the River Mimram (1.75 km north) and the River Lee (1.76 km south southwest). With regards to the shallow soils the site investigation did not identify any significant on-site (in ground) sources of contamination. Minor exceedances of stated soil screening values were found (See HHR01 Human Health). The 2017/2018 site investigation works completed along with data from the subsequent laboratory analysis suggest that residual petroleum hydrocarbon contamination is present in the deeper soils and groundwater		

Pathway	Receptor	Potential Pollutant Linkage and Significance
beneath the former tank farm/remediation area. However, the potential for there to be a pollution linkage with the River Mimram (1.75 km north) and the River Lee (1.76 km south southwest) is very low.		

Pathway	Receptor	Potential Pollutant Linkage and Significance
Migration from impacted soils to groundwater	**CWR02 Controlled Waters** Groundwater	**Likelihood [HIGH] x Consequence [MEDIUM] = HIGH**

The Site is partially located on a Secondary A Aquifer and a Secondary (Undifferentiated) Aquifer (superficial deposits) and underlain by a Principal Aquifer (bedrock). The site is in the Total Catchment (Zone 3) of an SPZ. The groundwater resources are highly sensitive.

The principal source of groundwater contamination is the historic polycell solvent tank farm which comprised of 13 (six in use when the site was operational, seven redundant) underground storage tanks (USTs) and one above ground storage tank (AST).

Delta-Simons undertook several phases of intrusive site investigation and long-term groundwater monitoring at the Site between 2003-2016. A long-term strategy was agreed (in conjunction with the Welwyn Hatfield Council and the Environment Agency) to undertake a voluntary groundwater remediation scheme to reduce the associated environmental risks. The scheme involved:

- Stage 1 – Tank pull and soil excavation – completed September/October 2008;
- Stage 2 – Soil excavation validation – completed October 2008;
- Stage 3 – On-site ex-situ biopile remediation – completed July 2009;
- Stage 4 – Pump and Treat groundwater remediation/Free product recovery – completed January 2011;
- Stage 5 – Soil vapour extraction – completed January 2011;
- Stage 6 – Oxygen Releasing Compound (ORC) injection – completed early 2011; and
- Stage 7 – Long-term groundwater monitoring/Monitored Natural Attenuation (MNA) – October 2008 to September 2015.

Delta-Simons work at the Site was completed in September 2015 with the final report issued in March 2016.

The 2017/2018 site investigation works completed along with data from the subsequent laboratory analysis suggest that residual petroleum hydrocarbon contamination is present in the deeper soils (below the previous remediation zone) and groundwater beneath the former tank farm/remediation area. The results of the risk assessment suggest that there is potential for impacts on off-site groundwater quality from residual groundwater contamination. However, the empirical site data demonstrates a clear reduction in petroleum hydrocarbon concentrations down hydraulic gradient.

Notwithstanding the empirical site data, based on the recorded elevated concentrations of petroleum hydrocarbons in groundwater and the sensitivity of the Principal Chalk Aquifer it is considered that remedial actions will be required in the form of environmental betterment. Any remedial actions will need to take into

Pathway	Receptor	Potential Pollutant Linkage and Significance
consideration current best practice guidance, including the principals of sustainable remediation. A standalone Foundation Works Risk Assessment (FWRA) will also be required in-line with current EA guidance.		

Pathway	Receptor	Potential Pollutant Linkage and Significance
Direct contact Migration of land gas through soils	**BER01 - Built Environment** On-site buildings, services and structures	**Likelihood [LOW] x Consequence [MINOR] = VERY LOW**
The property was subject to recent demolition and site clearance/turn-over (to two metres below ground level) including removal of two USTs, removal of in-ground ACM demolition material, removal of below ground firing range and cross site ducts. As such, the preparation works have been extensive and unexpected areas of potential contamination are not anticipated. No evidence of infilled areas on-site was found either during the site investigation or during the demolition activities. Three phases (8 separate rounds) of ground gas assessment have been undertaken on the southern site between 2006 and 2018. The CIRIA 665/BS 8485: 2015 guidance has been used for comparative purposes. As such, using the modified Wilson and Card Classification (CIRIA C665, 2007), in respect of the current data and the identified GSVs the worst-case situation (consideration of site-wide maximums) is (0.0 l/hr x 6.4 % v/v/100) = 0.00 l/hr or Characteristic Situation CS1 – Very Low Risk. Based on the BS 8485:2015 gas protection scores by CS and building type the minimum gas protection score would be 0 (Type B Building under BS8485:2015).		

15 Conclusions

15.1 Soils

An extensive shallow soils investigation was undertaken across the southern site during which, in combination with the six new boreholes, 51 soil samples were collected in the range 0 – 5.5 m bgl. All 51 samples were submitted for an extensive suite of analytes including General Inorganics, Total Phenols, Speciated PAHs, Heavy Metals and Metalloids, Monoaromatics, Petroleum Hydrocarbons (TPH – CWG), SVOCs and VOCs. In addition, selected samples were submitted for PCB analysis (10 samples) and asbestos (12 samples). The results have been screened using recognised Tier 1 values *i.e.* LQM/CIEH Public Open Spaces (Residential) S4ULs, Category 4 Screening Levels (C4SLs), Public Open Spaces 1 (Grassed area adjacent to residential housing) and C:LAIRE GAC residential without homegrown produce.

The only exceedences of the stated screening values relate to Arsenic, Beryllium and 1,2,4-Trimethylbenzene.

Arsenic

The concentration range was 5.7 – 140 mg/kg with 3 samples more than the 79 mg/kg LQM/CIEH (Residential without home grown produce S4UL, no Soil Organic Matter stated) screening value. According to the BGS Contaminant Distribution in Soil Atlas the Welwyn Garden City area has higher than average ‘normal background concentrations’ of Arsenic. The dataset was subject to statistical analysis in-line with CL:AIRE guidance which concluded that there was a Very High degree of confidence (99%) that the true mean concentration is less than the critical concentration of 79 mg/kg.

Beryllium

The concentration was 0.31 – 3.7 mg/kg with 4 samples more than the 2.2 mg/kg LQM/CIEH Public Open Spaces (Residential) S4UL, no Soil Organic Matter stated) screening value. The dataset was subject to statistical analysis in-line with CL:AIRE guidance which concluded that there was a Very High degree of confidence (99%) that the true mean concentration is less than the critical concentration of 2.2 mg/kg.

1,2,4-Trimethylbenzene

One sample was above the analytical detection limit (1800 µg/kg) and above the 410 µg/kg C:LAIRE GAC for 1% SOM residential without homegrown produce screening value. It is important to note that the sample was obtained from within the historic remediation zone immediately below the area subject to remediation (*i.e.* WS15 (3.0-3.7m). This corresponds well with the PID profile outlined within *Figure 8-2*.

It is concluded that the sampling demonstrates that the shallow ground 0 – 5.5 m bgl is not significantly contaminated in the range 0.0 – 5.5 m bgl except for the zone immediately below the area subject to remediation where localised elevated VOCs are still present. The Soil Vapour Survey (SVS) conducted across the previous remediation area did not detect significant soil vapour with a maximum PID level recorded was 0.4 ppmv.

15.2 Ground gases

Three phases of ground gas assessment have been undertaken on the southern site between 2006 (1 Round of monitoring by Delta-Simons), 2014 (2 Rounds of monitoring by Delta-Simons) and 2018 (5 Rounds of monitoring by EAME). The results are summarised below:

- No gas flow was detected in 7 of the 9 Windowless Sample locations during any of the 5 monitoring rounds.
- WS19-17 featured an instantaneous spike of 0.1 l/hr (at 45 seconds only) during monitoring Round 1. No other gas flows were recorded from WS19-17 during any of the next 5 monitoring events.
- WS23-17 featured an instantaneous spike of 1.8 l/hr (at 8 minutes) with an average over the 10-minute monitoring period of 0.3 l/hr (Figure 13 2). No other gas flows were recorded from WS23-17 during any of the next 4 monitoring events.
- During the 2018 monitoring events (Rounds 1 to 5) 271 individual data points were collected from 9 WS locations across 5 monitoring rounds of which there were 7 gas flow spikes from WS23-17 and 1 spike from WS19-17. Therefore, based on 6 rounds of gas monitoring (2014 – 2018) there is sufficient evidence to conclude that gas flows at the site are zero.
- No methane was detected in any of the monitoring well monitored between May 2018 – July 2018.
- The maximum Carbon dioxide reading was 6.4% v/v (WS02-17) observed during round 1.
- No hydrogen sulphide (H_2S) or carbon monoxide (CO) was detected in any of the locations monitored. Limited vapours from Volatile Organic Compounds (VOCs) were detected with a maximum PID level recorded was 0.5 ppmv (WS01-17).

This equates to a GSV of 0.00 l/hr or Characteristic Situation CS1 – Very Low Risk. Based on the BS 8485:2015 gas protection scores by CS and building type no gas protection measures would be required.

15.3 Groundwater

The site investigation works completed along with data from the subsequent laboratory analysis suggest that residual petroleum hydrocarbon contamination is present in the soils and groundwater beneath the former tank farm/remediation area.

The groundwater beneath the site is present within the Lewes Nodular and Seaford Chalk Formations. Appraisal of groundwater monitoring data suggests that two groundwater units are present beneath the site; an upper unit within the more weathered 'putty' chalk and a deeper unit within the Principal Chalk Aquifer. The data also suggests that there is a downward head gradient between the shallow and deeper groundwater within the chalk.

This is not uncommon in the chalk where the 'putty chalk' acts a leaky confining layer between shallow groundwater contained in the putty chalk itself and the deeper groundwater within the Principal Chalk Aquifer. Based on the monitoring data groundwater flow in the chalk is interpreted to be to the south east.

Concentrations of petroleum hydrocarbons have been recorded above relevant water quality standards and, on this basis, a detailed hydrogeological quantitative risk assessment has been undertaken. Based on the petroleum hydrocarbon contaminant characteristics key risk drivers were identified for assessment using bespoke EA approved modelling packages (RTW & ConSim v 2.5)

As with all modelling the packages the results have been used in the risk assessment to aid in professional judgement.

Overall the results of the risk assessment suggest that potential impacts associated with residual soil contamination are likely to be minimal.

The results of the risk assessment suggest that there is potential for impacts on off-site groundwater quality from residual groundwater contamination. However, the empirical site data demonstrates a clear reduction in petroleum hydrocarbon concentrations down hydraulic gradient.

Notwithstanding the empirical site data, based on the recorded elevated concentrations of petroleum hydrocarbons in groundwater and the sensitivity of the Principal Chalk Aquifer it is considered that remedial actions will be required in the form of environmental betterment. Any remedial actions will need to take into consideration current best practice guidance, including the principals of sustainable remediation.

Appraisal of primary and secondary lines of evidence suggests that there is potential for natural attenuation processes to be active within the groundwater contaminant plume.

A standalone Remediation Options Appraisal, Remediation Strategy, and proposed Verification Plan has been developed, in-line with CLR11, to address the stated groundwater issues described above.

Annex A: Figures

Annex B: Stage 1 – Groundwater Assessment (Existing Wells)

Annex C: Stage 2 – Soil and Groundwater Assessment (New Boreholes)

Annex D: Shallow Soils Assessment (Windowless Samples)

Annex E: Model Inputs and Outputs

Annex F: Remedial Target Worksheets

Annex G: Ground Gas Monitoring Data