

## 1. RISKS TO CONTROLLED WATERS- A REFINED CONTROLLED WATERS RISK ASSESSMENT

## 1.1. Introduction

This appendix presents the methodology and results of a Controlled Waters Risk Assessment performed on analytes detected in Plot C. Since the previous risk assessment was performed after the previous Phase II Investigation (REF: 44319623/R2037, dated 23<sup>rd</sup> June 2005), the driver for the risk assessment has changed. The previous phase II investigation provided a conservative estimate on the potential risks to controlled waters posed by the south western part of the site (now called 'Plot C'). The current risk assessment is considered to be more rigorous and representative of site conditions than the previous assessment, as it incorporates the additional geological and geochemical data obtained during the Plot C investigation with a more sophisticated modelling approach.

The refined CW QRA is based upon the UK Department of the Environment, Food and Rural Affairs (DEFRA) and Environment Agency (EA) "best practice" in regard to the assessment of contaminated land. More specifically, this approach follows the "*Source - Pathway - Receptor*" methodology as defined in Part IIa of the Environmental Protection Act (1990) [as inserted by Section 57 of the Environment Act (1995)] and detailed in the following UK Environment Agency's published guidance:

- 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);
- Environment Agency R&D Publication CLR11 (2004) *Model Procedures for the Management of Land Contamination* (referred to as CLR11).

The approach involves the identification of sources, pathways and receptors as derived from the 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 whose significance is evaluation using a tiered risk-based approach, in accordance with the Environment Agency's "Integrated Methodology".

## 1.2. Methodology

## **Tier 1 Screening Assessment**

The "Tier 1" 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 (in this case Freshwater Environmental Quality Standards (EQS) as published by the Environment Agency for the protection of the closest receptor, Sandwith Beck). The EQS values applicable to the



Beck were supplied to URS by the Environment Agency. This initial screening is designed to identify Potential Contaminants of Concern (PCoC), which could pose a potential risk to Controlled Waters. At Tier 1, no consideration is given to potential attenuation factors such as dilution, dispersion etc.

Soil Leach test results represent the mobile fraction of contamination that could potentially be released from the soil and be available to enter the groundwater system. Leach test analysis methods are suitable for low volatile contaminants such as metals, however, for Volatile Organic Compounds (VOCs) that are lost through volatilisation, leach tests are considered to be inaccurate or unrepresentative at best. As such, for VOC determinands soil analytical results have been utilised in the current DQRA.

Freshwater EQS values can be hardness dependent for selected heavy metals and, as such, the measured hardness of the receptor was considered in determining the actual EQS value to adopt for the QRA. A water hardness of between 45 and 295mg/l (as CaCO<sub>3</sub>) was measured for Sandwith Beck over eight monitoring rounds, as provided in the most recent detailed quarterly groundwater-monitoring report (REF: Groundwater Monitoring, Whitehaven Cumbria, Former Albright and Wilson Facility, Rounds 1 to 8, 44319646/R2216.BO2, dated 24<sup>th</sup> April 2006).

Where published Freshwater EQS values 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. Where no EQS values are available, then reference was made to UK/EU Drinking Water Standards.

Based on the results presented in the body of the main text of this report, a number of contaminants exceeded the Tier 1 screening values and have consequently been evaluated further as part of the CW Tier 2/3 QRA presented below.

## Tier 2/3 Quantitative Risk Assessment

The approach for assessing risks to Controlled Waters followed the "source-pathwayreceptor" methodology as defined in Part IIA of the Environmental Protection Act 1990 (as inserted by Section 57 of the Environment Act 1995). The identification of sources, pathways and receptors is derived from the 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 whose significance is evaluation using a tiered risk-based approach, in accordance with the Environment Agency's "Integrated Methodology".

Natural attenuation processes such as dilution, dispersion and other physical/geohemical processes are considered at this Tier of assessment, which ultimately becomes less conservative/generic and more site-specific conditions.

The concentrations simulated at the receptor (Sandwith Beck) by the Tier 2/3 QRA were compared against to the Tier 1 screening criteria, and where simulated concentrations



exceeded the screening criteria, the analyte was to be considered to present a potential risk to controlled waters.

In assigning the degree of significance of any exceedences of the model values, the likely time scale over which migration to the compliance point will occur needs to be considered along with the type of designated receptor/compliance point.

In the event that multiple sources of a single analyte were assessed (as was the case with copper), separate models were run for each defined source area, and then the simulated concentrations for each model were combined prior to comparison against the screening criteria. This was performed in order to assess potential 'cumulative' risks posed by the identified contamination.

## 1.3. Revised Conceptual Model

The revised Conceptual Site Model (CSM) is presented in the main text of this report. The key aspects of this CSM are summarised below, together with the key underlying assumptions.

## 1.3.1. Simulated Sources

For the purposes of this risk assessment, analytes which were detected at a concentration that exceeded the relevant Tier 1 screening criteria were considered to constitute potential sources of contamination and were therefore put forward for more detailed assessment in the CW Tier 2/3 QRA. The soil, leachate and groundwater samples are presented in Tables 3 to 15 of the main report, they include samples taken from the previous investigation (REF: 44319623/R2037, dated 23<sup>rd</sup> June 2005).

The following section provides a summary of the results of the Tier 1 Screening Process. In a limited number of cases, the method detection limit was higher than the screening value for the particular analyte. This occurred in the following analytes:

- Benzo(a)anthracene
- Benzo(a)pyrene
- Dibenzo(a,h)anthracene
- Fluoranthene
- Azobenzene
- Bis(2-chloroethyl)ether
- Hexachlorobutadiene
- N-nitrosodi-n-propylamine
- 1.1.1.2-Tetrachloroethane
- 1.1.2.2-Tetrachloroethane
- 1.2.3-Trichloropropane
- 1.2-Dibromo-3-chloropropane
- 1.2-Dibromoethane
- 1,3- Dichloropropane; and
- Vinyl Chloride



Standard practice where the MDL is greater than the Screening Value would be to include the analytes as sources at the Tier 2 stage, with concentrations at their MDL. However, it was considered reasonable to discount the above analytes as the samples taken within Plot C provided no evidence to suggest that these analytes may exist at all within Plot C. Furthermore, the Phase II Investigation report (REF: 44319623/R2037, dated 23<sup>rd</sup> June 2005) also did not identify these analytes to pose a risk within the investigation area.

The calculated upper 95th percentile mean concentrations (US95), as defined in CLR-7, were adopted as the source term concentrations for the current assessment. The methodology behind the calculation of US95 is designed to cope with heterogeneity within a defined source area. Thus, all measured concentrations within a defined source area are used to derive the US95 concentration for the source area. An example of how the US95 has been derived (in this case for anionic surfactant) is provided below.

|                                    |        |                                | Statistical Analysis |         |      |          |      |                    |   |
|------------------------------------|--------|--------------------------------|----------------------|---------|------|----------|------|--------------------|---|
| Sample Location<br>Target Compound | MDL    | Tier 1<br>Controlled<br>Waters | Minimum              | Maximum | Mean | Std. Dev | US95 | Number<br>Analysed | Number of<br>Samples<br>Exceeding Tier<br>1 |
| Anionic Surfactant                 | 50ug/l | 200                            | 50                   | 4400    | 323  | 948      | 771  | 14                 | 3   |

A source area was defined for anionic surfactant that incorporated each location that where an exceedence of Tier 1 screening criteria was measured. This area also incorporated the remaining 11 samples where measured concentrations were less than screening criteria. The calculated US95 concentration was adopted as the source term concentrations for this source area used in the model. The derivation of the US95 concentration included all the non-detect results at a concentration equal to the method detection limit.

## 1.3.1.1. Soil Contamination Tier 1 Screening

## Volatile Organic Compounds (VOCs)

No leachate tests were scheduled for VOC analysis due to the potential errors associated with the analytical method and volatile compounds, as outlined in the introduction. For this reason, measured soil (total) concentrations have been screened against Tier 1 Criteria.

The results of the Volatile Organic Compounds (VOCs) analyses for soils are presented in Table 3 and a statistical summary of the compounds that were measured above the method detection limit is provided below.



|                        |                                     |         | Statist | Number of Samples |       |                    |                  |
|------------------------|-------------------------------------|---------|---------|-------------------|-------|--------------------|------------------|
| Target Compound        | Tier 1 Controlled<br>Waters (mg/kg) | Minimum | Maximum | Mean              | US95  | Number<br>Analysed | Exceeding lier 1 |
| Toluene                | 0.049                               | 0.001   | 0.387   | 0.099             | 0.159 | 30                 | 1                |
| Ethylbenzene           | 0.794                               | 0.03    | 1.27    | 0.65              | -     | 30                 | 1                |
| p/m-Xylene             | 0.078                               | 0.11    | 4.65    | 2.38              | 3.39  | 30                 | 2                |
| o-Xylene               | 0.078                               | 0.093   | 2.878   | 1.486             | 2.104 | 30                 | 1                |
| 1.2.4-Trimethylbenzene | 0.097                               | 0.009   | 8.8     | 2.2               | 3.6   | 30                 | 1                |
| 1.3.5-Trimethylbenzene | 0.097                               | 0.01    | 2.42    | 0.83              | 1.26  | 30                 | 1                |
| Naphthalene            | 0.075                               | 4.383   | 4.383   | 4.383             | -     | 30                 | 1                |

The majority of measured VOC concentrations in excess of Tier 1 screening criteria were measured in a single sample taken from A117 C (at 3.2m), located approximately 25m to the south east of north pond).

## Metals and pH

The results of the total soils metals and pH analyses are presented in Table 4.

Tier 1 screening has not been performed on the total soil results for metals. Total soils analysis provides a measure of the total metals content of the soil after acid digestion and will include both mobile leachable fractions and immobile fractions that are present as insoluble salts (oxides, hydroxides etc) or irreversibly chemically bound to the soil fabric.

The total metals content of shallow soils is important for the assessment of potential Human Health risks (ingestion of soil particles, dermal contact etc), however, for controlled waters the mobile fraction is important. In the absence of leach test data, theoretical pore water concentrations are calculated form the total soils data using standard partitioning equations and assuming that all measured concentrations are available to partition. Such an approach is overly conservative and typically results in the gross over estimation of the leachable fraction. As a result leach test data provide a more accurate measure of the leachable fraction such that UK regulatory bodies accept and often prefer the use of leach test data in preference to totals soils data. As such, total soils analytical data has not been used further in this DQRA to define potential source areas.

The assessment of potential risks posed by metals has been performed on the metal



concentrations detected in the leachate analysis (refer to Section 3.1.2).

The pH of the site soils was measured as being neutral to alkaline with values in the range 6.4 to 12.2 (mean 8.3), and as such pH soil conditions may potentially assist in the reduction of the mobility of metals.

#### Polychlorinated Biphenyls (PCBs), Phosphates, Anionic Surfactants

The results of the PCB and phosphate (Ortho as  $PO_4$ ) analysis are presented in Table 5. Neither determinand was measured at concentrations in excess of the respective Tier 1 screening value.

Anionic surfactants were detected in 17 of the 18 samples analysed and the results have been incorporated into the modelling process. Given that anionic surfactant is a known contaminant on site, and it has been detected in a number of samples, the remaining non-detections have been set at the detection limit for the generation of likely concentrations for the model.

## Semi Volatile Organic Compounds (SVOC) and Polycyclic Aromatic Hydrocarbons (PAHs)

Tier 1 screening was not performed on this soils data given the substantial number of samples submitted for laboratory SVOC leachate analysis (see Section 3.1.2), and that leach testing provides a direct measure of the mobile fraction of these determinands in soil.

URS consider such an approach to be valid for the following reasons. The dominant proportion of low mobility organic compounds such as PAH compounds, high chain length TPH etc, becomes intimately bound to the soil organic matter and only a small proportion remains mobile. Also the length of time that an organic contaminant is present in soil is important, the longer it is present the more it becomes immobile. However, for mobile volatile organic compounds such an approach has not been adopted given that a high degree of lab error will be associated with the leach testing and that these compounds remain mobile within the soil and are not affected by residence time to the same degree as heavier molecular weight compounds as described above.

#### Total Petroleum Hydrocarbons (TPH)

Tier 1 screening was not performed on this soils data given the substantial number of samples submitted for laboratory TPH leachate analysis (see Section 3.1.2) and that leach testing provides a direct measure of the mobile fraction of these determinands in soil.

#### 1.3.1.2. Soil Leachate Results Tier 1 Screening

#### Metals, Anionic Surfactants, Phosphate

The results of the screening assessment of the metals leachate analysis are presented in Table 8 and a statistical summary of the determinands that were measured above the method detection limit is provided below. Phosphate was detected in only five of the twenty two samples submitted for analysis, no screening criteria currently exists for



phosphate. Any remaining analytes were either present at concentrations below the method detection limit, or less than respective Tier 1 criteria.

|                    |                                    |         | Statistical Analysis |         |      |      |                    |                     |  |  |
|--------------------|------------------------------------|---------|----------------------|---------|------|------|--------------------|---------------------|--|--|
| Target Compound    | Tier 1 Controlled<br>Waters (ug/L) | Minimum | Maximum              | Geomean | Mean | US95 | Number<br>Analysed | Exceeding<br>Tier 1 |  |  |
| Arsenic Dissolved  | 50                                 | 2       | 150                  | 5       | 15   | 29   | 23                 | 1                   |  |  |
| Barium Dissolved   | 700                                | 6       | 757                  | 46      | 83   | 139  | 23                 | 1                   |  |  |
| Copper Dissolved   | 10                                 | 2       | 170                  | 22      | 52   | 74   | 23                 | 8                   |  |  |
| Lead Dissolved     | 10                                 | 1       | 23                   | 3       | 6    | 10   | 23                 | 1                   |  |  |
| Selenium Dissolved | 10                                 | 2       | 13                   | 4       | 5    | 6    | 23                 | 1                   |  |  |
| Vanadium Dissolved | 20                                 | 1       | 66                   | 7       | 18   | 26   | 23                 | 4                   |  |  |
| Anionic Surfactant | 200                                | 60      | 4400                 | 188     | 571  | 1180 | 14                 | 3                   |  |  |

**Total Petroleum Hydrocarbons (TPHs)** The results of the screening assessment for TPH leachate analysis are presented in Table 9 and a statistical summary of the determinands that were measured above the method detection limit is provided below. Any remaining analytes were either present at concentrations below the method detection limit, or less than respective Tier 1 criteria.

|                         | Tier 1 | Tier 1 Statistical Analysis |         |         |      |      |                    |                       |  |
|-------------------------|--------|-----------------------------|---------|---------|------|------|--------------------|-----------------------|--|
| Target Compound (ug/L   |        | Minimum                     | Maximum | Geomean | Mean | US95 | Number<br>Analysed | Exceeding<br>Tier 1 * |  |
| m & p Xylene            | 30     | 34                          | 34      | 34      | 34   | -    | 22                 | 1                     |  |
| o Xylene                | 30     | 30                          | 30      | 30      | 30   | -    | 22                 | 1                     |  |
| Aliphatics >C8-C10      | 10     | 50                          | 50      | 50      | 50   | -    | 22                 | 1                     |  |
| Aliphatics >C10-C12     | 10     | 50                          | 50      | 50      | 50   | -    | 22                 | 1                     |  |
| Aliphatics >C12-C16     | 10     | 40                          | 40      | 40      | 40   | -    | 22                 | 1                     |  |
| Aliphatics >C16-C21     | 10     | 152                         | 152     | 152     | 152  | -    | 22                 | 1                     |  |
| Aliphatics >C21-C35     | 10     | 66                          | 66      | 66      | 66   | -    | 22                 | 1                     |  |
| Total Aliphatics C5-C35 | 10     | 358                         | 358     | 358     | 358  | -    | 22                 | 1                     |  |



| Aromatics >C7-C8                      | 10 | 17  | 17  | 17  | 17  | - | 22 | 1 |
|---------------------------------------|----|-----|-----|-----|-----|---|----|---|
| Aromatics >C8-C10                     | 10 | 140 | 140 | 140 | 140 | - | 22 | 1 |
| Aromatics >C10-C12                    | 10 | 74  | 74  | 74  | 74  | - | 22 | 1 |
| Aromatics >C12-C16                    | 10 | 96  | 96  | 96  | 96  | - | 22 | 1 |
| Aromatics >C16-C21                    | 10 | 75  | 75  | 75  | 75  | - | 22 | 1 |
| Aromatics >C21-C35                    | 10 | 53  | 53  | 53  | 53  | - | 22 | 1 |
| Total Aromatics C6-C35                | 10 | 455 | 455 | 455 | 455 | - | 22 | 1 |
| TPH (Aliphatics and Aromatics C5-C35) | 10 | 813 | 813 | 813 | 813 | - | 22 | 1 |

\* All measured exceedences were obtained from one sample (A117 C at 3.2m depth)

## Semi Volatile Organic Compounds (SVOC) and Polycyclic Aromatic Hydrocarbons (PAHs)

The results of the screening assessment for SVOC leachate analysis are presented in Table 10 and a statistical summary of the determinands that were measured above the method detection limit is provided below. Any remaining analytes were either present at concentrations below the method detection limit, or less than respective Tier 1 criteria.

|                    |                                    |         | Statistical Analysis |      |      |                    |                     |  |  |  |
|--------------------|------------------------------------|---------|----------------------|------|------|--------------------|---------------------|--|--|--|
| Target Compound    | Tier 1 Controlled<br>Waters (ug/L) | Minimum | Maximum              | Mean | US95 | Number<br>Analysed | Exceeding<br>Tier 1 |  |  |  |
| Fluoranthene (NRA) | 0.2                                | 2       | 2                    | 2    | -    | 22                 | 1*                  |  |  |  |
| Naphthalene (NRA)  | 5                                  | 15      | 15                   | 15   | -    | 22                 | 1**                 |  |  |  |

\*A113 at 1.0m,

\*\* A117 at 3.2m

## 1.3.1.3. Groundwater Results Screening

## Metals, Anionic Surfactants, Phosphates, and Major lons

The results of the screening assessment for the metals water analysis are presented in Table 11 and a statistical summary of the determinands that were measured above the method detection limit is provided below. No screening criteria is available for phosphate, however, no concentration was detected above the method detection limit in the groundwater samples and, as such, phosphate was not included in the assessment. Any remaining analytes were either present at concentrations below the method detection limit, or less than respective Tier 1 criteria.



|                    |                                    |         | Number of |      |      |                    |                  |
|--------------------|------------------------------------|---------|-----------|------|------|--------------------|------------------|
| Target Compound    | Tier 1 Controlled<br>Waters (ug/L) | Minimum | Maximum   | Mean | US95 | Number<br>Analysed | Exceeding Tier 1 |
| Selenium Dissolved | 10                                 | 2.0     | 34.0      | 9.8  | 13.6 | 7                  | 1                |
| Anionic Surfactant | 200                                | 60      | 430       | 179  | 326  | 7                  | 2                |

## Total Petroleum Hydrocarbons (TPHs)

The results of the screening assessment of the TPH water analysis are presented in Table 12 and a statistical summary of the determinands that were measured above the method detection limit is provided below. Any remaining analytes were either present at concentrations below the method detection limit, or less than respective Tier 1 criteria.

|                                       |                                    |         | Statistic | cal Analy | /sis |                    | Number of<br>Samples |
|---------------------------------------|------------------------------------|---------|-----------|-----------|------|--------------------|----------------------|
| Target Compound                       | Tier 1 Controlled<br>Waters (ug/L) | Minimum | Maximum   | Mean      | US95 | Number<br>Analysed | Exceeding<br>Tier 1  |
| Aliphatics >C12-C16                   | 10                                 | 47      | 47        | 47        | -    | 7                  | 1                    |
| Aliphatics >C16-C21                   | 10                                 | 96      | 96        | 96        | -    | 7                  | 1                    |
| Aliphatics >C21-C35                   | 10                                 | 67      | 67        | 67        | -    | 7                  | 1                    |
| Total Aliphatics C5-C35               | 10                                 | 210     | 210       | 210       | -    | 7                  | 1                    |
| TPH (Aliphatics and Aromatics C5-C35) | 10                                 | 210     | 210       | 210       | -    | 7                  | 1                    |

All of the detections in excess of Tier 1 Screening Criteria were measured in BH712, located in the vicinity of the above ground storage tank.

## Semi Volatile Organic Compounds (SVOC), Polycyclic Aromatic Hydrocarbons (PAHs) and Volatile Organic Compounds (VOCs) in Groundwater

SVOC, PAH and VOC compounds were not measured in groundwater above the laboratory method detection limits in the samples submitted for analysis. Further assessment was not required as the laboratory method detection limits were less than respective tier 1 screening criteria.

#### Summary of Identified Exceedences of Tier 1 Screening Criteria

From the Tier 1 Screening process the following analytes in *soils leachate/soils total or waters were* considered to pose a potential risk to Sandwith Beck or Groundwater within



the Evaporite sequence.

Potential Risks to Sandwith Beck from Plot C Soil, Soil Leachate, and Waters Contamination

- arsenic (soil leachate)
- barium (soil leachate)
- chromium (soil leachate)
- copper, two separate source areas (soil leachate)
- lead (soil leachate)
- selenium (soil leachate)
- vanadium (soil leachate)
- zinc (soil leachate)
- anionic surfactant (soil leachate)
- toluene (soils)
- ethylbenzene (soils)
- m & p Xylene (soil leachate)
- o-xylene (soil leachate)
- naphthalene (soil leachate)
- fluoranthene (soil leachate)
- 1,2,4 trimethylbenzene (soils)
- 1,3,5 trimethylbenzene (soils)
- total petroleum hydrocarbons (soil leachate)
- anionic surfactant (groundwater)
- selenium (groundwater)

All of the above determinands where identified as individual source areas (Source Areas 1 to 21) located within Plot C, these are presented in Figure D2and Table D1.

Potential Risks to Groundwater within the Evaporite Sequence from Plot C Soil, Soil Leachate, and groundwater Contamination

The risks to groundwater were limited to locations to the eastern side of the fault (refer to Figure D1/Figure 4- Cross Section C 1-1'. It is considered likely that in this area, the evaporite sequence may directly underlie the drift at depths as shallow as 8mbgl (meters below ground level). A water body may exist close to the top of this unit, which may be susceptible to overlying contamination in this area. In other areas of the site the evaporate sequence is known to contain solution features as a result of acid liquors and if present beneath this area of the site could act as potential pathways for migration. A more detailed description of this potential pathway is provided in Section 1.3.2 below.

The potential risks to groundwater in the evaporite sequence were assessed fro the following determinands:

- chromium (soil leachate) at TP511 at 0.3m
- Total Petroleum Hydrocarbons (groundwater) at BH712 C.



The above determinands where identified as individual source areas (Source Areas 22 and 23) located within Plot C, these are presented in Figure D2 and Table D1. Despite arsenic being present in exceedence to the eastern side of the fault, and potentially posing a risk to groundwater within the Evaporite Sequence, it was not considered necessary to incorporate this into the model. This assumption is based on the fact that where an exceedence was determined, namely Trial Pit A111 at 0.5m, it was not detected in the deeper sample taken from 3.2m at concentrations in excess of tier 1 screening criteria. Based on this sample, arsenic appears to not be migrating to 3.2m within the dry clay strata, and it is therefore reasonable to suggest that arsenic is unlikely to migrate to the groundwater within the Evaporite sequence, which is at approximately 8mbgl in this area. No other soil, soil leachate or groundwater sources where identified in exceedence to the east of the fault from the data set obtained.

The limited exceedences of Tier 1 screening criteria measured in groundwater provides an indirect measure of the leachable content of the overlying soils. Shallow groundwater would be expected to be in equilibrium with the overlying soils and the fact that relatively low concentrations and infrequent detections in excess of screening criteria are measured indicates that any residual determinands in the soil are dominantly of low mobility.

A full summary of the designated source areas and input concentrations used in the CW Tier 2/3 QRA are presented in Tables D.1 to D.3. The individual source areas have been digitised for the modelling process and they are presented in Figure D2 entitled "Graphical Definition of Individual Source Areas using CONSIM" at the back of this appendix.

## 1.3.2. Potential Pathways

The geological and hydrogeological conditions encountered during the site investigation are presented in Section 3 of the main report. These findings have been summarised below. N.B The conditions encountered at BH712C are uniquely different to the conditions encountered at the remaining locations. For this reason, BH712C is discussed separately at the end of this section.

- Made Ground comprising:
  - One or two layers of concrete, often containing steel reinforcement bars. These have been associated with historic foundations on the site, and exist at the majority of locations to the north of south pond. They are up to 1m in thickness, and occur at depths from 0.2m to approximately 4mbgl.
  - The area of land to the north of south pond contained a thickness of made ground, generally between 2 and 4.5mbgl. The dominant matrix of the made ground was, in general, reworked clay, and contained varying quantities of angular fine to medium gravel, ash and clinker, wood fragments, red brick, and wires.
  - Isolated perched groundwater horizons were found at a number of locations on the site. In this instance, water was pooling on top of concrete foundations.
- Unconsolidated Drift Deposits comprising:



- Boulder clay/till red-brown generally firm to stiff (occasionally soft) clay with varying amounts of inter-bedded silt and occasional fine to medium sand horizons. The sandy clay or sand lenses that were present were typically less that 0.3m thickness. The boulder clay was present to up to approximately 8.0m.
- A discontinuous groundwater table was encountered in the locations investigated across Plot C. Groundwater, where present, was associated with sand lenses within the boulder clay, or on occasion, within granular made ground, it was typically encountered between 1.75 and 2.72mbgl.

Measured groundwater elevations and interpreted discontinuous groundwater contours are presented as Figure 2 of the main report. In areas where some form of groundwater body was encountered, a generally convergent groundwater flow field to the south (towards Sandwith Beck) is inferred from the limited data, with an estimated hydraulic gradient of 0.0117.

#### Consolidated Deposits comprising:

Bedrock was not encountered during the latest URS investigations, however, results from previous deep drilling boreholes have been used to develop the geological cross-section through the site as outlined on Figure D1/Figure 4 (Cross Section *C* 1-1). For further information the reader is referred to the previous Phase II Investigation report (REF: 44319623/R2037, dated  $23^{rd}$  June 2005).

Geological maps of the area (BGS SHEET NX91NE and NX91SE) have also been used to aid in the interpretation and these suggest that there is **north-northwest to south-southeast trending fault running through Plot C**, as shown on the cross section (Figure D1/Figure 4). It is thought that the presence of this northwest-southeast trending fault has downthrown consolidated deposits on the western side of the fault (meaning they are deeper below the surface, relative to those on the eastern side of the fault). Therefore, the consolidated geology is much closer to the surface to the east. In BH201, located approximately 120m to the west of the fault, clay (comprising of Boulder Clay and underlain by an unknown thickness of weathered St. Bees Shale, which is clay rich in nature) has been proven to a depth of 34mbgl, overlying the consolidated horizons of St. Bees Shale unit. BH201 is screened within this shale unit, and measured rest-water levels are approximately 49mbgl (35mAOD).

BH605 is located approximately 10m to the west of the fault. At this location Boulder Clay has been proven to a depth of 8.8m. Below this, the St.Bees Shale is encountered to depth of 19mbgl. BH605 is again screened across the Shale unit and rest-water levels are measured at approximately 8.4mbgl (71.37mAOD). This apparent difference in groundwater elevations between BH201 and BH605 would suggest that the Shale unit is stratified, and groundwater flow within it is complex. The significant thickness of dry, low permeability clay on the western side of the fault, coupled with a unsaturated zone of up to 48m, is likely to significantly impede the vertical movement of contamination from shallow horizons to the deep groundwater. However, during the site investigation, substantially different conditions were found to exist on the eastern side of the fault (and in the vicinity of the former diesel AST area), as described below.



#### Localised Conditions Encountered at BH712

BH712 is situated to the eastern side of the fault, next to the former diesel above ground storage tank (AST). At this location Made Ground and concrete foundations were encountered to a depth of approximately 4.0mbgl, thought to be associated with the former cement kilns. Beneath the foundations Made Ground extended to a depth of approximately 7.8m BGL. Made Ground in this area was different to that encountered across the rest of the investigation area; it comprised of medium to coarse gravel sized fill, proven to a depth of at least 7.8mbgl. The gravel sized fill material appeared to consist of reworked evaporite material.. The presence of identical fill material above and below the concrete foundation implies an excavation and regrading of material occurred prior to the construction of the foundation and that similar material was used as backfill above the foundation.

These findings suggest that the evaporite sequence (the St.Bees Evaporites) are much closer to the surface on this side of the fault (refer to Figure D1/Figure 4), further supported by a deep borehole (BH101) located approximately 150m north of BH712C and on the same side of the fault. At this location the St. Bees Evaporite sequence was encountered at approximately 4.7m to 15mbgl.Surrounding monitoring wells BH710 and BH713 were drilled through clay horizons until refusals on what was considered to represent consolidated rock head at 6.9m and 7.5m respectively. These refusals could mark the start of the same evaporite sequence encountered in BH712.

BH712C was found to contain groundwater within the backfilled evaporite gravels at a depth of 7.8mbgl (75.67maOD). However, surrounding wells BH710 and BH713 were found to be dry, although some moisture was detected within the strata. It is likely that these wells have been installed within the unsaturated zone and that the groundwater body within the evaporite sequence may lie close to the base of this drift material.

BH101, located approximately 150m north of BH712C, is screened within the evaporite sequence and groundwater at an elevation of 72mAOD is present in this well, which is similar at a similar elevation to the groundwater elevation in BH712C (75mAOD), suggesting they may be part of the same unit.

Furthermore, measured groundwater levels in the drift deposits on the western side of the fault vary between 78.89mAOD (BH701C) and 81.73mAOD (BH707C), and are generally higher than that measured in BH712C (75.67maOD)... This further suggests a separation in groundwater conditions encountered to the west of the fault, from those on the east.

In conclusion:

- To the east of the fault, the receptor potentially impacted by shallow contaminated horizons in the Made Ground is considered to be groundwater within the underlying evaporate sequence.
- To the west of the fault, the receptor potentially impacted by shallow contaminated horizons in the Made Ground is considered to be **Sandwith Beck**



## 1.3.3. Controlled Waters Receptors

A detailed description of the potential controlled waters receptors that could potentially be affected by any residual contamination present in Plot C is present in Section 3.3 of the main report. The likely receptors requiring further assessment are outlined below.

| Receptor  | Receptor characteristics  |
|---|---|
| Controlled Waters:<br>Sandwith Beck                         | Small stream that runs from the southern edge of the site<br>south through Sandwith village, reaching the sea a few km<br>to the south. The topography of the site is such that<br>around two thirds of the site will drain to Sandwith Beck<br>once the former site drainage system ceases to function.<br>Surrounding fields also drain to Sandwith Beck. In Plot C,<br>contamination to the west of the fault is most likely to flow<br>to this receptor.  |
| Controlled waters: deep<br>groundwater                      | Water in the St. Bees Shales, Whitehaven Sandstone and<br>St. Bees Evaporites. The area to the eastern side of the<br>fault in Plot C will be modelled to a 50m compliance point<br>within the St. Bees Evaporites. This is a conservative<br>approach, as it is likely that any groundwater abstractions<br>in the area are substantially further away than this.  |
| Controlled waters: shallow groundwater                      | Groundwater in drift beneath the site. These are not<br>themselves considered as specific receptors*, but they<br>may receive groundwater that is ultimately destined for<br>Sandwith Beck (in ground to the west of the fault) or the<br>Groundwater within the Evaporite Sequence (in ground to<br>the east of the fault)   |
| Controlled Waters: The<br>Byerstead Spring and the<br>coast | These are distant receptors to the site, over 1.3km away.<br>The Byerstead Spring drains immediately into The Irish<br>Sea. The pollutant linkage to these receptors appears to<br>be complex (and is discussed in detail the previous Phase<br>II Investigation, REF: 44319623/R2037, dated 23 <sup>rd</sup> June<br>2005). Contamination may enter this deep groundwater<br>system to the eastern side of the fault within Plot C.<br>However, the risk assessment assumes a compliance<br>point of 50m from the point of source, and assesses the<br>risks at this point (as a conservative worst case). All points<br>further away from this are likely to produce lower<br>concentrations (due to greater dispersion, dilution etc),<br>and hence are not considered further. This receptor is<br>only likely to be at risk from contamination to the eastern<br>side of the fault within the Plot C area. |



\* The drift horizons within which the discontinuous shallow groundwater is encountered, is considered to be generally of low permeability (with the exception of some more permeable sand/silt horizons) and does not form part of a scheduled aquifer. The land use in the area is dominated by this former industrial site, which covers an area of approximately 50 hectares. It is considered highly unlikely that shallow groundwater, where present, would be used for potable supply, or could sustain high enough yields to be used if the water quality was deemed good enough.

As described in Section 1.3.2 above, the depth to which consolidated geological units within Plot C are encountered is controlled by the north-north west to south-southeast trending fault running through Plot C. To the west of the fault, there is a significant thickness of unsaturated strata between the shallow groundwater (approximately 81mAOD) within the top of the Boulder Clay, and the deep groundwater unit (approximately 35mOAD) within the St. Bees Shale below. This 46m thickness of unsaturated zone is likely to allow significant attenuation of any vertically migrating contamination, a process that will be accentuated by the low permeability of the stiff fine-grained strata. For this reason, it is considered reasonable to assume that to the west of the fault, the likelihood of shallow Plot C contamination (i.e. that found in the vicinity of north pond) migrating to the deeper groundwater is unlikely.

However, to the east of the fault, BH101 (150m north of the TPH "Hotspot") has proven that the consolidated geology (the St.Bees Evaporite sequence) is at much shallower depths, with a groundwater table at approximately 72.2mAOD. At BH712 (in the centre of the TPH area) is an area of infilled with evaporite material. To the base of the installed borehole, a groundwater strike was encountered at 75.67mAOD. This groundwater may be situated in the uppermost part of the St.Bees Evaporite. The presence of hydrocarbons in the BH712 groundwater sample at concentrations exceeding Tier 1 Screening values, proves that a pollutant linkage exists. Modelling was conducted based on the groundwater sample taken from this well to determine whether this groundwater source would impact a 50m compliance point.

## Summary of Modelled Pollutant Linkages

For significant risks from contaminated land to be manifested a significant 'source-pathway-receptor' pollutant linkage must be demonstrated.

Soil and groundwater source areas identified across Plot C are summarised in Table D.1. These defined source areas vary in size and concentration from maximum concentrations associated with small hot-spot sources to site wide diffuse contamination prescribed at US95 (CLR-7) concentrations. Contaminant physcio-chemical parameters including the partitioning parameters  $K_{oc}$  (organic contaminants) and  $K_d$  (metals) are presented in Tables D2 and D3.

For the subject site, the viable potential contaminant migration linkages modelled are presented below.



## 1.3.4. RISKS TO SANDWITH BECK

#### Sources

In the area to west of fault, shallow soil & groundwater contamination is considered to migrate within shallow weathered zone towards Sandwith Beck. Thick boulder clay and an unsaturated zone of approximately 41m prevents vertical migration. Any contamination to the east of the fault is unlikely to migrate horizontally towards the beck, however, in order to be conservative, these exceedences have been incorporated into the Sandwith Beck modelling assessment (the Sources are presented in Table D1 as sources 1 to 21).

#### Pathways

The viable pathway applicable to this source include the leaching of soil contamination downwards to the shallow water table, followed by mixing in shallow groundwater and subsequent *horizontal* migration of shallow groundwater within Made Ground and Glacial Drift deposits towards the receptor.

#### Receptor

The single receptor modelled in the Tier2/3 assessment is the closest surface water to the site, Sandwith Beck.

## 1.3.5. RISKS TO GROUNDWATER WITHIN THE EVAPORITE SEQUENCE

#### Sources

In the area to the east of the fault, shallow soil and groundwater contamination is considered to infiltrate down to groundwater contained within the Evaporite Sequence. Identified source areas include: chromium in soil leachate samples and TPH in groundwater, which are presented in Table D1 as source areas 22 and 23.

## Pathways

The viable pathway applicable to this source include the leaching of soil contamination downwards to the St.Bees Evaporite water table, followed by mixing in groundwater and subsequent vertical migration within the St.Bees Evaporite towards deeper strata.

#### Receptors

The receptor for this has been determined as the closest aquifer, the St.Bees Evaporites, and a hypothetical compliance point 50m away from the source has been deemed a suitable distance to assess the risk posed by a source of contamination.

## 1.4. Model Selection and Key Model Assumptions

CONSIM (version 2.02) computer software developed by Golder Associates was used to complete the risk calculations for the Tier 2/3 assessment. CONSIM was run in



probabilistic mode to allow for uncertainty in key input parameters. Simulated concentrations at a defined receptor are reported at the 95th percentile upper confidence limit. 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. 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 are presented in Table D3. 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 (meaning no unsaturated zone).
- Longitudinal dispersion set at 1/10<sup>th</sup> the travel distance to the receptor, Sandwith Beck, 80m away from the closest source.
- No vertical dispersion is simulated by CONSIM in the aquifer (horizontal) pathway. An inbuilt conservative assumption.

Overall, given the above assumptions and conservative input parameters selected, the Tier 2/3 QRA is considered to be conservative in nature.

## 1.5. Model Input Parameters

Model input parameters applied during this CW QRA are presented in Tables D1-D3. The model inputs, where possible, have been based on-site measurements & observations and laboratory analysis. Where site-specific data is absent, reference to published sources of information for values used are also presented.

The variations in parameters have been simulated using either a single, uniform or triangular Monte Carlo probabilistic approach.

## 1.6. Summary of Model Results

Simulated 50<sup>th</sup> and 95<sup>th</sup> percentile concentrations at the Sandwith Beck receptor are presented in Table D.4. Time-variant graphical outputs for each model run, presenting simulated concentrations of the analyte (at various levels of confidence, known as percentiles) and the Controlled Waters screening criteria are presented in Figure D2. Simulated 50th and 95th percentile concentrations can be interpreted as follows:



- 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).

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 Tier 1 screening criteria (EQS) and occur within a reasonable time frame, considered by URS to represent a travel time of 500 years or less. Predicted risks in excess of this time frame are considered to hypothetical in nature.

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.

In addition, current UK guidance conservatively requires that simulated 95<sup>th</sup> percentile concentrations are used to asses potential risks. However, in assessing the potential significance of an identified risk, predicted travel times and 50<sup>th</sup> percentile concentrations are taken into account.

Potential exceedences of the applicable screening criteria (in this case freshwater EQS values) at the Sandwith Beck are simulated occur for only two analytes, namely Copper and Anionic Surfactant. These are considered to be hypothetical in nature and are not considered to represent potentially 'significant' risks due to the following:

# 1.6.1. POTENTIAL RISKS FROM SOIL AND SOIL LEACHATE CONTAMINATION TO SANDWITH BECK

## Copper

The predicted maximum concentration at the 95<sup>th</sup> percentile confidence limit was 10.1µg/l (for Large source) and 15.6µg/l (for Copper cumulative risk). These are only slightly above the EQS value of 10µg/l. However at the 50<sup>th</sup> percentile confidence limit, both source's simulated maximum concentrations are significantly less than the EQS value ( less than 1µg/l). The timescale for simulated concentrations to exceed the EQS value is predicted to occur is 5,000years.

The risk to Sandwith Beck from copper is therefore not considered to be significant.

## Anionic Surfactant

The predicted maximum concentration at the 95<sup>th</sup> percentile confidence limit was  $300\mu g/l$ , which is above the EQS value of  $200\mu g/l$ . However at the 50<sup>th</sup> percentile confidence limit, simulated maximum concentrations are significantly less than the EQS value at less than  $40\mu g/l$ . The timescale for simulated concentrations to exceed the EQS value is predicted



to occur is 15,000 years.

The simulated results suggest that the theoretical risk posed by surfactant contamination within Plot C will not exist for over 15000 years. Surfactant is already detected in Sandwith Beck (e.g.  $80\mu$ g/L in January 2006, REF: Groundwater Monitoring, Whitehaven Cumbria, Former Albright and Wilson Facility, Rounds 1 to 8, 44319646/R2216.BO2, dated 24<sup>th</sup> April 2006). It is therefore thought that the theoretical risks posed by Plot C contamination may not be the most pertinent for the protection of Sandwith Beck.

Anionic Surfactant is likely to degrade over time. In the absence of a published half life values, a conservative estimate has been provided based on TPH (>EC21-35) aliphatic half-life fraction. This half life may be too conservative, allowing degradation to occur quicker than has been modelled. Consequently, simulated concentrations may reduce to below the EQS value.

It is concluded that the soil contamination in Plot C does not pose a significant risk to Sandwith Beck. A source elsewhere on site may be present.

## 1.6.2. Potential Risks From Shallow Groundwater Contamination To Sandwith Beck

No potential risks were simulated for Selenium and Anionic Surfactant based on the data utilised for the modelling process

## 1.6.3. East Of Fault: Potential Risks From Soil And Soil Leachate To A 50m Groundwater Compliance Point Within Evaporite Sequence

No potential risks were simulated for Chromium based on the data utilised for the modelling process.

## 1.6.4. East Of Fault: Potential Risks From Groundwater Sources To A 50m Compliance Point Within Evaporite Sequence

No potential risks were simulated for TPH based on the data utilised for the modelling process.

# 1.7. Limitations of Controlled Waters Tier 2/3 Quantitative Risk Assessment

The risk assessment assumed a future "right to roam" end use without any continued industrial operations and no significant changes to the site layout, or off-site changes. As such, if such changes occur it will be necessary to reassess the risk assessment results and conclusions.

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<sup>th</sup> 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.

#### Assessment of Uncertainty

A degree of uncertainty is associated with the adopted parameters characterising the various geological strata encountered at the site that make up the source and pathways. As such, a probabilistic 'Monte Carlo' assessment has been adopted encompassing distributions in the likely range in parameters that could be considered appropriate for the strata encountered at the site. In addition, the undertaking of probabilistic modelling and simulating concentrations at the 50th & 95th percentile level of confidence presents an assessment of the effects of the variability in parameters, be they poorly or well understood. Simulated 50th and 95th percentile concentrations can be interpreted as follows:

- 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, low degradation rate etc).

The simulation of 95th percentile concentrations already takes into account a worse case scenario resulting from the combination of worse case parameters such as high permeability etc. In addition, calibration exercises typically result in the predicted concentrations at the 50<sup>th</sup> percentile confidence level matching observed data (*Pers. Comm.* Hugh Potter of Environment Agency, Groundwater Modelling Seminar, Birmingham, 8 May 2006).

## 1.8. References

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

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

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.

## 1.9. Tables

Tables D1 to D4: Modelling Parameters

## 1.10. Figures

Figure D1: (Figure 4 of the Main Report) - Cross Section 1-1'

Figure D2: Consim Model Baseplan, Graphical Definition of Source Areas, Model Graphical Outputs