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G.1 INTRODUCTION

A site wide investigation of the Whitehaven site was undertaken by URS in 2005. A controlled waters quantitative risk assessment (CWQRA) was undertaken based on the site data using a mass balance model to assess risks to deep groundwater beneath the site. A number of areas of the site were identified that posed potential risks to controlled waters.

In June 2006 URS was commissioned to undertake a detailed investigation of Plot B within the Whitehaven Site and to carry out a detailed risk assessment with regard to controlled waters using relevant data gathered from previous investigations and data from the 2006 investigation. This appendix presents the methodology and results of the CWQRA for Plot B.

The risk assessment set out in this appendix is considered to be more rigorous and representative of site conditions than the previous risk assessment for the whole of the Whitehaven site as it incorporates additional geological and geochemical data obtained during the Plot B investigation and uses a more sophisticated modelling approach.

The CWQRA is based upon the UK Department of the Environment, Food and Rural Affairs (DEFRA) and Environment Agency (EA) guidance including:

- Environment Agency R&D Publication 20 (1999) Methodology for the Derivation of Remedial Targets for Soil and Groundwater to Protect Water Resources (referred to as R&D P-20); and
- Environment Agency R&D Publication CLR11 (2004) Model Procedures for the Management of Land Contamination (referred to as CLR11).

Using CLR 11 methodology, risk assessment is carried out in three stages:

Stage 1 – Preliminary Risk Assessment

Stage 2 - Generic Quantitative Risk Assessment; and

Stage 3 – Detailed Quantitative risk assessment.

Stage 1 involves the development of a conceptual understanding of the site and the surrounding environment's geology, hydrogeology, observed contamination (and its distribution), and potential receptors. From this conceptual understanding, potential pollutant linkages (*source-pathway-receptor* relationships) are identified. This stage of the risk assessment is set out in Section 5 of the main body of the report.

Risk assessment at Stages 2 and 3 for Plot B is presented in full in this appendix.

G.2 STAGE 2 - GENERIC QUANTITATIVE ASSESSMENT

G.2.1 Methodology

The generic screening was undertaken by making a comparison of measured chemical concentrations in soil, soil leachate, and groundwater against conservative screening criteria appropriate for a designated potential receptor. This initial screening is designed to identify Potential Contaminants of Concern (PCoC), which could pose a potential risk to controlled waters. At the generic screening stage, no consideration is given to pathways or potential attenuation factors such as dilution, dispersion or biodegradation.

For this assessment the receptor is considered to be deep groundwater in the Whitehaven Sandstone Formation and the screening values that have been used are the UK Drinking Water Quality Standards (UK DWS) for soil leachate and shallow groundwater samples. Where published UK DWSs for certain contaminants were not readily available, reference was made to World Health Authority (WHO) guidelines. In the absence of WHO guidelines, United States Environmental Protection Agency (US EPA) Region 9 Pathway Specific values were used for screening purposes.

VOC analysis was not carried out on soil leachates as the leaching methodology is unsuitable for VOCs, i.e. it allows VOCs to escape during the leaching process and thus any results obtained would be unrealistically low. Thus, for soils samples, concentrations of VOCs have been compared to theoretical soil concentrations that are protective or drinking water. The theoretical concentrations have been derived using partitioning equations, as outlined in EA R&D-P20 (EA, 1999).

The Stage 2 soils VOC screening values are derived using the following site-specific parameters:

- Fraction of Organic Carbon;
- Soil Type (Silt, Gravel, Clay etc);
- Total Porosity;
- Water and Air Filled Porosity; and
- Dry bulk density.

Details of the sources of all Stage 2 screening criteria are given in Tables G1 (soil VOCs) and G2 (soil leachate and groundwater).

Where concentrations of contaminants exceeded the generic screening criteria, they have been evaluated further as part of the Stage 3 assessment.

G.2.2 Statistical Analysis Method

The calculated upper 95th percent confidence limit of the mean concentrations (US95), as defined in CLR-7, were adopted as the source term concentrations for the Stage 2 assessment for soils and soil leachates. For groundwater, all exceedances of Stage 2 criteria are considered potential sources. If the sample population was too small to calculate the US95 value, the maximum recorded concentration for the compound was adopted. Values less than the method reporting limits are taken as equal to the method reporting limit for the purpose of calculating US95 values.

Where the maximum values in any data set exceeded the Stage 2 screening criterion, the potential for the existence of hotspots was considered. This consideration included assessing the spatial distribution of the potential contaminant across the area, and use of the maximum value test to detect statistical outliers.

Where potential hotspots were detected, these contaminants were carried through to Stage 3, even if the US95 did not exceed the Stage 2 screening criterion.

For Stage 2, the averaging area used is the entire Plot B area. This averaging area was selected because:

- The Plot B area itself represents the area that is expected on the basis of historical uses and previous investigations to be potentially contaminated by gasworks type contamination;
- The Plot B area is reasonably consistent geologically and is not readily zoned by pathway type or receptor type; and
- The potential hotspots, although centred in similar places, are very different in size and shape for different contaminants. Use of different averaging areas for different contaminants makes Stage 2 extremely complicated, and in this instance was judged unlikely to make a difference to those contaminants passed through to Stage 3, where hotspots are considered in more detail.

The US95 was calculated from the entire sample data set (including data from previous and the 2006 investigations) for Plot B using the following calculation:

$$\textbf{\textit{US 95}} = x + ((t \times sd)/ (\sqrt{n}))$$

Where x is the mean concentration, t is the t-value for a given sample population, n is the number of samples in the data set and sd is the standard deviation of the data set.

G.2.3 Soil Contamination Generic Screening

With the exception of VOC's, generic screening was not performed on soils data. This is because the screening was done using leach test data, which is considered more representative of the potential risks to controlled waters.

A summary of the determinands whose concentrations exceeded the Stage 2 generic screening values is given in Table G3.

G.2.4 Soil Leachate Generic Screening

G.2.4.1 Metals and other Inorganic Ions

A summary of the determinands whose concentrations exceeded the Stage 2 generic screening values is given in table G4.

G.2.4.2 Total Petroleum Hydrocarbons (TPHs)

A summary of the determinands whose concentrations exceeded the Stage 2 generic screening values is given in Table G5.

G.2.4.3 Semi Volatile Organic Compounds (SVOC) and Polycyclic Aromatic Hydrocarbons (PAHs)

A summary of the determinands whose concentrations exceeded the Stage 2 generic screening values is given in Table G6.

G.2.5 Shallow Groundwater Results Generic Screening

Shallow groundwater was generally not encountered across Plot B, however, samples were collected from two trial pits and two shallow boreholes TP659B, TP675B, WS552B and WS553B. The groundwater sample from WS552B was analysed for heavy metals, anions, phenols, SVOCs, TPH and VOCs, while the remainder of the samples were analysed for VOCs only.

The results of the screening assessment for metals, SVOCs and TPH from the single shallow groundwater sample summarised below:

- Nickel (162 μg/l);
- Chloride (277,000μg/l);
- Ammoniacal nitrogen (28,900μg/l);
- Total cyanide (170μg/l); and
- SVOC and TPH concentrations were either comparable to, or lower than concentrations detected in the soil leachate, the results of which are presented in the previous section.

Four shallow groundwater samples were submitted for VOC analysis. Exceedances of the Stage 2 generic screening criteria are given in table G7.

G.2.6 Summary of Identified Exceedances of Generic Screening Criteria

From the Stage 2 generic screening process the determinands in soils, soil leachate and shallow groundwater that exceeded the Stage 2 screening criteria are summarised in Table G8 below. All of the determinands were identified at one or more locations across Plot B.

Table G8 – Stage 2 Assessment – Summary of Screening Criteria Exceedances

Soil	Soil Leachate	Shallow Groundwater
benzene	benzene	benzene
toluene	toluene	toluene
ethylbenzene		
xylenes	xylenes	xylenes
naphthalene	naphthalene	naphthalene
1,2,4-Trimethylbenzene		1,2,4-Trimethylbenzene
1,3,5-Trimethylbenzene		1,3,5-Trimethylbenzene
1,2-Dichlorobenzene		
Cis-1,2-Dichloroethene		Cis-1,2-Dichloroethene
Styrene		Styrene
Trichloroethene		Trichloroethene
	arsenic	
	lead	
	nickel	nickel
	vanadium	
	ammoniacal nitrogen	ammoniacal nitrogen
	sulphate	
	total cyanide	total cyanide
	total petroleum hydrocarbons	
	2,4-dimethylphenol	
	4-methylphenol	
	acenaphthylene	
	carbazole	
	dibenzofuran	
	fluoranthene	
	phenanthrene	
	phenol	
		Chloride
		Vinyl chloride

G.3 STAGE 3 DETAILED QUANTITATIVE RISK ASSESSMENT

G.3.1 Methodology

Those determinands whose concentrations exceeded the Stage 2 screening criteria have been taken forward to a Stage 3 detailed quantitative risk assessment. Natural attenuation processes such as dilution, dispersion and other physical/geochemical processes are considered at this stage of assessment. The Stage 3 assessment has been carried out using ConSim (v2.02) software. Three scenarios have been modelled:

- Model 1 – For all determinands that exceeded the Stage 2 screening criteria, a site wide (all of Plot B) source with an unsaturated zone;
- Model 2 – For all determinands that exceeded the Stage 2 screening criteria a site wide source without an unsaturated zone; and
- Model 3 – For those determinands that exceeded the screening criteria in Model 2, Stage 3, a hotspot source without an unsaturated zone.

G.3.2 Model Selection and Key Model Assumptions

ConSim (version 2.02) was run in probabilistic mode to allow for uncertainty in key input parameters. Simulated concentrations at a defined receptor are reported both the 50th percentile and the 95th percentile. Simulated concentrations at the 50th percentile confidence limit represent 'on the balance of probabilities' the most likely simulated concentrations given the range of parameters applied. Simulated concentrations at the 95th percentile confidence limit represent a worse case or extreme condition, resulting from a worse case combination of parameters (e.g. high permeability, high source concentrations and low degradation rate). This approach is consistent with that recommended in EA R&D-P20 (EA, 1999).

The CONSIM model allows for the input of site-derived parameters such as aquifer permeability, hydraulic gradient, organic carbon content, bulk density and effective porosity. These parameters are assumed to be continuous (and homogeneous) between the site and designated receptor or compliance point. The physical parameters used to define the model used in this assessment are set out in Tables G9 to G11. Other key model assumptions include:

- Given that site operations have ceased, declining source terms have been assigned to all designated soil sources. This assumption has been made as no fresh contamination inputs to ground will occur in the future and any contamination present in soils or groundwater represents residual contamination having a finite mass.

- Conservative estimates of biodegradation have been applied. Conservative half-lives applied and relevant literature sources for the physical/chemical parameters used in the model are presented in Table G12. The applied degradation rates were obtained, where available, from EA (2002) R&D Technical Report P2-228/TR.

- No attenuation or biodegradation processes have been simulated in the unsaturated zone. It has been assumed the soil source extends to the water table, i.e. no unsaturated zone is present for models 2 and 3.

- Longitudinal dispersion set at 1/10th the travel distance to the receptor 50m away from the source.

- Vertical dispersion is not simulated by ConSim.

G.3.3 Sources

For Models 1 and 2, a single source has been modelled representing the entire area of Plot B and using the calculated US95 values for each contaminant concentration (in soil, soil leachate and shallow groundwater). Where the US95 was less than the Stage 2 screening value, the maximum value has been used. The source concentrations and dimensions used for Models 1 and 2 given in tables G13 to G18.

For Model 3, hotspots have been determined, the source sizes being established around the maximum concentrations encountered within Plot B. Source concentrations and dimensions used in the Stage 3 assessment are detailed in Tables G19 to G24.

G.3.4 Pathways

The pathways that are considered applicable to this assessment include the partitioning of contaminants from the soil into the soil pore water, migration of contaminants as soil leachate, and shallow perched groundwater (where present) vertically into the Whitehaven Sandstone.

Due to the potential that vertical migration through the unsaturated zone may occur either rapidly via fracture flow, or more slowly via seepage through pore space, a number of model scenarios have been adopted, as follows:

- **MODEL 1** (site wide source with an unsaturated zone present)

This model assumes that an unsaturated zone is present and that migration is via slow infiltration through the sandstone matrix pore space. The degree of vertical attenuation that can occur if an unsaturated zone is present may significantly decrease the concentrations of determinands before they reach the underlying groundwater.

Model 1 assumes that once in the Whitehaven Sandstone (situated below the source zone), the determinands move vertically through the pore spaces of approximately 18m of

unsaturated rock, before reaching the deep groundwater table. From the point of entry of determinands into the groundwater within the Whitehaven Sandstone, the groundwater moves laterally towards the compliance point.

- **MODEL 2** (site wide source without an unsaturated zone present)

A second model has been run that assumes that an unsaturated zone does not exist. This considers that the determinands rapidly migrate vertically through (potential) fractures in the Whitehaven Sandstone, directly into the underlying groundwater. In effect, it can be considered that this model assumes the source zone is directly overlies the deeper groundwater table.

This scenario is highly conservative, but is useful, as it provides an understanding of a reasonable worst-case scenario for the impact of contamination within Plot B on the underlying groundwater body.

From the point of entry of determinands into the groundwater within the Whitehaven Sandstone, contamination moves laterally towards the compliance point.

Model 2 assumes the unsaturated zone does not act to attenuate the contaminants, as flow through the sandstone is rapid through a network of fractures. This is a conservative assumption as although fracture flow may be the predominant flow mechanism, it is unlikely to be the sole transport mechanism for contamination that may be migrating from the source area to deep groundwater; as transport through pore spaces is likely to be occurring also. Furthermore, a degree of attenuation can actually take place when water migrates through fracture flow. Model 2 assumes that this is not occurring.

- **MODEL 3** (hotspot source without an unsaturated zone present)

This model uses the assumptions of Model 2, but only considers the determinands for which potential risks are generated by Model 2 and re-assess these as hotspot sources of contamination. Such an approach is considered to be more realistic than the site wide source originally adopted for Model 2, as the calculated US95 concentrations are strongly influenced by isolated high concentrations that are not representative on a site-wide scale. However, an element of conservatism is considered to remain as maximum concentrations have been assumed to represent the adopted hotspot.

G.3.5 Receptors

The receptor for Plot B derived contaminants has been determined as the Whitehaven Sandstone Formation. For the purposes of this assessment a theoretical compliance point located 50m down hydraulic gradient of the site boundary has been used as the receptor. A theoretical compliance point has been adopted given the absence of identifiable groundwater abstractions or discharge points to surface close to the site. The compliance point is designed to be protective of water resources present within the Whitehaven Sandstone Formation and is positioned such that large portions of the aquifer are protected (rather than being used to attenuate any site derived contamination).

Consideration of the effects on a receptor located approximately 400m down gradient, i.e. at the approximate point of entry of groundwater into the Irish Sea has also been made with regard to a limited number of determinands.

G.3.6 Summary of Model Results

Simulated 50th and 95th percentile concentrations at the theoretical compliance point within the Whitehaven Sandstone Formation at a distance of 50m down hydraulic gradient from the source area are presented in Tables G25 to G30. Time-variant graphical outputs for each model run, presenting simulated concentrations of the determinands are presented in Figures G2a-c. The ConSim model files are included on the CD in Appendix H to the main report.

For simulated contaminant concentrations at a given compliance point to pose a potentially significant risk to shallow controlled waters, they must be in excess of defined generic screening criteria, in this case UKDWS and should occur within a reasonable time frame.

Calculated travel times provide a measure of the relative mobility of individual contaminants and the time scale over which breakthrough of concentrations at the receptor is likely to occur. URS considers a travel time of 500 years or less to be meaningful in terms of assessing risk.

In addition, current UK guidance suggests that simulated 95th percentile concentrations are used to assess potential risks. However, in assessing the potential significance of an identified risk, predicted travel times and 50th percentile concentrations are taken into account. The results are summarised below.

G.3.6.1 Risks From Soil To Deep Groundwater

Model 1 (site wide source with an unsaturated zone present)

All determinands that were identified to be in exceedance of the Stage 2 generic screening criteria where included in Model 1.

The model did not generate any determinand concentrations above their respective screening criteria at the 50m compliance point within the Whitehaven Sandstone.

Model 2 (site wide source without an unsaturated zone present)

All determinands that were identified to be in exceedance of the Stage 2 generic screening criteria where included in Model 2.

Predicted exceedances of screening criteria at the 50m compliance point within the Whitehaven Sandstone were simulated (at the 95th percentile) for the following contaminants for a site wide soil source zone:

- Benzene was simulated to exceed the UK DWS of 1μg/l with a maximum concentration of 98μg/l modelled at approximately 1 year from the start of the simulation. Risks from benzene simulated using the soil leachate data were much lower than those modelled using the soil concentrations which suggests that either the theoretical partitioning equations used in the model are more conservative than the actual partition of benzene occurring on site, or that some of the volatile was lost during the leachate sample preparation;

- Naphthalene was simulated to exceed the USEPA value of 6.2μg/l with a maximum concentration of 63μg/l modelled at 100 years. Risks from naphthalene were not simulated using the soil leachate data which may indicate that the theoretical partitioning equations used in the model are more conservative than the actual partitioning of naphthalene occurring on site, or that some of the volatile was lost during the leachate sample preparation; and

- Trichloroethene (TCE) was simulated to slightly exceed the UK DWS of 10μg/l with a maximum concentration of 14μg/l modelled at 100 years. TCE is considered unlikely to pose a risk to the aquifer given the relative low exceedance concentration and the absence of an unsaturated zone.

It should be noted that none of the above contaminants presented a risk at the 50th percentile.

The above three contaminants for which potential risks were simulated, were carried through to a targeted risk assessment, Model 3, described below.

Model 3 (hotspot source without an unsaturated zone)

Those determinands whose predicted concentrations exceeded the screening criteria using Model 2 were included in Model 3, which simulates the potential risks posed by hotspot source areas. Maximum concentrations of benzene, naphthalene and TCE were modelled using a defined source area of 400m^2, located around TP660B, TP671B and TP672B (where maximum concentrations were identified). Potential exceedances of screening criteria at the 50m compliance point within the Whitehaven Sandstone were simulated (at the 95th percentile) for the following contaminants:

- Benzene was simulated to exceed the UK DWS of 1μg/l with a maximum concentration of 303μg/l modelled at approximately 5 years from the start of the simulation;

- Naphthalene was simulated to exceed the USEPA value of 6.2μg/l with a maximum concentration of 51μg/l modelled at 10 years; and

- Trichloroethene (TCE) was simulated to exceed the UK DWS of 10μg/l with a maximum concentration of 46μg/l modelled at 5 years.

It should be noted that only one of the above contaminants presented a risk at the 50th percentile (benzene 20.6μg/l).

Model 3 was also run with a 400m compliance point; this is the point at which the groundwater reaches the Irish Sea. At this point, all simulated concentrations were less than their respective screening criteria.

G.3.6.2 Risks From Soil Leachate To Deep Groundwater

Model 1 (site wide source with an unsaturated zone present)

All determinands that were identified to be in exceedance of the Stage 2 generic screening criteria where included in Model 1.

The model did not generate any determinand concentrations above their respective screening criteria at the 50m compliance point within the Whitehaven Sandstone.

Model 2 (site wide source without an unsaturated zone present)

Potential exceedances of generic screening criteria at the 50m compliance point within the Whitehaven Sandstone were simulated (at the 95th percentile confidence limit) for the following contaminants for a site wide soil leachate source zone:

- Ammoniacal nitrogen was simulated to exceed the generic screening criteria of 500μg/l with a concentration of 761μg/l within 1 year;
- Benzene was simulated to slightly exceed its UK DWS of 1μg/l with a maximum concentration of 3μg/l. Risks from benzene simulated using the soil data were higher than those modelled using the soil leachate concentrations which suggests that either the theoretical partitioning equations used in the soil model are more conservative than the actual partition of benzene occurring on site, or that some of the volatile was lost during the leachate sample preparation;
- Cyanide was simulated to exceed the UK DWS of 50μg/l with a maximum concentration of 314μg/l modelled at 28 years. It should be noted, however, that the total cyanide concentrations were compared to the free cyanide drinking water standard, in the absence of other criteria, and this is likely to be a very conservative estimate of the actual concentrations of free cyanide present in the sample. If the majority of the concentration comprises complex cyanide (which is normally the case), risks to controlled waters will be significantly reduced; and
- Phenol was simulated to exceed the screening criteria values of 0.5μg/l with a maximum concentration of 2μg/l within 1 year.

It should be noted that only cyanide of the above determinands was predicted to exceed the screening criteria at the 50th percentile (cyanide 63μg/l).

Model 3 (hotspot source without an unsaturated zone)

Those determinands whose predicted concentrations exceeded the screening criteria using Model 2 were included in Model 3, which simulates the potential risks posed by

hotspot source areas. Maximum concentrations were taken for benzene, total cyanide, phenol, and ammoniacal nitrogen, which were modelled using a source area of 400m^2 and centred around TP664B and TP665B. Predicted exceedances of screening criteria at the 50m compliance point within the Whitehaven Sandstone were simulated (at the 95th percentile) for the following contaminants:

- A maximum concentration for ammoniacal nitrogen was simulated at 8664μg/l, 1 year following the start of the simulation. This concentration is above the generic screening criterion of 500μg/l for this determinand;
- Benzene was simulated to exceed its UK DWS of 1μg/l with a maximum concentration of 17.4μg/l after 5 years;
- Cyanide was simulated to exceed the UK DWS of 50μg/l with a maximum concentration of 1,002μg/l modelled at 100 years; and
- Phenol was simulated to exceed the screening criteria value of 0.5μg/l with a maximum concentration of 1.25μg/l within 1 year.

It should be noted that phenol did not present a risk at the 50th percentile. The remaining determinands still presented a theoretical risk (ammoniacal nitrogen 2875 μg/l, cyanide 332μg/l, and benzene 4.8μg/l).

Model 3 was also run with a 400m compliance point. At this point, simulated concentrations of phenol and benzene no longer exceeded the screening criteria. Concentrations of ammoniacal nitrogen and cyanide were 2564μg/l and 305μg/l respectively (at the 95th percentile).

G.3.6.3 Risks From Shallow Groundwater To Deep Groundwater

Model 1 (site wide source with an unsaturated zone present)

All determinands that were identified to be in exceedance of the Stage 2 generic screening criteria where included in Model 1.

The model did not generate any determinand concentrations above their respective screening criteria at the 50m compliance point within the Whitehaven Sandstone.

Model 2 (site wide source without an unsaturated zone present)

Potential exceedances of generic screening criteria at the 50m compliance point within the Whitehaven Sandstone were simulated (at the 95th percentile) for the following contaminants:

- Ammoniacal nitrogen was simulated to exceed the generic screening criteria of 500μg/l with a concentration of 718μg/l within 1 year. Information regarding ammoniacal nitrogen concentration is based on one data point only. In the

absence of additional data, the source was taken to encompass the whole site, however, based on the soils and soils leachate data it is more likely that this is reflective of an isolated hotspot;

- Benzene was simulated to slightly exceed its UK DWS of 1μg/l with a maximum concentration of 2μg/l; and
- Naphthalene was simulated to exceed the USEPA value of 6.2μg/l with a maximum concentration of 237μg/l modelled at 17 years.

It should be noted that none of the above contaminants presented a risk at the 50th percentile.

Model 3 (hotspot source without an unsaturated zone)

Those determinands whose predicted concentrations exceeded the screening criteria using Model 2 were included in Model 3, which simulates the potential risks posed by hotspot source areas.

Due to the lack of a continuous shallow groundwater body in Plot B, only a limited volume of water was obtainable from the installed wells. Consequently, only a limited analysis was possible. Therefore, delineation of individual contaminant hotspots could not be undertaken. However, due to the apparent absence of the shallow groundwater across much of the area, the use of a source encompassing the entire area of Plot B is highly conservative. Therefore, a source area covering 5000m^2, centred on WS552B and limited by the location of the adjacent monitoring wells (dry) was modelled using the input concentrations as defined in the entire site source model. Results are summarised as follows:

- A maximum concentration for ammoniacal nitrogen was simulated at 642μg/l, 1 year following the start of the simulation. This concentration is above the generic screening criterion of 500μg/l for this determinand;
- A maximum benzene concentration of 3.8 μg/l was simulated after 5 years, above the generic screening criteria of 1μg/l; and
- Naphthalene was simulated to exceed the USEPA value of 6.2μg/l with a maximum concentration of 562μg/l modelled at 10 years.

It should be noted that none of the above contaminants presented a risk at the 50th percentile.

Model 3 was also run with a 400m compliance point. At this point, all simulated concentrations were less than the screening criteria.

Table G31 – Stage 3 Assessment – Summary

Model/ Source	50m Compliance point						400m compliance point – Site Boundary					
	Soil		Soil Leachate		Shallow Groundwater		Soil		Soil Leachate		Shallow Groundwater	
	50%ile	95%ile	50%ile	95%ile	50%ile	95%ile	50%ile	95%ile	50%ile	95%ile	50%ile	95%ile
1	IR	IR	IR	IR	IR	IR	IR	IR	IR	IR	IR	IR
2	IR	Benzene (0.098mg/L), naphthalene (0.063mg/L), TCE (0.014mg/L)	Cyanide (0.063mg/L)	Ammoniacal nitrogen (0.761mg/L),benzene (0.003mg/L), cyanide (0.314mg/L), phenol (0.0020mg/L)	IR	Ammoniacal nitrogen (0.718mg/L), benzene (0.002mg/L), naphthalene (0.237mg/L)	NM	NM	NM	NM	NM	NM
3	Benzene (0.02mg/L)	Benzene (0.303mg/L), naphthalene (0.051mg/L), TCE (0.046mg/L)	Ammoniacal nitrogen (2.875mg/L), cyanide (0.332mg/L), benzene (0.0048mg/L)	Ammoniacal nitrogen (8.664mg/L, cyanide (1.002mg/L), phenol (0.0013mg/L), benzene (0.017mg/L).	IR	Ammoniacal nitrogen (0.64mg/L), benzene (0.0038mg/L), naphthalene (0.562mg/L)	IR	IR	Ammoniacal nitrogen (0.844mg/L, cyanide (0.061mg/L)	Ammoniacal nitrogen (2.564mg/L, cyanide (0.305mg/L)	IR	IR

NM- Not modelled
IR – insignificant risk, i.e. predicted concentrations do not exceed screening criteria

G.4 UNCERTAINTIES

It is acknowledged that there are uncertainties inherent in all risk assessment methodologies, particularly in relation to the assignment of assumed values for difficult to measure site specific variables, such as infiltration rate. However, a reasonable body of research exists such that these variables can be estimated with reasonable accuracy, and in a manner that is known to be conservative. It is therefore likely that risks are, if anything, overestimated, as a result of these assumptions (constant source terms, use of 95^{th} percentile concentrations), and so the results of the controlled waters risk assessment should be viewed in this context.

The assessment can only be undertaken on the data set available from site investigations, thus it is possible that higher concentrations of ground contaminants than observed during the recent site assessment works may exist. This uncertainty has been reduced as far as is reasonably practical with use of a relatively high sampling density and several phases of site investigation. It is also balanced by the inherent conservatism of the modelling process.

G.5 SUMMARY OF RISKS TO CONTROLLED WATERS

The conservatism in Models 2 and 3 must be taken into account when considering the potential risk to controlled waters posed by residual contamination within Plot B. These models assumed fracture flow was the sole mechanism for transport. In reality, it is likely that a combination of fracture flow and flow through seepage through sandstone matrix pore space is occurring, with the migration through pores allowing attenuation to occur. Furthermore, attenuation can also occur in fracture flow. The connectivity of the fractures has not been considered since the model has assumed migrating water passes vertically through a fracture directly to the water table. It is more likely that water migrates through a complex system of fractures within the 18m between the source zone and underlying groundwater table. This will increase the residence time of the water in this system, again increasing the attenuation that can occur.

The possible pollutant linkages identified relate to the risk of soil leachate or shallow contaminated groundwater entering the Whitehaven Sandstone minor aquifer by migration from the Made Ground source and directly into the underlying aquifer.

It must be noted that Model 1 may underestimate actual risks because of the paucity of data on vertical hydraulic conductivity and the presence of fractures that could provide a rapid flow mechanism. Models 2 and 3 are considered to be conservative in so far as an unsaturated zone has not been modelled, the results being unrealistically high breakthrough concentrations. It is considered that the "real" situation would lie somewhere in between these models, with an unsaturated zone and a degree of attenuation in the unsaturated zone, which suggests that Model 1 is closer to actual site conditions.

Taking into account the physical site conditions, it can be seen that where soils, soil leachate and shallow groundwater with high concentrations have been identified, the majority of these are present in areas where concrete hardstanding is present at the surface. In addition, shallow perched groundwater has been identified, indicating that the potential for vertical migration is limited by the presence of buried concrete slabs or clayey drift deposits, suggesting that the majority of the contamination identified within Plot B is retained in the upper parts of the unsaturated zone. There is no evidence to suggest significant volumes of contaminants are entering bedrock.

Overall, taking into account both the physical site evidence and the results of the risk assessment and modelling, it is considered that the potential risks to controlled waters are insignificant, if present at all, i.e. there are no significant pollutant linkages with regard to controlled waters within Plot B.

G.6 REFERENCES

1) CLR-7 (2002) Assessment of Risks to Human Health from Land Contamination: An overview of the Development of Soil Guideline Values and Related Research. Department for the Environment, Food and Rural Affairs (DEFRA) and Environment Agency (EA), Appendix A.

2) CLR-11 (2004) Model Procedures for the Management of Land Contamination" (Environment Agency, 2004).

3) Environment Agency (1999) Methodology for the Derivation of Remedial Targets for Soil and Groundwater to Protect Water Resources. Authors Marsland, P.A. and Carey, M.A. Environment Agency R&D Publication 20, 89pp.

FIGURES

TABLES

TABLE G1 – STAGE 2 SCREENING CRITERIA – VOCS IN SOILS

Target Compound	*Controlled Waters mg/kg*	*Source*
1,1,1-Trichloroethane	4.5747	WHO DWG
1,1-Dichloroethane	0.4188	USEPA Region 9 (pathway specific)
1,2,4-Trimethylbenzene	0.1689	USEPA Region 9 (pathway specific)
1,2-Dichlorobenzene	6.3285	WHO DWG
1,3,5-Trimethylbenzene	0.1689	USEPA Region 9 (pathway specific)
1,3-Dichlorobenzene	3.6466	USEPA Region 9 (pathway specific)
1,4-Dichlorobenzene	1.9038	USEPA Region 9 (pathway specific)
Benzene	0.0015	UK DWS (2000)
Cis-1,2-Dichloroethene	0.0331	WHO DWG
Ethylbenzene	1.3585	WHO DWG
Isopropylbenzene	3.5170	USEPA Region 9 (pathway specific)
M,P-Xylene	2.2177	WHO DWG
Naphthalene	0.0809	USEPA Region 9 (pathway specific)
O-Xylene	2.2177	WHO DWG
P-IsopropylToluene (Methyl benzene)	NV	No Criterion
Propylbenzene	NV	No Criterion
Sec-Butylbenzene	6.9408	USEPA Region 9 (pathway specific)
Styrene	0.1588	WHO DWG
Tetrachloroethene	0.0185	UK DWS (2000)
Toluene (Methyl benzene)	1.1260	WHO DWG
Trans-1,2-Dichloroethene	0.0917	UK DWS (2000)
Trichloroethene	0.0185	UK DWS (2000)
tert-Butylbenzene	8.3580	UK DWS (2000)
n-Butylbenzene	2.7635	USEPA Region 9 (pathway specific)

NV: No value available
USEPA Region 9 PRG- United States Environment Protection Agency Region 9 Preliminary Remediation Goal
WHO DWG - World Health Organisation Drinking Water Guidelines
UK DWS (2000) - United Kingdom Drinking Water Standards

TABLE G2 – STAGE 2 SCREENING CRITERIA – SOIL LEACHATE AND SHALLOW GROUNDWATER

Target Compound	*Controlled Waters µg/L*	*Source*
1,1,1,2-Tetrachloroethane	0.432	USEPA Region 9 (pathway specific)
1,1,1-Trichloroethane	2000	URS GAC
1,1,2,2-Tetrachloroethane	0.0553	URS GAC
1,1,2-Trichloroethane	0.200	URS GAC
1,1-Dichloroethane	811	USEPA Region 9 (pathway specific)
1,1-Dichloroethene	30.0	WHO DWG
1,1-Dichloropropene	NV	No Criterion
1,2,3-Trichlorobenzene	NV	No Criterion
1,2,3-Trichloropropane	0.00560	USEPA Region 9 (pathway specific)
1,2,4-Trichlorobenzene	7.16	USEPA Region 9 (pathway specific)
1,2,4-Trimethylbenzene	12.3	USEPA Region 9 (pathway specific)
1,2-Dibromo-3-Chloropropane	0.100	UK DWS (2000)
1,2-Dibromoethane	0.100	UK DWS (2000)
1,2-Dichlorobenzene	1000	WHO DWG
1,2-Dichloroethane	3.00	URS GAC
1,2-Dichloropropane	0.100	UK DWS (2000)
1,3,5-Trimethylbenzene	12.3	USEPA Region 9 (pathway specific)
1,3-Dichlorobenzene	183	USEPA Region 9 (pathway specific)
1,3-Dichloropropane	0.100	UK DWS (2000)
1,4-Dichlorobenzene	300	WHO DWG
2,2-Dichloropropane	NV	No Criterion
2,4,5-Trichlorophenol	9.00	WHO DWG
2,4,6-Trichlorophenol	200	WHO DWG
2,4-Dichlorophenol	NV	No Adequate Data
2,4-Dimethylphenol	730	USEPA Region 9 (pathway specific)
2,4-Dinitrotoluene	73.0	USEPA Region 9 (pathway specific)
2,6-Dinitrotoluene	36.5	USEPA Region 9 (pathway specific)
2-Chloronaphthalene	487	USEPA Region 9 (pathway specific)
2-Chlorophenol	NV	URS GAC
2-Chlorotoluene	122	USEPA Region 9 (pathway specific)
2-Methylnaphthalene	NV	No Criterion
2-Methylphenol	182	URS GAC
2-Nitroaniline	109	USEPA Region 9 (pathway specific)
2-Nitrophenol	NV	No Criterion
3-Nitroaniline	3.20	USEPA Region 9 (pathway specific)
4-Bromophenyl Phenyl Ether	NV	No Criterion
4-Chloro-3-Methylphenol	40.0	UK Marine/Estuarine EQS Surface Waters
4-Chloroaniline	146	USEPA Region 9 (pathway specific)
4-Chlorophenyl Phenyl Ether	NV	No Criterion
4-Chlorotoluene	NV	No Criterion
4-Methylphenol	182	USEPA Region 9 (pathway specific)
4-Nitroaniline	3.20	USEPA Region 9 (pathway specific)
4-Nitrophenol	NV	No Criterion

Target Compound	*Controlled Waters µg/L*	*Source*
Acenaphthene	365	USEPA Region 9 (pathway specific)
Acenaphthylene	10.00	UK DWS (2000)
Anthracene	1830	USEPA Region 9 (pathway specific)
Ammonium As NH4	NV	No Criterion
Arsenic	10.00	URS GAC
Azobenzene	0.611	USEPA Region 9 (pathway specific)
Benzene	1.00	URS GAC
Benzo(a)Anthracene	0.0921	USEPA Region 9 (pathway specific)
Benzo(a)Pyrene	0.0100	UK DWS (2000)
Benzo(b)Fluoranthene	See PAHs	UK DWS (2000)
Benzo(g,h,il)Perylene	See PAHs	UK DWS (2000)
Benzo(k)Fluoranthene	See PAHs	UK DWS (2000)
Bis(2-Chloroethoxy)Methane	NV	No Criterion
Bis(2-Chloroethyl)Ether	0.0102	USEPA Region 9 (pathway specific)
Bis(2-Ethylhexyl)Phthalate	8.00	WHO DWG
Boron	1000	URS GAC
Bromobenzene	20.3	USEPA Region 9 (pathway specific)
Bromochloromethane	NV	No Criterion
Bromodichloromethane	NV	See note (i)
Bromoform	NV	See note (i)
Bromomethane	8.66	USEPA Region 9 (pathway specific)
Butylbenzylphthalate	7300	USEPA Region 9 (pathway specific)
Cadmium	5.00	URS GAC
Carbazole	3.36	USEPA Region 9 (pathway specific)
Carbon Disulfide	1040	USEPA Region 9 (pathway specific)
Carbon Tetrachloride	3.00	UK Marine/Estuarine EQS Surface Waters
Chlorobenzene	NV	No Criterion
Chloroethane	4.64	USEPA Region 9 (pathway specific)
Chloroform	NV	See note (i)
Chloromethane	158	USEPA Region 9 (pathway specific)
Chromium	50.0	URS GAC
Chrysene	9.21	USEPA Region 9 (pathway specific)
Cis-1,2-Dichloroethene	60.8	USEPA Region 9 (pathway specific)
Cis-1,3-Dichloropropene	NV	No Criterion
Copper	2000	URS GAC
Cyanide (total)	NV	No Criterion
Dibenz(a,h)Anthracene	0.00921	URS GAC
Dibenzofuran	12.2	USEPA Region 9 (pathway specific)
Dibromochloromethane	NV	See note (i)
Dibromomethane	60.8	USEPA Region 9 (pathway specific)
Dichlorodifluoromethane	395	USEPA Region 9 (pathway specific)
Dichloromethane	20.0	WHO DWG
Diethylphthalate	29200	USEPA Region 9 (pathway specific)
Dimethylphthalate	365000	USEPA Region 9 (pathway specific)
Di-N-Butylphthalate	NV	No Criterion
Di-N-Octylphthalate	1460	USEPA Region 9 (pathway specific)

Target Compound	*Controlled Waters µg/L*	*Source*
Electrical Conductivity	NV	No Criterion
Ethylbenzene	300	WHO DWG
Fluoranthene	0.200	UK DWS (2000)
Fluorene	243	USEPA Region 9 (pathway specific)
Hexachlorobenzene	1.00	URS GAC
Hexachlorobutadiene	0.600	UK Marine/Estuarine EQS Surface Waters
Hexachlorocyclopentadiene	219	USEPA Region 9 (pathway specific)
Hexachloroethane	4.80	USEPA Region 9 (pathway specific)
Indeno(1,2,3-cd)Pyrene	NV	see PAHs
Isophorone	70.8	USEPA Region 9 (pathway specific)
Isopropylbenzene	658	USEPA Region 9 (pathway specific)
Lead	25.0	UK Marine/Estuarine EQS Surface Waters
MBAS (Anionic Surfactant)	Nv	No Criterion
Mercury	10.9	URS GAC
Methyl T-Butyl Ether	11.0	USEPA Region 9 (pathway specific)
Naphthalene	6.20	URS GAC
Nickel	20.0	URS GAC
Nitrate	50000	UK DWS (2000)
Nitrobenzene	3.40	USEPA Region 9 (pathway specific)
N-Butylbenzene	243	USEPA Region 9 (pathway specific)
N-Nitroso-Di-N-Propylamine	0.00960	USEPA Region 9 (pathway specific)
Pentachlorophenol	9.00	URS GAC
Phenanthrene	10.00	UK DWS (2000)
Phenol	0.500	URS GAC
Phosphate	NV	No Criterion
P-Isopropyltoluene	NV	No Criterion
Ph	9.50	URS GAC
Phenols (total)	NV	No Criterion
Propylbenzene	243	URS GAC
Pyrene	183	USEPA Region 9 (pathway specific)
Sec-Butylbenzene	NV	No Criterion
Selenium	10.00	UK DWS (2000)
Styrene	20.0	URS GAC
Sulphate Soluble	NV	No Criterion
Tert-Butylbenzene	243	USEPA Region 9 (pathway specific)
Tetrachloroethene	NV	See note (ii)
Toluene	700	URS GAC
Thiocyanate	NV	No Criterion
Total Organic Nitrogen	NV	No Criterion
Trans-1,2-Dichloroethene	122	USEPA Region 9 (pathway specific)
Trans-1,3-Dichloropropene	NV	No Criterion
Trichloroethene	NV	See note (ii)
Trichlorofluoromethane	1290	USEPA Region 9 (pathway specific)
Vinyl Chloride	0.500	UK DWS (2000)
Zinc	3000	URS GAC
M,P-Xylene	NV	See Xylenes

Target Compound	*Controlled Waters µg/L*	*Source*
O-Xylene	NV	See Xylenes
Sum Xylenes	500	URS GAC
TPH >EC5-EC6 Aliphatic	10.00	URS GAC
TPH >EC6-EC8 Aliphatic	10.00	UK DWS (2000)
TPH >EC8-EC10 Aliphatic	10.00	UK DWS (2000)
TPH >EC10-EC12 Aliphatic	10.00	UK DWS (2000)
TPH >EC12-EC16 Aliphatic	10.00	UK DWS (2000)
TPH >EC16-EC21 Aliphatic	10.00	UK DWS (2000)
TPH >EC21-EC35 Aliphatic	10.00	UK DWS (2000)
Total Aliphatics (C5-C35)	NV	See individual fractions
TPH >EC6-EC7 Aromatic	10.00	URS GAC
TPH >EC7-EC8 Aromatic	10.00	UK DWS (2000)
TPH >EC8-EC10 Aromatic	10.00	UK DWS (2000)
TPH >EC10-EC12 Aromatic	10.00	UK DWS (2000)
TPH >EC12-EC16 Aromatic	10.00	UK DWS (2000)
TPH >EC16-EC21 Aromatic	10.00	UK DWS (2000)
TPH >EC21-EC35 Aromatic	10.00	UK DWS (2000)
Total Aromatics (C6-C35)	NV	See individual fractions
Tph (Sum Aliphatics&Aromatics C5-C35)	NV	See individual fractions
Pro C4-C12	NV	No Criterion

Key:

NV: No Value Available
URS GAC- URS Generic Assessment Criteria
USEPA Region 9 Prg- United States Environment Protection Agency Region 9 Preliminary Remediation Goal
WHO DWG - World Health Organisation Drinking Water Guidelines
UK DWS (2000) - United Kingdom Drinking Water Standards

Note:

Acute value used to assess cyanides
Sum of m,p,o- xylene compared against criteria
Phenols assessed against the value for 2,6-dimthylphenol

Note (i) - The specified compounds are: chloroform, bromoform, dibromochloromethane, bromodichloromethane. The parametric value, 100µg/l, applies to the sum of the concentrations of individual compounds detected and quantified in the monitoring process.

Note (ii) the parametric value, 10µg/l, applies to the sum of the concentrations of the individual compounds tetrachloroethene (tetrachloroethylene) (pce) and trichloroethene (trichloroethylene) (tce), detected and quantified in the monitoring process.

Table G3 – Stage 2 Assessment – VOCs in Soils

Target Compound	Generic Controlled Waters Screening Criteria (mg/kg)	Statistical Analysis					Number of Samples Exceeding Generic Screen
		Minimum (mg/kg)	Maximum (mg/kg)	Mean (mg/kg)	US95 (mg/kg)	Number Analysed	
1,2,4-Trimethylbenzene	0.169	0.001	14.89	2.18	3.86	23	6
1,2-Dichlorobenzene	6.328	0.001	41.34	1.80	<sc	23	1
1,3,5-Trimethylbenzene	0.169	0.001	7.93	1.17	2.023	23	9
Benzene	0.0015	0.001	99.18	8.39	18.22	23	11
Cis-1,2-Dichloroethene	0.033	0.001	3.074	0.152	0.382	23	2
Ethylbenzene	1.358	0.001	6.88	0.591	<sc	23	3
Total Xylenes	2.218	0.001	141.55	5.25	22.3	23	4
Naphthalene	0.081	0.001	5,735	412.44	863.57	23	14
Styrene	0.159	0.001	19.22	0.942	2.38	23	3
Toluene	1.126	0.001	60.90	4.026	8.95	23	3
Trichloroethene	0.019	0.001	8.52	0.581	1.29	23	4

<sc – less than generic screening criteria therefore maximum concentrations used in simulation.

Table G4 – Stage 2 Assessment – Leachable Metals and Inorganic Ions

Target Compound	Generic Controlled Waters Screening Criteria (µg/L)	Statistical Analysis					Number of Samples Exceeding Generic Criteria
		Minimum (µg/L)	Maximum (µg/L)	Mean (µg/L)	US95 (µg/L)	Number Analysed	
Arsenic	10	1	13	4	5	25	1
Lead	25	1	47	5	9	25	2
Nickel	20	1	139	19	31	25	7
Vanadium	37	1	38	6	10	18	1
Ammoniacal Nitrogen	500	200	530,000	14,775	30,234	60	32
Sulphate	250,000	3000	1,585,000	133,867	316,770	15	1
Total Cyanide	50	50	61,080	3,872	10,558	16	16

Table G5 – Stage 2 Assessment – Leachable TPH

Target Compound	Generic Controlled Waters Screen (µg/L)	Statistical Analysis					Number of Samples Exceeding Generic Criteria
		Minimum	Maximum	Mean	US95	Number Analysed	
Aliphatics >C6-C8	10	10	73	15	19	31	31
Aliphatics >C8-C10	10	10	829	118	194	31	31
Aliphatics >C10-C12	10	10	8,703	1,217	1,933	31	31
Aliphatics >C12-C16	10	10	83	20	27	31	31
Aliphatics >C16-C21	10	10	28	11	13	31	31
Aliphatics >C21-C35	10	10	101	14	20	31	31
Total Aliphatics C5-C35	10	10	9,584	1,355	2,136	31	31
Aromatics >C6-C7	10	10	6,930	360	766	31	31
Aromatics >C7-C8	10	10	2,186	168	319	31	31
Aromatics >C8-C10	10	10	4,594	429	751	31	31
Aromatics >C10-C12	10	10	13,055	1,822	2,897	31	31
Aromatics >C12-C16	10	10	2,228	466	676	31	31
Aromatics >C16-C21	10	10	732	146	210	31	31
Aromatics >C21-C35	10	10	78	20	25	31	31
Total Aromatics C6-C35	10	10	22,062	3,374	5,264	31	31
Benzene	1	10	6,930	360	766	31	31
Toluene	700	10	2,186	168	319	31	31
Total Xylene	500	10	3,221	248	454	31	31

Table G6 – Stage 2 Assessment – Leachable SVOC and PAH

Target Compound	Generic Controlled Waters Screening Criteria (µg/L)	Statistical Analysis					Number of Samples Exceeding Generic Screen
		Minimum	Maximum	Mean	US95	Number Analysed	
2,4-Dimethylphenol	730	2	4,044	1,080	2,040	8	3
4-Methylphenol	182	2	4,449	1,388	3,138	5	4
Acenaphthylene	10	2	484	167	268	12	7
Carbazole	3	2	492	165	251	14	10
Dibenzofuran	12	1	214	62	91	18	10
Fluoranthene	0.2	1	18	5	9	9	9
Naphthalene	6	1	7,797	1,822	2,608	33	23
Phenanthrene	10	1	158	44	69	17	8
Phenol	1	2	376	162	484	3	3

Table G7 – Stage 2 Assessment – VOCs Shallow Groundwater

Target Compound	Generic Controlled Waters Screening Criteria (µg/L)	Statistical Analysis					Number of Samples Exceeding Generic Screen
		Minimum (µg/l)	Maximum (µg/l)	Mean (µg/l)	US95 (µg/l)	Number Analysed	
1,2,4-Trimethylbenzene	12.3	1	2,785	721	2,341	4	2
1,3,5-Trimethylbenzene	12.3	1	1,445	374	1,214	4	2
Benzene	1	7	881	254	749	4	4
Cis-1,2-Dichloroethene	60.8	1	76	20	64	4	1
Naphthalene	6.2	185	189,985	48,216	159,418	4	4
Total Xylenes	500	15	6,078	1,567	5,106	4	1
Styrene	20	1	26	7	22	4	1
Toluene	700	7	2,751	712	2,312	4	1
Trichloroethene	10	1	34	10	29	4	1
Vinyl chloride	3	1	8	3	7	4	4

Table G9 – Stage 3 Assessment – Source Zone Model Parameters

Parameter (units)	Parameter Value			Distribution Used	Comment
	Min	Most Likely	Max		
Total Organic Carbon (%)	0.07	0.66	1.0	Triangular	Most likely value taken from a sample from the Made Ground in Plot B. Min value taken from minimum value detected in the silt underlying the Made Ground and the maximum value from the maximum value detected in the unsaturated zone.
Infiltration rate (mm/year)	54	107	161	Triangular	Based on impervious hardstanding and building structures, as well as the low permeability drift cover. Assumed to vary between 5, 10 and 15% of long-term (1970-2000) average rainfall of approximately 1070mm (estimated from Meteorological Office UK Rainfall Maps, retrieved via the internet).
Air filled porosity (fraction)	0.045	0.215	0.31	Triangular	Adopted range of likely air filled porosities for sandy gravel dominated Made Ground. Min value for clay; most likely value for sandy gravel; and maximum value for gravel).Todd, D.K., 1980. Ground Water Hydrology, 2d ed., New York: Wiley, P. 535.
Water filled porosity (fraction)	0.04	0.06	0.28	Triangular	Adopted range of likely water filled porosities for sandy gravel dominated Made Ground. Min value for gravel; most likely value for sandy gravel; and maximum value for clay). Brady, N.C., 1984. The nature and properties of soils. Macmillan Publishing Company, New York, pp. 750.
Dry bulk density (g/cm^3)	1.64	1.72	1.92	Triangular	Adopted range min value for silty clay (based on presence of clay within Made Ground), most likely value for gravel and max value for sandy gravel (based on borehole log descriptions). Calculated from total porosity assuming a solid particle density of 2.65g/cm3 (Freeze & Cherry, 1979).

Table G10 – Stage 3 Assessment – Unsaturated Zone Model Parameters

Parameter (units)	Parameter Value			Distribution Used	Comment
	Min	Most Likely	Max		
Thickness (m) for risks to Deep Groundwater	0	0	0	-	Owing to the limited information regarding the hydraulic conductivity of the Whitehaven Sandstone and the likelihood of vertical contaminant migration being dominated by fracture flow, the unsaturated aquifer has been omitted as a potential pathway.
Dry bulk density (g/cm3)	-	1.86	2.52	Uniform	Calculated from the range in porosities for sandstone provided in the ConSim manual and assuming a solid particle density of 2.65 g/cm3 (Freeze & Cherry, 1979).
Hydraulic conductivity (m/s)	3×10^{-9}	6×10^{-6}	4.3×10^{-5}	Triangular	Minimum and most likely values represent the range of hydraulic conductivities provided for sandstone in ConSim manual. Maximum conductivity taken from the EA aquifer properties database (The Physical Properties of major aquifers in England and Wales, Hydrogeology Group Technical Report WD/97/34, Environment Agency R&D Publication 8) for the St. Bee's Triassic sandstone - assumed surrogate for Carboniferous Whitehaven Sandstones. The high value is low for a major aquifer and demonstrates the high degree of cementation in the strata.
Water filled porosity (fraction)	0.03	0.06	0.09	Triangular	Adopted range of likely water filled porosities for sandy gravel dominated Made Ground. (Min and max values taken as 0.5x and 1.5x the most likely value) Brady, N.C., 1984. The nature and properties of soils. Macmillan Publishing Company, New York, pp. 750.
Vertical dispersivity (m)	1.6	1.822	1.93	Triangular	Assumed value of $1/10^{th}$ of the unsaturated zone travel distance.
Fraction of organic carbon (Percentage)	0.028	0.15	2.2	Triangular	The Whitehaven Sandstone unit forms part of the Carboniferous Coal Measures however it is unlikely to have a FOC content as high as those encountered in the siltstones and mudstones were coal bands are present. Therefore, the following ConSim manual FOC values have been conservatively estimated to represent this unit: (Min taken to be the mean value for permo-triassic sandstone; most likely value taken as the maximum value for permo-triassic sandstone; and the maximum value taken to be the mean value for Carboniferous Coal Measures).

Table G11 – Stage 3 Assessment – Saturated Zone Model Parameters

Parameter (units)	Parameter Value			Distribution Used	Comment
	Min	Most Likely	Max		
Hydraulic conductivity (m/s)	3×10^{-9}	6×10^{-6}	4.3×10^{-5}	Triangular	Minimum and most likely values represent the range of hydraulic conductivities provided for sandstone in ConSim manual. Maximum conductivity taken from the EA aquifer properties database (The Physical Properties of major aquifers in England and Wales, Hydrogeology Group Technical Report WD/97/34, Environment Agency R&D Publication 8) for the St. Bee's Triassic sandstone - assumed surrogate for Carboniferous Whitehaven Sandstones. The high value is low for a major aquifer and demonstrates the high degree of cementation in the strata.
Hydraulic gradient	0.056	-	-	Single	Interpreted from on-site groundwater contour plot.
Effective porosity (fraction)	0.05	0.15	0.3	Triangular	In the absence of effective porosity data, range of porosities for sandstone taken from Domenico & Schwartz pg.15 (2nd edition).
Aquifer Bulk Density (g/cm^3)	-	1.86	2.52	Uniform	Calculated using sandstone porosity ranging from 5% to 30% (Domenico& Schwartz) and assuming a bulk density of 2.65g/cm3
Fraction of organic carbon (Percentage)	0.028	0.15	2.2	Triangular	The Whitehaven sandstone unit forms part of the Carboniferous Coal Measures however it is unlikely to have a FOC content as high as those encountered in the siltstones and mudstones were coal bands are present. Therefore the following ConSim manual FOC values have been conservatively estimated to represent this unit: (Min taken to be the mean value for permo-triassic sandstone; most likely value taken as the maximum value for permo-triassic sandstone; and the maximum value taken to be the mean value for Carboniferous Coal Measures).
Groundwater flow direction (degrees)	250	-	-	Single	Inferred groundwater flow direction based on measured groundwater elevations. (ConSim requirement). A southward flow to a compliance point 50m away
Longitudinal Dispersivity (m)	0.5	-	-	Single	Longitudinal Dispersivity (m): Assumed 1/10th travel distance to receptor (this is the minimum distance between closest part of contaminant source and identified receptor) as defined in ConSim manual.
Lateral Dispersivity (m)	0.17	-	-	Single	Lateral Dispersivity (m):Assumed 1/3rd longitudinal dispersivity: defined in ConSim manual.

	Parameter Value				
Saturated Aquifer Thickness (m)	24	69	158	Triangular	Calculated from the variation in thickness of the Whitehaven Sandstone across the site taken from the geological map and using the dip of the unit (10^{o}) minus the variation in distance between the top of the sandstone unit and the water table within the sandstone.
Retarded Travel in UZ	YES			It is considered likely that retardation will occur	
Retarded Travel in Aquifer	YES				
Biodegredation in UZ	YES			It is considered likely that biodegradation will occur, effecting the organic contamination only.	
BIodegredation in Aquifer	YES				

Table G12 – Stage 3 Assessment – Physical/Chemical Parameters

Analytical Suite	Contaminant	Partition Coefficient, K_{oc} or K_d (ml/g)	Ref.	Maximum Solubility (mg/l)	Ref.	Henry's Law Constant, H (unitless)	Ref.	Half-life (years)			
								Minimum	Most Likely	Maximum	Ref.
Heavy Metals	Arsenic	2.93E+01	a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Lead	9.95E+01	c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Nickel	3.80E+01	a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Vanadium	1.00E+03	c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Inorganics	Ammoniacal Nitrogen	1.00E-20	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Chloride	1.00E-20	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Sulphate	1.00E-20	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Total Cyanide	9.90E+00	a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
VOCs	Styrene	7.76E+02	b	3.00E+02	q	1.21E-01	a	1.00E+06	-	-	
	Trichloroethene (TCE)	1.62E+02	b	1.07E+03	l	4.18E-01	i	-	2.74	-	l
	1,2,4-trimethylbenzene	1.35E+03	p	5.70E+01	a	2.52E-01	a	9.5	19	28.5	h
	1,2-dichlorobenzene	6.17E+02	a	1.30E+02	q	1.90E-03	a	9.5	19	28.5	h
	1,3,5-trimethylbenzene	1.35E+03	b	7.28E+01	b	2.41E-01	a	9.5	19	28.5	h
	cis-1,2-dichlorothene	3.55E+01	b	3.50E+03	a	1.67E-01	a	0.14	1	8.22	i
	Vinyl chloride	6.30E+01	a	n/a	n/a	7.93E-01	i	0.14	0.55	1.37	i
SVOCs	2,4-Dimethylphenol	9.55E+01	a	n/a	n/a	7.35E-05	b	0.27	0.82	1.62	h
	4-Methylphenol	4.90E+01	b	n/a	n/a	9.66E-06	b	0.14	0.27	0.82	h
	Acenaphthylene	5.62E+03	b	n/a	n/a	0.0034	i	1.9	3.8	5.7	h
	Carbazole	1.74E+02	b	n/a	n/a	0.00613	b	1.9	3.8	5.7	h
	Dibenzofuran	5.15E+03	p	n/a	n/a	0.000515	a	4.1	8.2	19	h
	Fluoranthene	1.07E+05	i	n/a	n/a	4.20E-04	i	2.1	6.9	68.5	h

Analytical Suite	Contaminant	Partition Coefficient, K_{oc} or K_d (ml/g)	Ref.	Maximum Solubility (mg/l)	Ref.	Henry's Law Constant, H (unitless)	Ref.	Half-life (years)			
								Minimum	Most Likely	Maximum	Ref.
	Naphthalene	1.29E+03	i	3.10E+01	q	1.75E-02	i	1.90	3.80	5.70	i
	Phenanthrene	2.29E+04	b	n/a	n/a	0.00131	i	3.8	19	38.1	h
	Phenol	2.88E+01	b	n/a	n/a	1.63E-05	i	0.14	0.27	0.82	i
BTEX	Benzene	1.34E+02	a	1.78E+03	i	1.82E-01	i	0.14	1	1.4	i
	Ethylbenzene	4.32E+02	a	1.69E+02	i	2.73E-01	i	0.14	0.55	2.19	i
	Toluene	1.40E+02	i	5.35E+02	i	0.275	i	0.14	0.55	0.82	i
TPH	**AROMATIC**										
	TPH (>EC6-7) aromatic	1.00E+03	d	n/a	n/a	2.30E-01	d	1.0	1.9	2.8	h
	TPH (>EC7-8) aromatic	1.26E+03	d	n/a	n/a	2.70E-01	d	1.9	3.8	5.7	h
	TPH (>EC8-10) aromatic	1.58E+03	d	n/a	n/a	4.80E-01	d	1.9	3.8	5.7	h
	TPH (>EC10-12) aromatic	2.51E+03	d	n/a	n/a	1.40E-01	d	4.8	9.5	14.3	h
	TPH (>EC12-16) aromatic	5.01E+03	d	n/a	n/a	5.30E-02	d	9.5	19.0	28.5	h
	TPH (>EC16-21) aromatic	1.58E+04	d	n/a	n/a	1.30E-02	d	19.0	38.1	57.1	h
	TPH (>EC21-35) aromatic	1.26E+05	d	n/a	n/a	6.70E-04	d	37.5	75.0	112.5	h
	ALIPHATIC										
	TPH (>EC5-6) aliphatic	7.94E+02	d	n/a	n/a	3.30E+01	d	1.0	1.9	2.8	h
	TPH (>EC6-8) aliphatic	3.98E+03	d	n/a	n/a	5.00E+01	d	1.0	1.9	2.9	h
	TPH (>EC8-10) aliphatic	3.16E+04	d	n/a	n/a	8.00E+01	d	1.0	1.9	2.8	h
	TPH (>EC10-12) aliphatic	2.51E+05	d	n/a	n/a	1.20E+02	d	1.0	1.9	2.8	h
	TPH (>EC12-16) aliphatic	5.01E+06	d	n/a	n/a	5.20E+02	d	1.0	1.9	2.8	h
	TPH (>EC16-21) aliphatic	6.31E+08	d	n/a	n/a	4.90E+03	d	1.9	3.8	5.7	h
	TPH (>EC21-35) aliphatic	7.59E+09	d	n/a	n/a	2.00E+04	d	4.8	9.5	14.3	h

Table G12

Note: All heavy metals are K_d, all other contaminants are K_{oc}

N/A - Not applicable (metals do not volatilise or degrade). No value was found for half life of Anionic Surfactant, so in order to be conservative, it was assumed that this substance does not degrade

Literature Sources:

a USEPA. 1996. Technical Background Document for Soil Screening Guidance - Review Draft.

b Mackay, D.,Wan-Ying, S., Kuo-Ching, M. 1997. Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals

c Dragun, J. 1988. The Soil Chemistry of hazardous materials. Haz. Mat. Res. Inst.

h URS derived conservative degradation rates.

i Environment Agency (2003). Review of the Fate and Transport of Selected Contaminants in the Soil Environment, Draft Technical Report P5-079/TR1.

j values used in modelling (Appendix B)

k Inchem.org website

m Lowest value derived form internet search: Koc range 264.7 - 120,600 www.heraproject.com for Sodium Lauryl Sulphate

q US EPA 2003 User's Guide for Evaluating Subsurface Vapour Intrusion into Buildings

Table G13 – Stage 3 Assessment – Models 1 &2 Justification of Soil Source Concentrations

MODELLED RECEPTOR	Compound	Source Concentration mg/kg (soil)			Distribution Used	Justifications	
		Most Likely	Minimum	Maximum		Input contaminant value	Justification
50m Compliance Point within the Whitehaven Sandstone	**VOCs**						
	1,2,4-Trimethylbenzene	3.858	-	-	single	US95	US95 of all concentrations within determined source area
	1,2-Dichlorobenzene	41.340	-	-	single	Max value	Max Value used as calculated US95 did not exceed the screening value.
	1,3,5-Trimethylbenzene	2.023	-	-	single	US95	US95 of all concentrations within determined source area
	Benzene	18.221	-	-	single	US95	US95 of all concentrations within determined source area
	Cis-1,2-Dichloroethene	0.382	-	-	single	US95	US95 of all concentrations within determined source area
	Ethylbenzene	6.880	-	-	single	Max value	Max Value used as calculated US95 did not exceed the screening value.
	Naphthalene	863.600	-	-	single	US95	US95 of all concentrations within determined source area
	Total xylenes	22.300	-	-		US95	US95 of all concentrations within determined source area
	Styrene	2.376	-	-	single	US95	US95 of all concentrations within determined source area
	Toluene (Methyl benzene)	8.951	-	-	single	US95	US95 of all concentrations within determined source area
	Trichloroethene	1.291	-	-	single	US95	US95 of all concentrations within determined source area

Table G14 – Stage 3 Assessment – Models 1 &2 Justification of Soil Source Dimensions

MODELLED RECEPTOR	Compound		Most Likely	Min	Max	Distribution Used	Comment
50m Compliance Point within the Whitehaven Sandstone	All contaminants	Source Thickness (m)	1.43	0.4	3.7	Triangular	source zone specific- Depth range representing the Variation in thickness of the Made Ground which was determined to be contaminated throughout.
		Source Area (m^2)	15675			-	Defined on Plan

Table G15 – Stage 3 Assessment – Models 1 &2 Justification of Soil Leachate Source Concentrations

MODELLED RECEPTOR	Compound	Source Concentration mg/l (leachate)			Distribution Used	Justifications	
		Most Likely	Minimum	Maximum		Input contaminant value	Justification
50m Compliance Point within the Whitehaven Sandstone	**Metals**						
	Arsenic	0.013	-	-	single	Max value	Max Value used as calculated US95 did not exceed the screening value.
	Lead	0.047	-	-	single	Max value	Max Value used as calculated US95 did not exceed the screening value.
	Nickel	0.031	-	-	single	US95	US95 of all concentrations within determined source area
	Vanadium	0.038	-	-	single	Max value	US95 of all concentrations within determined source area
	Inorganics						
	Ammoniacal Nitrogen	30.234	-	-	single	US95	US95 of all concentrations within determined source area
	Sulphate	316.770	-	-	single	US95	US95 of all concentrations within determined source area
	Total Cyanide	10.558	-	-	single	US95	US95 of all concentrations within determined source area
	SVOCs						
	2,4-Dimethylphenol	2.040	-	-	single	US95	US95 of all concentrations within determined source area
	4-Methylphenol	3.138	-	-	single	US95	US95 of all concentrations within determined source area
	Acenaphthylene	0.268	-	-	single	US95	US95 of all concentrations within determined source area
	Carbazole	0.251	-	-	single	US95	US95 of all concentrations within determined source area
	Dibenzofuran	0.091	-	-	single	US95	US95 of all concentrations within determined source area
	Fluoranthene	0.009	-	-	single	US95	US95 of all concentrations within determined source area
	Naphthalene	2.608	-	-	single	US95	US95 of all concentrations within determined source area
	Phenanthrene	0.069	-	-	single	US95	US95 of all concentrations within determined source area
	Phenol	0.484	-	-	single	US95	US95 of all concentrations within determined source area
	TPH						
	Leachable TPH (>EC5-6) aliphatic	0.010	-	-	single	US95	US95 of all concentrations within determined source area
	Leachable TPH (>EC6-8) aliphatic	0.019	-	-	single	US95	US95 of all concentrations within determined source area
	Leachable TPH (>EC8-10) aliphatic	0.194	-	-	single	US95	US95 of all concentrations within determined source area
	Leachable TPH (>EC10-12) aliphatic	1.933	-	-	single	US95	US95 of all concentrations within determined source area

MODELLED RECEPTOR	Compound	Source Concentration mg/l (leachate)			Distribution Used	Justifications	
		Most Likely	Minimum	Maximum		Input contaminant value	Justification
	Leachable TPH (>EC12-16) aliphatic	0.027	-	-	single	US95	US95 of all concentrations within determined source area
	Leachable TPH (>EC16-21) aliphatic	0.013	-	-	single	US95	US95 of all concentrations within determined source area
	Leachable TPH (EC21-35) aliphatic	0.020	-	-	single	US95	US95 of all concentrations within determined source area
	Leachable TPH (>EC6-7) aromatic	0.766	-	-	single	US95	US95 of all concentrations within determined source area
	Leachable TPH (>EC7-8) aromatic	0.319	-	-	single	US95	US95 of all concentrations within determined source area
	Leachable TPH (>EC8-10) aromatic	0.751	-	-	single	US95	US95 of all concentrations within determined source area
	Leachable TPH (>EC10-12) aromatic	2.897	-	-	single	US95	US95 of all concentrations within determined source area
	Leachable TPH (>EC12-16) aromatic	0.676	-	-	single	US95	US95 of all concentrations within determined source area
	Leachable TPH (>EC16-21) aromatic	0.210	-	-	single	US95	US95 of all concentrations within determined source area
	Leachable TPH (EC21-35) aromatic	0.025	-	-	single	US95	US95 of all concentrations within determined source area
	BTEX	0.000	-				
	Leachable Benzene	0.766	-	-	single	US95	US95 of all concentrations within determined source area
	Leachable Toluene (Methyl benzene)	2.186	-	-	single	Max value	Max Value used as calculated US95 did not exceed the screening value.
	Total Xylene	3.221	-	-	single	Max value	Max Value used as calculated US95 did not exceed the screening value.

Table G16 – Stage 3 Assessment – Models 1 &2 Justification of Soil Leachate Source Dimensions

MODELLED RECEPTOR	Compound		Most Likely	Min	Max	Distribution Used	Comment
50m Compliance Point within the Whitehaven Sandstone	All contaminants	Source Thickness (m)	1.43	0.4	3.7	Triangular	source zone specific- Depth range representing the Variation in thickness of the Made Ground which was determined to be contaminated throughout.
		Source Area (m^2)	15675			-	Defined on Plan

Table G17– Stage 3 Assessment – Models 1 &2 Justification of Shallow Groundwater Source Concentrations

MODELLED RECEPTOR	Compound	Source Concentration mg/l (groundwater)			Distribution Used	Justifications	
		Most Likely	Minimum	Maximum		Input contaminant value	Justification
50m Compliance Point within the Whitehaven Sandstone	**Metals**						
	Nickel	0.162	-	-	single	Max value	Max Value used as calculated US95 did not exceed the screening value.
	Inorganics						
	Ammoniacal Nitrogen	28.9	-	-	single	Max value	Max Value used as calculated US95 did not exceed the screening value.
	Chloride	277	-	-	single	Max value	Max Value used as calculated US95 did not exceed the screening value.
	Total Cyanide	0.170	-	-	single	Max value	Max Value used as calculated US95 did not exceed the screening value.
	VOCs						
	1,2,4-Trimethylbenzene	2.341	-	-	single	US95	US95 of all concentrations within determined source area
	1,3,5-Trimethylbenzene	1.214	-	-	single	US95	US95 of all concentrations within determined source area
	Benzene	0.749	-	-	single	US95	US95 of all concentrations within determined source area
	Cis-1,2-Dichloroethene	0.064	-	-	single	US95	US95 of all concentrations within determined source area
	Naphthalene	159.418	-	-	single	US95	US95 of all concentrations within determined source area
	Total xylenes	5.106	-	-	single	US95	US95 of all concentrations within determined source area
	Styrene	0.022	-	-	single	US95	US95 of all concentrations within determined source area
	Toluene	2.312	-	-	single	US95	US95 of all concentrations within determined source area
	Trichloroethene	0.029	-	-	single	US95	US95 of all concentrations within determined source area
	Vinyl Chloride	0.007	-	-	single	US95	US95 of all concentrations within determined source area

Table G18 – Stage 3 Assessment – Models 1 &2 Justification of Shallow Groundwater Source Dimensions

MODELLED RECEPTOR	Compound		Most Likely	Min	Max	Distribution Used	Comment
50m Compliance Point within the Whitehaven Sandstone	All contaminants	Source Thickness (m)	1.43	0.4	3.7	Triangular	source zone specific- Depth range representing the Variation in thickness of the Made Ground which was determined to be contaminated throughout.
		Source Area (m^2)	15675			-	Defined on Plan

Table G19 – Stage 3 Assessment – Model 3 Justification of Soil Source Concentrations

MODELLED RECEPTOR	Compound	Source Concentration mg/kg (soil)			Distribution Used	Justifications	
		Most Likely	Minimum	Maximum		Input contaminant value	Justification
50m Compliance Point within the Whitehaven Sandstone	**VOCs**						
	Benzene	99.180	-	-	single	Max	Maximum concentration
	Naphthalene	5,734.000	-	-	single	Max	Maximum concentration
	Trichloroethene	8.520	-	-	single	Max	Maximum concentration

Table G20 – Stage 3 Assessment – Model 3 Justification of Soil Source Dimensions

MODELLED RECEPTOR	Compound		Most Likely	Min	Max	Distribution Used	Comment
50m Compliance Point within the Whitehaven Sandstone	All contaminants	Source Thickness (m)	1.43	0.4	3.7	Triangular	source zone specific- Depth range representing the Variation in thickness of the Made Ground which was determined to be contaminated throughout.
		Source Area (m^2)	400			-	Defined on Plan (area surrounding TP660B, TP671B and TP672B)

Table G21 – Stage 3 Assessment – Model 3 Justification of Soil Leachate Source Concentrations

MODELLED RECEPTOR	Compound	Source Concentration mg/l (leachate)			Distribution Used	Justifications	
		Most Likely	Minimum	Maximum		Input contaminant value	Justification
50m Compliance Point within the Whitehaven Sandstone	**Inorganics**						
	Ammoniacal Nitrogen	0.090	-	-	single	US95	US95 of all concentrations within determined source area
	Total Cyanide	61.080	-	-	single	Max	Maximum concentration
	SVOCs						
	Phenol	0.376	-	-	single	Max	Maximum concentration
	BTEX		-				
	Leachable Benzene	6.930	-	-	single	Max	Maximum concentration

Table G22 – Stage 3 Assessment – Model 3 Justification of Soil Leachate Source Dimensions

MODELLED RECEPTOR	Compound		Most Likely	Min	Max	Distribution Used	Comment
50m Compliance Point within the Whitehaven Sandstone	All contaminants	Source Thickness (m)	1.43	0.4	3.7	Triangular	source zone specific- Depth range representing the Variation in thickness of the Made Ground which was determined to be contaminated throughout.
		Source Area (m^2)	400			-	Defined on Plan (area surrounding TP664B and TP665B)

Table G23 – Stage 3 Assessment – Model 3 Justification of Shallow Groundwater Source Concentrations

MODELLED RECEPTOR	Compound	Source Concentration mg/l (groundwater)			Distribution Used	Justifications	
		Most Likely	Minimum	Maximum		Input contaminant value	Justification
50m Compliance Point within the Whitehaven Sandstone	**Inorganics**						
	Ammoniacal Nitrogen	28.9	-	-	single	Max value	Max Value used as calculated US95 did not exceed the screening value.
	VOCs						
	Benzene	0.749	-	-	single	US95	US95 of all concentrations within determined source area
	Naphthalene	159.418	-	-	single	US95	US95 of all concentrations within determined source area

Table G24 – Stage 3 Assessment – Model 3 Justification of Shallow Groundwater Source Dimensions

MODELLED RECEPTOR	Compound		Most Likely	Min	Max	Distribution Used	Comment
50m Compliance Point within the Whitehaven Sandstone	All contaminants	Source Thickness (m)	1.43	0.4	3.7	Triangular	source zone specific- Depth range representing the Variation in thickness of the Made Ground which was determined to be contaminated throughout.
		Source Area (m^2)	5000			-	Defined on Plan (centred around WS552B and confined by the adjacent monitoring wells)

Table G25 – Stage 3 Assessment – Models 1&2 Soil Source Simulated Receptor Concentrations

MODELLED RECEPTOR	Individual Compounds (Soil and Leachate Concentrations)	Stage 2 Controlled Waters Screening Criteria (mg/l)	Source	SIMULATED TIME TO EXCEED DWS (years)	Concentrations at Receptor	
					50th PERCENTILE (mg/l)	95th PERCENTILE (mg/l)
50m Compliance Point within the Whitehaven Sandstone	**VOCs**					
	1,2,4-Trimethylbenzene	0.012	UK DWS (2000)	IR	IR	IR
	1,2-Dichlorobenzene	1	WHO DWG	IR	IR	IR
	1,3,5-Trimethylbenzene	0.012	USEPA	IR	IR	IR
	Benzene	0.001	UK DWS (2000)	**1**	IR	**0.098**
	Cis-1,2-Dichloroethene	0.0608	USEPA	IR	IR	IR
	Ethylbenzene	0.3	WHO DWG	IR	IR	IR
	Naphthalene	0.0062	USEPA	**6**	IR	**0.063**
	Total xylenes	0.5	WHO DWG	IR	IR	IR
	Styrene	0.02	WHO DWG	IR	IR	IR
	Toluene (Methyl benzene)	0.70	WHO DWG	IR	IR	IR
	Trichloroethene	0.01	UK DWS (2000)	**0.5**	IR	**0.014**

Table G26 – Stage 3 Assessment – Model 3 Soil Source Simulated Receptor Concentrations

	TP660B, TP671B and TP672B HOTSPOT					
MODELLED RECEPTOR	Individual Compounds (Soil and Leachate Concentrations)	Stage 2 Controlled Waters Screening Criteria (mg/l)	Source	SIMULATED TIME TO EXCEED DWS (years)	Maximum Simulated Concentrations at Receptor (Whitehaven Sandstone)	
					50th PERCENTILE (mg/l)	95th PERCENTILE (mg/l)
50m Compliance Point within the Whitehaven Sandstone	**VOCs**					
	Benzene	0.001	UK DWS (2000)	**1**	IR	**0.086**
	Naphthalene	0.0062	USEPA	**16**	IR	**0.011**
	Trichloroethene	0.01	UK DWS (2000)	**1**	IR	**0.021**

Table G27 – Stage 3 Assessment – Models 1&2 Soil Leachate Source Simulated Receptor Concentrations

MODELLED RECEPTOR	Individual Compounds (Soil and Leachate Concentrations)	Stage 2 Controlled Waters Screening Criteria (mg/l)	Source	SIMULATED TIME TO EXCEED DWS (years)	Maximum Simulated Concentrations at Receptor	
					50th PERCENTILE (mg/l)	95th PERCENTILE (mg/l)
50m Compliance Point within the Whitehaven Sandstone	**Metals**					
	Arsenic	0.01	UK DWS (2000)	IR	IR	IR
	Lead	0.025	UK DWS (2000)	IR	IR	IR
	Nickel	0.02	UK DWS (2000)	IR	IR	IR
	Vanadium	0.037	USEPA Region 9 (pathway specific)	IR	IR	IR
	Inorganics					
	Ammoniacal Nitrogen	0.5	UK DWS (2000)	**1**	IR	**0.761**
	Sulphate	250	UK DWS (2000)	IR	IR	IR
	Total Cyanide	0.05	UK DWS (2000)	**28**	**0.063**	**0.3**
	SVOCs					
	2,4-Dimethylphenol	0.73	USEPA Region 9 (ps)	IR	IR	IR
	4-Methylphenol	0.18	USEPA Region 9 (ps)	IR	IR	IR
	Acenaphthylene	0.01	UK DWS (2000)	IR	IR	IR
	Carbazole	0.00	USEPA Region 9 (ps)	IR	IR	IR
	Dibenzofuran	0.01	USEPA Region 9 (ps)	IR	IR	IR
	Fluoranthene	0.00	UK DWS (2000)	IR	IR	IR
	Naphthalene	0.01	UK DWS (2000)	IR	IR	IR
	Phenanthrene	0.01	UK DWS (2000)	IR	IR	IR
	Phenol	0.00	UK DWS (2000)	**1**	IR	**0.002**
	TPH					
	Leachable TPH (>EC5-6) aliphatic	0.01	UK DWS (2000)	IR	IR	IR
	Leachable TPH (>EC6-8) aliphatic	0.01	UK DWS (2000)	IR	IR	IR
	Leachable TPH (>EC8-10) aliphatic	0.01	UK DWS (2000)	IR	IR	IR
	Leachable TPH (>EC10-12) aliphatic	0.01	UK DWS (2000)	IR	IR	IR

MODELLED RECEPTOR	Individual Compounds (Soil and Leachate Concentrations)	Stage 2 Controlled Waters Screening Criteria (mg/l)	Source	SIMULATED TIME TO EXCEED DWS (years)	Maximum Simulated Concentrations at Receptor	
					50th PERCENTILE (mg/l)	95th PERCENTILE (mg/l)
	Leachable TPH (>EC12-16) aliphatic	0.01	UK DWS (2000)	IR	IR	IR
	Leachable TPH (>EC16-21) aliphatic	0.01	UK DWS (2000)	IR	IR	IR
	Leachable TPH (EC21-35) aliphatic	0.01	UK DWS (2000)	IR	IR	IR
	Leachable TPH (>EC6-7) aromatic	0.01	UK DWS (2000)	IR	IR	IR
	Leachable TPH (>EC7-8) aromatic	0.01	UK DWS (2000)	IR	IR	IR
	Leachable TPH (>EC8-10) aromatic	0.01	UK DWS (2000)	IR	IR	IR
	Leachable TPH (>EC10-12) aromatic	0.01	UK DWS (2000)	IR	IR	IR
	Leachable TPH (>EC12-16) aromatic	0.01	UK DWS (2000)	IR	IR	IR
	Leachable TPH (>EC16-21) aromatic	0.01	UK DWS (2000)	IR	IR	IR
	Leachable TPH (EC21-35) aromatic	0.01	UK DWS (2000)	IR	IR	IR
	BTEX					
	Leachable Benzene	0	UK DWS (2000)	**1**	IR	**0.003**
	Leachable Toluene (Methyl benzene)	0.7	UK DWS (2000)	IR	IR	IR
	Total Xylene	0.5	UK DWS (2000)	IR	IR	IR

Table G28 – Stage 3 Assessment – Model 3 Soil Leachate Source Simulated Receptor Concentrations

	TP664B and TP665B HOTSPOT					
MODELLED RECEPTOR	Individual Compounds (Soil Leachate Concentrations)	Stage 2 Controlled Waters Screening Criteria (mg/l)	Source	SIMULATED TIME TO EXCEED DWS (years)	Maximum Simulated Concentrations at Receptor	
					50th PERCENTILE (mg/l)	95th PERCENTILE (mg/l)
50m Compliance Point within the Whitehaven Sandstone	**Inorganics**					
	Ammoniacal Nitrogen	0.5	UK DWS (2000)	IR	IR	IR
	Total Cyanide	0.05	UK DWS (2000)	**16**	**0.354**	**4.860**
	SVOCs					
	Phenol	0.0005	UK DWS (2000)	**14**	IR	**0.002**
	BTEX					
	Leachable Benzene	0.001	UK DWS (2000)	**1**	IR	**0.031**

Table G29 – Stage 3 Assessment – Models 1&2 Shallow Groundwater Source Simulated Receptor Concentrations

MODELLED RECEPTOR	Individual Compounds (Soil and Leachate Concentrations)	Stage 2 Controlled Waters Screening Criteria (mg/l)	Source	SIMULATED TIME TO EXCEED DWS (years)	Maximum Simulated Concentrations at Receptor (Whitehaven Sandstone)	
					50th PERCENTILE (mg/l)	95th PERCENTILE (mg/l)
50m Compliance Point within the Whitehaven Sandstone	**Metals**					
	Nickel	0.02	UK DWS	IR	IR	IR
	Inorganics					
	Ammoniacal Nitrogen	0.5	UK DWS	**1**	IR	**0.718**
	Chloride	250	UK DWS	IR	IR	IR
	Total Cyanide	0.05	UK DWS	IR	IR	IR
	VOCs					
	1,2,4-Trimethylbenzene	0.012	USEPA	IR	IR	IR
	1,3,5-Trimethylbenzene	0.012	USEPA	IR	IR	IR
	Benzene	0.001	UK DWS	**2**	IR	**0.002**
	Cis-1,2-Dichloroethene	0.06	USEPA	IR	IR	IR
	Naphthalene	0.01	USEPA	**7**	IR	**0.237**
	Total xylenes	0.50	WHO DWG	IR	IR	IR
	Styrene	0.02	WHO DWG	IR	IR	IR
	Toluene	0.70	WHO DWG	IR	IR	IR
	Trichloroethene	0.01	UK DWS	IR	IR	IR
	Vinyl Chloride	0.00	UK DWS	IR	IR	IR

Table G30 – Stage 3 Assessment – Model 3 Shallow Groundwater Source Simulated Receptor Concentrations

	WS552B HOTSPOT					
MODELLED RECEPTOR	Individual Compounds (Soil and Leachate Concentrations)	Tier 1 Controlled Waters Screening Criteria (mg/l)	Source	SIMULATED TIME TO EXCEED DWS (years)	Maximum Simulated Concentrations at Receptor (Whitehaven Sandstone)	
					50th PERCENTILE (mg/l)	95th PERCENTILE (mg/l)
50m Compliance Point within the Whitehaven Sandstone						
	Ammoniacal Nitrogen	0.5	UK DWS	IR	IR	IR
	VOCs					
	Benzene	0.001	UK DWS	IR	IR	IR
	Naphthalene	0.01	USEPA	**12**	IR	**0.015**

Tables G25- G30

Key

IR	Insignificant risks calculated
*	UK Drinking Water Standards, 2000
**	UK Freshwater EQS Surface Waters (Dangerous Substances)(Classification) Regulations 1989 No 2286 (Water Resources, England & Wales) 83/513/EEC
***	UK Freshwater EQS Surface Waters (Dangerous Substances)(Classification) Regulations 1998 No 389 (Water Resources, England & Wales)
****	UK Marine / Estuarine EQS Surface Waters (Dangerous Substances)(Classification) Regulations 1989 No 2286 (Water Resources, England & Wales) 83/513/EEC