Post-Remediation Quantitative Risk Assessment for Controlled Waters

Former Bayer CropScience Site
Hauxton
Cambridgeshire

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On behalf of:

Harrow Estates Plc

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Table of Contents

Appendices

1.0 Introduction

VertaseFLI have been appointed by Harrow Estates Plc to undertake remedial works at the former Bayer Crop Science agrochemicals works in Hauxton, Cambridgeshire (the site). The site was determined as a Special Site under Part 2a of the Environmental Protection Act (EPA) 1990 due to significant pollutant linkages being identified with respect to groundwater and surface water resulting from the former use of the site in the production and storage of agrochemicals.

At the time of writing, all buildings and structures at the site had been demolished and removed (with the exception of the Mill House in the northernmost corner of the site) and remedial works had been completed prior to redevelopment of the site for primarily residential purposes. Remedial works at the site comprised the following:

- The excavation of contaminated soil material;
- The treatment of contaminated soil material via the formation of biopiles or treatment beds (including the addition of organic matter) and turning of the contaminated soil material;
- The recovery, treatment and discharge of contaminated groundwater, and;
- The reinstatement of the remediated soil material.

During the remedial works, in order for the remediated soil material to be reinstated, it was necessary to demonstrate through the development of an appropriately detailed risk assessment and derivation of remedial targets, that the reinstated soils would not present a significant risk to local receptors such as groundwater and surface water. Initial risk assessment and remedial targets for the site were based on site investigation data collected prior to remediation (Atkins (2007), Reference 1). As the remedial works progressed, more data was collected regarding the properties and volumes of soil materials and a more representative post remedial conceptual site model (CSM) was developed and the remedial targets were revised accordingly (VertaseFLI (July 2011), Reference 2).

However, these risk assessments were still based on limited data, particularly with respect to the hydraulic properties of the reinstated soil material, and the final distribution of residual contaminants in the remediated soils. Therefore, as part of the validation process for the remediated site, and in accordance with the VertaseFLI remediation method statement (Reference 3), a final risk assessment has been undertaken for the Riddy Brook with respect to the remediated site using all available data collected during the remedial works including final contaminant concentrations, distributions and *in-situ* testing of the reinstated remediated soils.

This report therefore forms part of the validation of the site and describes and assesses the risk assessment post remediation with respect to controlled waters including the methodology used, the parameters used and their selection and the findings.

1.1 Limitations

It is important to note that this document refers to the CSM with respect to the controlled waters risk assessment only. A risk assessment addressing Human Health will be undertaken separately and submitted under separate cover.

2.0 Remediation Strategy and Approach to Risk Assessment

As previously described in VertaseFLI (July 2011), Reference 2, the main strategy for the remediation at the site was to excavate all materials at the site to ensure that all uncertainty regarding contaminants and geological conditions are removed. All excavated soil material was to be segregated, classified and treated as appropriate before being reinstated and validated. Any contaminated groundwater was to be separated, treated and disposed from the site under discharge consent. Following the remediation and reinstatement of soils, a clean cover system will be imported from off-site above the finished levels by the developer.

Paragraphs 6.3 and 6.4 of the Remediation Method Statement (Reference 3) set out the approach to be used in developing the risk assessment with respect to environmental receptors as follows:

> *6.3 An important part of the approach of our remedial strategy will be to collect further information on the geology, hydrogeology, contamination, material parameters and characteristics during the remedial works. It is our intention that this information will be used to further develop the site model to re-evaluate the remediation targets. This will be continually re-assessed as the remediation is continued and may ultimately result in the preparation of a numerical model that represents exact site conditions with a high degree of certainty to prove that materials present on site post remediation do not represent a significant risk of significant harm to the environment and that adequate remediation works have been completed to satisfy the requirements under Part IIa of the Environmental Protection Act 1990.*
>
> *6.4 This modelling approach will be calibrated by site based monitoring and the mode calibrated appropriately. It does mean that some material will be replaced at the site that does not meet the present generic criteria but through the remediation we will have detailed data and knowledge of this material which will allow clearer understanding of the site. This knowledge and understanding will be used to present a new conceptual model and appropriate risk assessment.*

Based on the above approach, this report represents the final iteration of the risk assessment as part of the validation of the reinstated soil materials. The risk assessment model has been reassessed and updated to incorporate all relevant data collected through the remediation and validation process and any new data relating to contaminants of concern (COCs) to accurately and robustly assess the risks to controlled waters from the COCs in the soils at the site following completion of the remediation works.

3.0 Summary of Site Activities and Environmental Works

The history and development of the site including historic site processes are discussed in detail in Enviros (2005) (Reference 4) and Atkins (2006) (Reference 5).

The following bullet points briefly summarise the key developments at the site and the environmental investigations / works undertaken to date:

- Pre 1940, the site was largely undeveloped, with the exception of a petrol station understood to have been located in the north of the site;
- 1940 - The site was occupied by a contract spraying company;
- 1943 – The site was first used for synthesis of pesticides;
- 1970's – A bentonite clay and cement cut-off wall was constructed along the boundary between the site and the Riddy Brook;
- 1986 to 1989 – The warehouse building in the south of the site was constructed;
- 1991 to 1996 – Aspinwall & Co (now Enviros Consulting Ltd) conducted four phases of investigation, primarily to assess the groundwater flow regime and contaminant levels across the site;
- 1991 to 1996 – It is understood that the groundwater abstraction sumps were installed in the north of the site during this period;
- 2003 – The site was determined as a Special Site under Part IIa of the Environment Protection Act (1990) by the Environment Agency (EA);
- 2004 – Site ceased operating;
- 2004 to 2006 - Decommissioning of plant and some demolition undertaken;
- 2005 – Enviros Consulting Ltd conducted further investigations and risk assessments to assess the previously identified potentially significant pollutant linkages with respect to the Part IIa Special Site designation;
- 2006 – Atkins prepared a preliminary Conceptual Model for the site;
- 2006 to 2007 – Atkins undertook intrusive investigations at the site and prepared detailed quantitative risk assessments for both human health and controlled waters;
- 2007 – Demolition of above ground structures completed;

- 2008 - First iteration of the VertaseFLI Remediation Method Statement Issued;
- 2010 – Remedial works commenced in March 2010;
- July 2011 – Most recent iteration of groundwater risk assessment issued by VertaseFLI (Reference 2);
- November 2011 – Remedial works largely completed and all remediated soils reinstated;
- November 2011 – Addendum risk assessment to July 2011 groundwater risk assessment issued by VertaseFLI to address risks from Contaminants not previously identified (CNPIs) on site (Reference 6 – reissued March 2012); and
- May 2012 – Remedial works completion report issued by VertaseFLI (Reference 7), and reissued in December 2012 (Rev B);
- August 2012 – Addendum completion report issued by VertaseFLI (Reference 27) and reissued December 2012 (Rev B);
- August 2012 – Groundwater Validation report issued by VertaseFLI (Reference 28) and reissued December 2012 (Rev B);
- August 20120 – Groundwater Validation Addendum Report issued by VertaseFLI (Reference 29) reissued December 2012 (Rev B);
- August 2012 – Post Remediation Risk Assessment model issued by VertaseFLI, and reissued in December 2012

4.0 Environmental Setting

4.1 Site Description

The site is situated approximately 200 m northwest of the village of Hauxton (National Grid Ref TL 432524), and covers an area of approximately 9 hectares. A location plan is presented in Drawing D907_01, Appendix A.

It was most recently occupied by Bayer CropScience and used for the production and storage of agrochemicals including pesticides, insecticides and herbicides. Remedial works have recently been completed at the site and it currently comprises reinstated soils across the entire extent.

The site is bounded to the west by the A10 trunk road beyond which is agricultural land and the Waste Water Treatment Plant (WWTP) for the Site. The northern and eastern site boundaries are formed by the Riddy Brook, with Church Road forming the southern site boundary and the southeast of the site bounded by agricultural land.

The remediated site slopes gently towards the north with ground levels falling from approximately 13 m AOD in the extreme south to approximately 11 m AOD in the north.

4.2 Geology

4.2.1 Pre-Remediation Ground Conditions

The British Geological Survey (BGS) Solid and Drift Geology Map for the area (Sheet 205 – Saffron Walden) (Reference 8) shows the geology in the immediate area of the site to comprise the following:

- Made Ground – Not indicated as present at the site;
- Drift Deposits – The map indicates the site to be underlain by River Terrace Deposits comprising silt, sand and gravel, with alluvium (silt, clay, sand and gravel with peat) present along the eastern site boundary;
- West Melbury Marly Chalk Formation (WMMCF) – The WMMCF is shown to underlie the drift deposits and is described by the BGS as '*buff, grey and off-white, soft marly chalk and hard grey limestone'*;
- Cambridge Greensand Member – The Cambridge Greensand Member forms the base of the WMMCF and is described by the BGS as *'pale greenish grey marl rich in phosphatic nodules (so called "coprolites") at base'*. It should be noted that the

Cambridge Greensand Member was excavated extensively in the local area during the mid to late 19th century for the phosphate rich coprolites (Reference 9). Given the relative shallow depths to the base of the WMMCF it is considered likely that the site has been affected by these activities.;

- Gault Formation – '*Pale to dark grey or blue grey clay or mudstone',* and
- Woburn Sands Formation – Part of the Lower Greensand Group comprising sandstone or loose sand.

Based on the information provided by Enviros (2005) and Atkins (2006) (References 4 and 5), the pre-remediation ground conditions at the site are presented in Table 1.

Table 1: Ground Conditions

Description	**Thickness**
Made Ground (consisting of reworked sand and gravel, chalk marl, alluvium, brick rubble and clinker), foundations, drainage features and voids	Typically up to 2 m bgl, with a maximum thickness of 5 m
Superficial Deposits – Alluvium and River Terrace Gravels typically comprising	Generally < 3 m thick where present. Completely replaced by Made Ground in parts of the site
WMMCF – typically comprising stiff clay with thin isolated discontinuous lenses of sand and gravel	Present in the south and northwest of the Site only. Typically less than 3m thick with a maximum thickness of 7m in some areas.
Cambridge Greensand	Not identified in available logs/data.
Gault Formation (Gault Clay)	Typically present at a depth of 5 m bgl underlying Made Ground/Superficial Deposits/WMMCF, the thickness is understood to be up to 50 m (based on historic borehole data presented in Atkins (2006) (Reference 5)
Woburn Sands Formation (Lower Greensand)	Not encountered but typically between 15 – 20 m thick based on the BGS solid and drift map.

4.2.2 Post Remediation Ground Conditions

In the main excavation/remediation areas, excavation and remediation of soil material was typically undertaken to depths of between 5 and 6 m with the maximum depth extending to 7 m in some locations and 8 to 10m in grid squares K7 and L7 (see drawing D907_07A). The extent and depths of excavations are shown in drawing (D907_207A). Excavated soil material comprised the following:

- Type A – Granular soils including granular Made ground. The deposits of sand and gravel were typically clayey with clay percentages typically between 20 to 60% (see Appendix B);
- Type B – WMMCF and cohesive Made Ground; and
- Type C – Gault Formation.

It is important to note, that the excavation and remediation of each of the soil types resulted in the homogenisation of the soils and in the case of the WMMCF, this has resulted in the removal, in the remediated soils, of the lenses of sand and gravel observed in the pre-remediation investigations and during the remedial works.

During the remediation works, a buffer zone of a minimum of 20 m (Zone 1) was set from the site boundary with the Riddy Brook in which very stringent remedial targets were set. Generally, only clean material comprising Type B and Type C material was reinstated in the buffer zone with the exception of an area where clean sand and gravel was reinstated between 1 and 2.5 m bgl with the thickness increasing towards the Riddy Brook.

Outside of the buffer zone, reinstatement of the remediated soil material replicated the naturally occurring strata as closely as possible so that Type A material was placed over Type B material over Type C material. During reinstatement, soil material was placed in layers with a typical thickness of 200 mm layers and compacted in accordance with the specification. Additionally, a hard to dig layer of crushed concrete was placed over the reinstated soil material. The thickness of each unit is as follows:

- No Dig Layer – Typically 0.3 m thick, locally 0.5 m thick in south of site (see D907_215);
- Reinstated Type A material – The Type A material was reinstated in discrete discontinuous zones across the site. Where present the reinstated Type A material is typically up to 0.5 m thick with a maximum thickness of 1 m in some locations. As described above, clean sand and gravel was also reinstated within Zone 1 to depths typically between 1 and 2.5 m bgl along a portion of the eastern site boundary (adjacent to the Riddy Brook) with the thickness increasing towards the Riddy Brook. The distribution of the reinstated Type A material is shown in drawing D907_224, Appendix A;
- Natural Type A material –Natural clean deposits of sand and gravel (typically slightly clayey to clayey) remain *in-situ* in the south of the site as shown on drawing

D907_213A. Deposits of the natural sand were between 0.7 to 2.3 m thick in the southwest of the site and typically 1 to 1.8 m thick to the southeast. It is important to note that following the remedial works at the site, these deposits are not continuous and are not in connectivity with the remediated reinstated Type A material discussed above.

- Type B material – Following remediation and soil reinstatement, thickness of the Type B material (including soils that were not excavated) in the north and centre of the site was between 0.25 to 3.75 thick with a typical thickness of approximately 2.0 m (see drawing D907_220A). In the south of the site, thickness of the Type B material is typically a maximum of 5 m. Borehole logs from the Atkins (2006) investigations indicate a typical thickness of between 2 and 4 m although one borehole located in the far southeast corner of the site (approximate grid square D26) indicated a thickness of 7.5 m. Distribution of the WMMCF is shown in drawing D907_213A; and
- Type C material – The total thickness of Gault Formation underlying the site is understood to be up to 50 m, the distribution of reinstated Type C material is shown in drawing D907_212.

Cross sections showing the post remediation ground conditions are presented in drawing D907_236, Appendix A. Further details of the treatment and reinstatement of remediated soils are presented in the VertaseFLI completion report for the site (Reference 7).

It should be noted that prior to the final development and as detailed in the remediation method statement (Reference 3), it will be necessary to import a minimum of 1 m thick capping layer comprising subsoil and topsoil onto site.

4.3 Hydrogeology

4.3.1 Made Ground and Drift Deposits

The natural drift deposits at the site comprise River Terrace Gravels and Alluvium and are classified by the Environment Agency as a Secondary A Aquifer which are described as:

> *‘permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers. These are generally aquifers formerly classified as minor aquifers.’*

4.3.2 West Melbury Marly Chalk Formation

The Lower Chalk (which includes the WMMCF) is classified by the Environment Agency as a Principal Aquifer. A Principal Aquifer is described as:

> *'These are layers of rock or drift deposits that have high intergranular and/or fracture permeability - meaning they usually provide a high level of water storage. They may support water supply and/or river base flow on a strategic scale. In most cases, principal aquifers are aquifers previously designated as major aquifer.'*

4.3.3 Gault Formation

The underlying Gault Formation is considered to act as an aquiclude (Atkins 2006, Reference 5), preventing continuity between any shallow groundwater present in on the site and the Lower Greensand which underlies the Gault.

4.3.4 Groundwater Levels and Flow Direction

4.3.4.1 Pre-Remediation Conditions

Prior to remediation, groundwater was typically present at depths between 0.69 and 2.42 m below ground level (bgl) with an average depth on the site of 1.3 m bgl. Based on the available site investigation data (References 4 & 5) pre remediation, groundwater flow was assumed to occur within the granular Made Ground and drift deposits, site infrastructure, and within the discontinuous sand and gravel lenses within the underlying WMMCF.

The local groundwater flow direction was generally from the south and west towards the Riddy Brook and the River Cam. However, groundwater flows on site were significantly altered due to the presence of a bentonite clay and cement cut-off wall along the northeast site boundary and abstraction of groundwater in both the north and the south of the site. As a result of the dewatering/groundwater abstraction in the south of the site, a groundwater 'low' developed which resulted in groundwater flow towards this area and a steeper hydraulic gradient over much of the site compared to off-site. It should be noted that the bentonite wall and all groundwater abstractions were removed during the remedial works.

4.3.4.2 Observations in WMMCF During Remediation

Prior to remediation, groundwater flow to the Riddy Brook through the site was assumed to be through granular Made Ground and granular drift deposits with the majority of any flow through the discontinuous lenses of sand and gravel within the WMMCF. However, the WMMCF predominantly comprises stiff clay with thin isolated discontinuous lenses of sand and gravel. The full thickness of WMMCF was exposed in the sides of the remediation excavations. Based on these exposed sections, groundwater flow within the *in-situ* WMMCF surrounding the site was very low with any flow generally occurring as small seepages through the discontinuous sand and gravel lenses. Once the sand and gravel lenses were exposed, these seepages decrease with time (typically becoming dry over 3-4 weeks) suggesting negligible recharge through natural strata as would be expected given the discontinuous nature of the sand and gravel lenses and the surrounding stiff clay/marl. As a result, the excavations which were to depths significantly below the natural water table over much of the site, largely remained dry (with the exception of rainfall) for the duration of the remediation. It should also be noted that these lenses of sand and gravel have now been removed due to homogenisation of the WMMCF/Type B material during the remediation.

4.3.4.3 *Groundwater Observations During Investigations Outside of Main Excavation*

Outside of the main excavation areas at the site, trial pits were excavated in the south and northwest corner of the site during August and September 2011. The trial pit logs are presented in Appendix C, and show ground conditions prior to excavation/remediation works. The trial pits were typically excavated into the WMMCF and representive photos of the trial pits are presented in Appendix D. The depths at which groundwater was encountered is summarised in Table 2 below. In general, during the investigations and subsequent excavations in the south of the site, groundwater was only present within deposits of WMMCF and was not encountered within the overlying Type A and Made Ground deposits.

Table 2 – Groundwater Depths During Trial Pit Investigation

Trial Pit	Groundwater Depth(mbgl)	Geological Unit	Trial Pit	Groundwater Depth (mbgl)	Geological Unit
C21	2.9	WMMCF	**I21**	2	WMMCF
D14	3	WMMCF	**J20**	2.8	WMMCF
D17	4	WMMCF	**K17**	2.5	WMMCF
E17	4	WMMCF	**K20**	2.5	WMMCF
E18	3.5	WMMCF	**M4**	2	WMMCF
E19	4	WMMCF	**M5**	2	WMMCF
F12	2.3	WMMCF	**M6**	1.3	WMMCF
F17	3.2	WMMCF	**M7**	1.8	WMMCF
F18	3.5	WMMCF	**M8**	3.1	WMMCF
F20	3	WMMCF	**M9**	1.85	WMMCF
F21	4	WMMCF	**N4**	2.2	WMMCF
H21	2.5	WMMCF	**N5**	1.9	WMMCF

I18	3.6	WMMCF	**N6**	1.8	WMMCF

Additionaly, a trial pitting exercise undertaken in April 2012 to confirm the thickness of the clean sand and gravel deposits reinstated in the 20 m buffer zone did not identify the presence of any groundwater. The trial pits were excavated during a period of heavy rain and flooding in the immediate vicinity of the site which coincided with increased groundwater levels elsewhere on the site and the absence of groundwater within the sand and gravel has been taken as an indicator that there is negligible groundwater flow in the reinstated soil materials within this area.

4.3.4.4 Post Remediation Conditions

Monitoring Boreholes

Sixteen on-site groundwater monitoring boreholes were installed at the site following completion of the remedial works. The borehole locations are shown on drawing D907_226A, and the borehole logs presented in Appendix E. All borehole locations were agreed with the Environment Agency prior to drilling.

Details of the borehole response zones are detailed in Table 3 below.

Table 3 – Validation Borehole Response Zones

Borehole	Response zone (m)	Strata
A18	2-4	WMMCF
E14	2-4	WMMCF
D20	2-4	WMMCF
D25	1.3-3	Type A – Sand and Gravel
F12	2-3	WMMCF
F23	4-6	Reinstated Type B/WMMCF
G10	2-3	Reinstated Type B
G21	2.2-4	Type A – Sand and Gravel
H7	1-3	Reinstated Type B
H15	1-3	Reinstated Type B
I18	3-5	WMMCF/Gault Clay
I24	3-5	WMMCF
J10	2-5	Reinstated Type B and Type C
K5	2-5	WMMCF/Gault Clay
K14	1-3.5	Reinstated Type B
K21	3.7-5.7	WMMCF

In addition, groundwater monitoring has been undertaken in three historic boreholes (VN3, BH9 and BH11). No logs were available for these historic boreholes, all three were installed prior to remediation to a maximum depth of 5m bgl.

Groundwater Levels and Sampling

Six post remediation groundwater monitoring rounds had been undertaken at the site at monthly intervals. Drawings D907_223A, and D907_225 presented in Apendix A present groundwater levels between December 2011 and June 2012. The results of the monitoring showed a significant low in the groundwater levels present in reinstated soil material in the north of the site with two possible interpretations:

- The low indicates groundwater flow in the north is towards the centre of the site, away from the local watercourses; or
- The low indicates a zone of effective negligable flow within the reinstated soil materials and that groundwater on site will flow around rather than through the reinstated soil. If this is the case, it is likely that the reinstated Type B and C soils in the south of the site may also be zones of effective no flow.

Post remediation, outside of the groundwater low, average groundwater levels were approximately 1.5 m bgl (typically 10 to 11 mAOD) although groundwater levels were less than 1 m bgl (10 to 10.5 m AOD) in three boreholes all of which were installed in Type B material. In the initial months (December 2011 to February 2012)following remediation and the ending of groundwater controls, outside of the groundwater low, groundwater levels increased as they returned to more natural levels.

Drawing D907_236, presents cross-sections across the site including the groundwater levels. The cross-sections show that groundwater levels is typically within the WMMCF and reinstated Type B material. Groundwater levels are also generally below the level of remaining natural sand and gravel deposits with the exception of deposits in the far south and southwest of the site (both up hydraulic gradient) and isolated deposits in the south of the south.

Analysis and assessment of groundwater samples is presented in the VertaseFLI Groundwater Validation report (December 2012, Reference 28). However, it is important to note that it has not been possible to obtain samples from 5 of the 6 boreholes installed within remediated soils indicating low to negligable flow rates within the remediated soils.

Groundwater Flow Direction

The groundwater contour plots suggest that in the south of the site (outside the groundwater low), groundwater flow is typically towards the northeast although flow at the southeast site boundary appeares to more easterly. In the northwest corner of the site, groundwater flows in a more northerly direction.

Type C Material

As stated in Section 4.3.3, the Gault Formation is considered to be an aquiclude. Given the level of compaction achieved in the reinstated Type C and very low permeability of the Gault formation material it is considered that this material will also act as an aquiclude.

Type B Material

Observations during trial pitting, drilling of boreholes and groundwater monitoring indicates that outside of the main excavations, the main groundwater body in the south of the site is the WMMCF (see Table 2 above), with very little groundwater observed in Type A deposits during investigations and in subsequent excavations.

111 *in-situ* permeability tests were undertaken within Type B material across the site. Tests were undertaken at a range of depths in reinstated materials from the base of excavations to the upper surface of the Type B and in trial pits excavated in areas outside of the main excavations. The location of the permeability tests is shown in drawing D907_238 and the results are presented in Appendix P and summarised as histograms in Appendix L. The testing recorded a range of *in-situ* hydraulic conductivities between 1.6 x 10^{-10} to 6.1 x 10^{-6} ms^{-1} with a typical value of 2.2 x 10^{-7} ms^{-1}. The results of the testing are discussed further in Section 6.

Type A Material

Given the limited and shallow deposits of the reinstated Type A material (drawing D907_224) (reinstated over Type B material) , it is anticipated that any flow of water will follow the fall of the reinstated site levels and flow to the north. However, as the Type A material was reinstated in discreet discontinuous bodies at the surface above the water table, the reinstated Type A material is not considered to represent a significant groundwater body.

Following remediation Type A material remains in the southeast and southwest corners of the site (Drawing D907_2123A). However, the Type A deposits are discontinuous and given the general absence of groundwater (discussed in 4.3.4.3 above) within the natural sand and gravel, the natural Type A material is unlikely to represent a significant groundwater body. It should also be noted that borehole D25, installed in the sand and gravel, to the southeast of the site has very poor recovery rates (indicative of either low permeability material or an absence of groundwater) (VertaseFLI Groundwater Validation report (2012)).

4.4 Hydrology

The Riddy Brook and Hauxton Mill Race are the closest water bodies to the site, forming much of the northern and eastern site boundary. The Riddy Brook and Hauxton Mill race meet immediately to the north of the site where they enter the River Cam. For the purposes of the risk assessment, shallow groundwater at the site is considered to be in direct continuity with the Riddy Brook.

Water levels in the Riddy Brook were regularly monitored at upstream and downstream locations (see drawing D907_203A) during remediation and showed relatively little variation Between January and October 2011 water levels in the Riddy Brook were:

- Upstream – 0.16 to 0.50 m deep, median depth 0.26 m; and
- Downstream – 0.14 to 0.54 m deep, median depth 0.21m.

Plots of the levels in the Riddy Brook are presented in Appendix F.

5.0 Risk Assessment Approach

Previous iterations of the controlled waters risk assessments for the site have been undertaken for a number of different reasons:

- Enviros 2005 (Reference 4) – Risk assessment was undertaken to establish the presence of risks to controlled waters under Part 2A of the Environmental Protection Act 1990;
- Atkins 2007 (Reference 1) – Risk assessment was undertaken to develop preliminary remedial targets;
- VertaseFLI 2011 (Reference 2) – Risk assessment was undertaken to revise the preliminary remedial targets in respect of findings of the initial remedial works to provide working targets for the remediation.

In accordance with the remedial method statement, this final iteration of the risk assessment has been undertaken to validate the remedial works and the key outcome is to assess the risks from the remediated site to controlled waters (the Riddy Brook). Therefore, further remedial targets have not been derived and instead the distribution of reinstated soils and final contaminant concentrations achieved by the remediation have been used together with the measured soil properties to model, as accurately as possible, the remediated site and the potential risks to the Riddy Brook.

5.1 Post Remediation Site Model

The Site Model is presented in Drawing D907_154C, Appendix A, based on the post remediation site conditions as described in Section 4. Groundwater flow is assumed to be towards the Riddy Brook as a conservative assumption.

5.1.1 Contaminant Source

The contaminant source in the post remediation CSM comprises the residual CoC concentrations remaining in the remediated soils (see Section 5.3). Based on post remediation groundwater levels and the assumed groundwater flow direction, a large proportion of the contaminant source is present below the water table.

5.1.2 Pathways

Potential pathways at the site are limited to leaching of contaminants into groundwater from reinstated Type A and Type B material and subsequent horizontal migration via groundwater towards the Riddy Brook.

As the remediated Type A has been reinstated as discreet discontinuous units (typically a maximum of 0.5 m thick but up to 1.0 m thick in some locations) over Type B material no direct pathway will exist through the Type A material with the exception of very limited vertical migration through the unsaturated zone.

5.1.3 Receptor

The primary receptor is considered to be the Riddy Brook, located between 1 and 6 m from the northeast boundary of the remediated site boundary. For the purposes of the risk assessment, where the clean sand and gravel was reinstated in Zone 1, the receptor is conservatively assumed to be the boundary between Zone 1 and the remainder of the site.

5.2 Risk Assessment Methodology

Due to the remediation and reinstatement of soil material below typical groundwater levels at the site, the following levels of assessment will be used to conservatively assess the risks to controlled waters:

- Level 1: Used to predict the worst case porewater (leachate) concentration from the soil material concentrations based on fundamental properties of the soil material (porosity and bulk density) and contaminants (Henry's Law constant and soil/water partition coefficient)
- Level 3 (Groundwater): This level of assessment (Level 3a in Consim) will be used to model the risks to receptors from the range of groundwater concentrations modelled by the Level 1 assessment.

The methodology was discussed in detail in VertaseFLI 2011 (Reference 2) and makes the following conservative assumptions:

- There is no attenuation of the contaminants as there is considered to be no unsaturated zone;
- There is no dilution of the groundwater/leachate concentrations in the aquifer; and
- The Level 3 assessment assumes a non declining contaminant source.

A flow chart outlining the methodology is presented in Appendix G.

5.3 Assessment of CoC Distribution

5.3.1 Zoning of Reinstated Soil Materials

The distribution of each CoC in the reinstated soils has been assessed and zoned based on the locations of reinstated remediated treatment beds for both the Type A and Type B soils (detailed in the VertaseFLI completion report, Reference 7). The zoning is based on the presence of the CoC in 22 m grid squares used to map the reinstated soils (see Drawing D907_07A) and will conservatively assume that the CoC is present across the entire grid square.

5.3.2 Deriving Probability Density Functions

Probability density functions (PDFs) have been developed for each CoC in each zone based on the range of CoC concentrations in soil material. As a conservative assumption, PDFs were developed based only on reinstated soil from treatment beds that recorded elevated concentrations of the CoC following remediation. It should be noted that typically, a range of CoC concentrations were recorded in these treatment beds which including non-detects. For the purposes of developing PDFs, **all** non-detects in each zone were conservatively set to the limit of detection and treated as a single value.

Where appropriate, selection of the PDF mid-point was based on a visual assessment of the PDF and supported with calculation of the median value of the concentration range.

5.4 Level 1 Assessment

The following equation is used in Level 1 assessments to predict porewater (leachate) concentration from soil source concentrations in both ConSim (Reference 11) and the Environment Remedial Targets Methodology (Reference 12):

$$C_l = C_s / [K_d + (\theta_w + \theta_s.H)/\rho_s]$$

Where
C_l = Leachate concentration (mg/l)
C_s = Soil source concentration (mg/l)
K_d = partition coefficient (ml/g)
Θ_w = Water filled porosity of soil (fraction)
Θ_s = air filled porosity of soil (fraction)
H = Henry's Law constant (dimensionless); and
ρ_s = soil dry bulk density

For the purposes of the risk assessment, an Excel spreadsheet has been set up for each CoC to undertake probabilistic Monte-Carlo analysis using the Level 1 equation above so that the variability in contaminant concentrations in each zone, and the soil and contaminant properties can be taken into account. Whilst both applications use the same equations the use of an Excel spreadsheet has the principal advantage over ConSim in this situation is that the result of each iteration can be viewed and the final range and distribution of predicted leachate concentrations fully understood. Being able to fully assess the outputs of the Level 1 assessment has allowed a representative and appropriate PDF of predicted leachate concentrations for each CoC in each identified zone to be derived and used in the Level 3 groundwater assessment.

The selection of contaminant and aquifer parameters is discussed in Section 6.

5.5 Level 3 (Groundwater) Assessment

The Level 3 Assessment has been undertaken using the Level 3a option in Consim. A model has been produced for each CoC where any 95th percentile of the predicted leachate concentration exceeded the appropriate screening criteria. Each zone has been modelled as a separate source for each CoC using the leachate concentration PDFs derived in the Level 1 assessment as source inputs.

All groundwater flow has been modelled through the reinstated Type B material. The predicted 95th percentile worst case concentration (at each receptor location was then compared with the appropriate water quality standard to assess the risks to the Riddy Brook.

Type A Material

Considering the discontinuous deposits of natural Type A material and the negligable groundwater observed in these deposits during trial pit and borehole excavations, negligable groundwater flow is anticipated in this material. The reinstated remediated Type A material is very limited in extent and thickness and is discontinuous across the site and therefore no groundwater flow is anticipated in this material.

Based on the limited extent and thickness of the reinstated Type A material and the proposed 1 m thick cover layer, the volume of leachate generated from the reinstated Type A material is likely to be very low. Groundwater in the south of the site is predominantly limited to the Type B and given the low permeability of the Type B material (see section

4.3.4, upward migration of contaminants into the Type A material is considered highly unlikely.

Given the above, the impact of leachate from the reinstated Type A material on the groundwater and therefore risks to receptors is likely to be minimal compared with the leachate from the Type B material. However, for completeness and to validate the risks from the potential leachate from reinstated Type A material, a Level 3 assessment has also been undertaken for all CoCs using the same method as described above assuming flow through the Type B material.

Type C Material

As stated in Section 4.3.4.4, the Type C material (Gault Formation) is considered to be an aquiclude and has therefore not been considered for modelling.

6.0 Model Inputs

6.1 Contaminants

A total of 23 contaminants of concern (CoCs) were identified by Atkins (2006 and 2007) for additional risk assessment as listed in Table 4 below. In addition, nine contaminants not previously identified (CNPIs) were identified at the site that exceeded the Atkins preliminary remedial targets with respect to controlled waters (VertaseFLI March 2012 (Reference 6)), these nine CNPIs are also listed in Table 4.

Table 4: Contaminants of Concern

Contaminant	Contaminant Type
Dicamba	Pesticide/Herbicide
MCPA	Pesticide/Herbicide
Mecoprop	Pesticide/Herbicide
Bis(2-chloroethyl)ether	Chlorinated Hydrocarbon (Breakdown product)
Schradan	Pesticide/Herbicide
Dichlorprop	Pesticide/Herbicide
4,6-Dinitro-o-cresol (4,6DNOC)	Pesticide/Herbicide
1,2-Dichloroethane	Chlorinated Hydrocarbon (Breakdown product)
Ethofumesate	Pesticide/Herbicide
Cyclohexanone	Aromatic Hydrocarbon (Solvent)
Hempa	Pesticide/Herbicide
Vinyl chloride	Chlorinated Hydrocarbon (Breakdown Product)
Phenol	Aromatic Hydrocarbon (Breakdown Product)
Trichloroethene	Chlorinated Hydrocarbon (Breakdown Product)
Tetrachloroethene	Chlorinated Hydrocarbon (Breakdown Product)
Cis 1,2-Dichloroethene	Chlorinated Hydrocarbon (Breakdown Product)
1,2-Dichorobenzene	Chlorinated Aromatic Hydrocarbon (Breakdown Product)
Toluene	Aromatic Hydrocarbon (Process Chemical – BTEX)
Simazine	Pesticide/Herbicide
Dimefox	Pesticide/Herbicide
2,4,6-Trichlorophenol	Chlorinated Aromatic Hydrocarbon (Breakdown Product)

Xylene	Aromatic Hydrocarbon (Process Chemical – BTEX)
4-chloro-2-methylphenol	Chlorinated Aromatic Hydrocarbon (Process Chemical and Breakdown Product) (CNPI)
Dichloro methylphenol (all isomers)	Phenolic compounds/ Breakdown Product (CNPI)
Trichlorotoluene (all isomers)	Chlorinated Hydrocarbon (Production chemical/breakdown product) (CNPI)
2,6-bis (1-methylpropylphenol)	Phenolic compounds/breakdown product (CNPI)
Dimeythl Nitroanaline (all isomers)	Chlorinated Hydrocarbon /Breakdown product (CNPI)
Chlorazine	Pesticide/Herbicide (CNPI)
Dinoseb	Pesticide/Herbicide (CNPI)
1,2-bis(2,4,6-trichloropenoxy)ethane	Chlorinated Hydrocarbon/breakdown product (CNPI)
Oxathiane 4, 4-dioxide	Hydrocarbon/Breakdown product (CNPI)
1-(2-chloroethloxy)-2-(o-tolyoxy)-ethane	Chlorinated Hydrocarbon/Breakdown Product (CNPI)

Of these CoCs, cyclohexanone, dimethyl nitroanaline, chlorazine or oxathiane 4, 4-dioxide were not detected in the reinstated remediated soils and are therefore not considered further in this report.

As discussed in Section 5, the final range of CoC concentrations present in the reinstated remediated soil material distribution has been used to develop the final risk assessment model for each contaminant. Each contaminant has been zoned based on the distribution of treatment beds and the corresponding CoC concentrations used to derive representative PDFS for the Type A and Type B material.

6.1.1 CoC Distribution and Concentrations

As discussed in Section 5, the site has been zoned for each CoC based on the distribution of the reinstated soil material and the residual CoC concentrations remaining in the remediated soils. For each zone of contamination, the final concentrations recorded in all reinstated soils from each treatment bed have been assessed and appropriate PDFs developed. The zoning of each CoC and the selected soil concentration PDFs for each of the zones are presented in Appendix H and Appendix I respectively. Source data is presented Appendix P (Data CD).

6.2 Receptors

Receptors locations have been placed at regular intervals along the western bank of the Riddy Brook (See drawing D907_227, Appendix A) to confirm that the selected screening criteria are not exceeded on any stretch of the water course.

Where Zone 1 has been reinstated with sand and gravel, the boundary between Zone 1 and Zone 2S/2N has been conservatively assumed to be the receptor and receptor locations have been placed at regular intervals along the Zone1 boundary.

6.3 Selection of Screening Criteria

Since the start of the remedial works and risk assessment process, new screening criteria have been published for a number of the CoCs. Therefore, the screening criteria used to assess the risks to the Riddy Brook have been reviewed and where appropriate updated.

To assess the risks to the Riddy Brook, Environmental Quality Standards (EQS) values for freshwater have been used where available. Preference has been given to UK EQS values followed by European EQS values and then EQS values from other regulatory frameworks. It should be noted that both UK and European EQSs are derived following the same methodology set out in the Water Framework Directive using published ecological toxicity data and therefore European EQSs are considered to be protective of water quality to the UK.

Where appropriate EQS values are not available UK Drinking Water Standards (DWS) are used, and where neither is available, detection limit is used.

6.3.1 Derivation of Pesticide Screening Criteria

For a number of pesticide CoCs such as Schradan, Hempa, Dimefox and 4,6 DNOC no published EQS is available and the only screening value is the UK DWS for pesticides (other than Aldrin, Dieldrin, Heptachlor and Heptachlor epoxide) is 0.1 ug/l. The DWS for pesticides is not a health based standard but was determined by the European Drinking Water Directive in 1980 and set at typical laboratory detection limits for pesticides in order to prevent the occurrence of pesticides in drinking water (Defra, Reference 13).

Given the lack of scientific basis of the DWS it is considered appropriate to derive Predicted No Effect Concentrations (PNECs) for the CoCs where appropriate ecological toxicity data for freshwater receptors is available. Derivation of the PNECs follows the methodology set out in UK Technical Advisory Group on the Water Framework Directive document ‘Proposals for Environmental Quality Standards for Annex VIII Substances. Final (SR1 –

2007), the same methodology used to derived EQSs. Full details of the derivation of the screening criteria for Schradan and Hempa are presented in Appendix J.

In the absence of any appropriate ecological toxicity data, the DWS screening value of 0.1 ug/l has been used for 2,4,6 Dinitro-o-cresol and Dimefox.

6.3.2 Dichlorprop

The Swedish Chemical Agency has derived an EQS of 10 ug/l for dichlorprop-p (Reference 16), an isomer of dichlorprop. Currently no EQS is available for dichlorprop. It is considered likely that the EQS for dichlorprop-p will also be protective of fresh water for dichlorprop. However, given the absence of specific EQS for dichlorprop, it has been conservatively screened against the DWS for pesticides of 0.1 ug/l.

6.3.3 Selected Screening Criteria

The selected water quality screening criteria are presented in Table 5.

Table 5 – CoC/CNPI Selected Water Quality Screening Criteria

Contaminant	Screening Criteria (ug/l)	Source	Justification
1,2-Dichloroethane	10	EQS Freshwater	
Dicamba	10	Canadian EQS for Fresh Water	Water quality guideline for the protection of aquatic life more appropriate with respect to Riddy Brook than UK Pesticide DWS
Schradan	0.35	VertaseFLI derived PNEC	
Bis(2-chloroethyl)ether	1	Limit of Detection	No other screening value available
Ethofumesate	30	Swedish Freshwater EQS	Derived using EU recommended methodology (as used for UK EQS) (Reference 16). Considered more appropriate with respect to Riddy Brook than UK Pesticide DWS
Trichloroethene	10	UK DWS	
Tetrachloroethene	10	UK DWS	
Cis 1,2, Dichloroethene	6.7	Dutch Freshwater Maximum Permissible Concentration	European Freshwater quality guideline (Reference 26) considered appropriate with respect to Riddy Brook – no other guidance values available
Vinyl Chloride	0.5	UK DWS	
Hempa	350	VertaseFLI derived PNEC	See Appendix E

1,2 Dichlorobenzene	0.7	Canadian Freshwater EQS	
2,4,6 Trichlorophenol	2	Limit of Detection	No other screening value available
4,6 Dinitro-o-cresol	0.1	UK DWS	Limit for other Pesticides
4-Chloro-2 methylphenol	50	European Union Risk Assessment Aquatic PNEC	PNEC derived using EU recommended methodology (as used for UK EQS) (Reference 17)
Dichlorprop	0.1	UK DWS	Limit for other Pesticides
Dimefox	0.1	UK DWS	Limit for pesticides other than Aldrin, Dieldrin, Heptachlor and Heptachlor epoxide. No alternative value available
MCPA	12	Freshwater EQS	UK Non-statutory EQS listed by Environment Agency as used by UK regulatory authorities (Reference 25)
Mecoprop	18	Annual mean Freshwater EQS	Environment Agency – River Basin District Typography, Standards and Groundwater Threshold Values (Reference 15)
Phenol	7.7	Annual mean Freshwater EQS	Environment Agency – River Basin District Typography, Standards and Groundwater Threshold Values (Reference 15)
Simazine	1	Freshwater EQS	Environment Agency – River Basin District Typography, Standards and Groundwater Threshold Values (Reference 15)
Toluene	50	EQS Freshwater	
Xylene	30	EQS Freshwater	
Dichloro methylphenol	1	Limit of Detection	No other screening criteria available
Trichlorotoluene	1	Limit of Detection	No other screening criteria available
2,6-bis (1-methylpropylphenol)	1	Limit of Detection	No other screening criteria available
Dinoseb	0.29	European Chemical Agency PNEC	PNEC derived using EU recommended methodology (as used for UK EQS) (Reference 18)
1,2-bis(2,4,6-trichlorophenoxy)ethane	0.1	UK DWS	Limit for pesticides other than Aldrin, Dieldrin, Heptachlor and Heptachlor epoxide
1-(2-chloroethoxy)-2-(o-tolyloxy)-ethane	1	Limit of Detection	No other screening criteria available

6.4 Soil Source Parameters – Level 1 Assessment

The Level 1 assessment (see Section 5.3) requires the following soil parameters

- Dry Bulk Density;
- Fraction of Organic Carbon (FOC); and
- Total soil Porosity – Calculated from soil moisture content, dry density and particle density.

Due to the relatively small volumes of the Type A material reinstated at the site, site specific data, appropriate values from previous investigations or conservative literature values have been used in the Level 1 assessment. For the Type B material, site specific data has been obtained for the reinstated soil material. Appropriate PDFs have been selected based on the histogram of the data as described below. The inputs are summarised in Table 6.

6.4.1 Dry Bulk Density

Dry bulk density values for the Type A material were obtained from geotechnical testing. Only two values were obtained (1.77 and 1.88 g/cm^3) and therefore a uniform distribution using the Consim suggested range for a sand and gravel was conservatively used in the model.

For the type B material, over 250 *in-situ* measurements of dry bulk density were recorded in the reinstated soil material with a nuclear density gauge. Based on a histogram of the results (see Appendix L), a normal distribution was selected with an average value of 1.8 g/cm^3 and a standard deviation of 0.065.

6.4.2 Fraction of Organic Carbon

Due to the relatively small volumes Type A material remediated and reinstated, only limited testing of Type A material was undertaken during remediation and FOC values were not obtained. Therefore, FOC for the Type A material is based on the range of site specific values obtained by Enviros and Atkins (References 4 and 5) for sand and gravel, and granular made ground. It should be noted that remediation works included the addition of mushroom compost to material and therefore, the FOC values are likely to under represent the FOC values in the reinstated Type A material. A total of FOC 34 values were obtained by Atkins and Enviros and based on the histograms of the FOC values and log FOC values (see Appendix K) a loguniform PDF gave the best fit to the FOC data. One value (17%)

was significantly outside the range of all other values (0.72 to 5.8 %) and was therefore discounted as an outlier.

FOC was been obtained for 33 soil samples taken from the remediated Type B material test beds. Histograms of the FOC values and log values were plotted (see Appendix L), and based on these it was considered that a logtriangular PDF gave the best fit to the data with minimum and maximum values of 0.75 and 4.8 % respectively and a mean value of 1.78%. The FOC value of 0.28 was discounted as based on assessment of both histograms it was outside the range of the other 32 FOC values.

6.4.3 Soil Moisture Content

Type A Material – Forty five samples of Type A material were tested for moisture content. Based on the histogram of the data (presented in Appendix K) a normal distribution based on an average value of 10.33 % with a standard deviation of 2.95 was selected.

Type B Material – Over 250 *in-situ* measurements were taken of the moisture content of the Type B material with a nuclear density gauge following reinstatement. The histogram of the results (Appendix L) shows a normal distribution, with a average value of 17.5 % and a standard deviation of 2.3.

6.4.4 Particle Density

Geotechnical testing of 29 samples the Type B material (presented in Appendix P) indicated a particle density between 2.54 and 2.75 g/cm^3. The PDF (see Appendix L) of the results indicated a typical particle density of 2.73 g/cm^3.

For the Type A material, at the time of writing no testing of particle density testing had been undertaken and a value of 2.78 g/cm^3 was selected based on the recommended value in EA Remedial Targets Methodology and worksheet (Reference 12).

Table 6: Summary of ConSim Soil Source Inputs

Aquifer Property (unit)	PDF (Property value)	Source
Type A Soil Material		
Particle Density (g/cm^3)	Single (2.78)	Standard value taken from EA RTW
Dry bulk density (g/cm^3)	Uniform (1.37,1.81)	ConSim suggested range for gravelly sand
Moisture Content (%)	Normal (10.33,2.95)	Based on distribution of site specific data.
Fraction of Organic Carbon (%)	Loguniform (0.72,5.8)	Site specific values taken from Atkins and Enviros reports
Type B Soil Material		
Particle Density (g/cm^3)	Triangular (2.54,2.73,2.75)	Site specific *In-situ* data
Dry bulk density (g/cm^3)	Normal (1.8,0.065)	Site specific *In-situ* data
Moisture Content (%)	Normal (17.5,2.3)	Site specific *In-situ* data
Fraction of Organic Carbon (%)	Logtriangular (0.75,1.78,4.8)	Site specific data for Type B soil material

6.5 Selection of Aquifer Pathway Parameters – Level 3a Assessment

The reinstated Type A material was placed above the water table. Groundwater was not encountered within the natural sand and gravel remaining in the south of the site during intrusive investigations. The natural sand and gravel deposits that remain on the site (and are down hydraulic gradient of the reinstated soils) are discontinuous across the site and generally present above groundwater levels with the exception of relatively isolated deeper sand and gravel deposits (see drawing D907_236). The Type C material is considered to be an aquiclude

Therefore, the modelling of contaminant migration in the Level 3a assessment as been undertaken for the Type B soils only. For the Level 3a assessment, the following hydrogeological parameters are required:

- Aquifer Thickness;

- Dry Bulk Density;
- Mixing Zone Thickness;
- Hydraulic Conductivity;
- Effective Porosity;
- Hydraulic Gradient;
- Groundwater Flow direction;
- Longitudinal and Lateral Dispersivity; and
- Fraction of Organic Carbon.

6.5.1 Aquifer Thickness

Post remediaition, the thickness of the Type B material was (where proved) between 0.5 and 3.75 m thick with a typical thickness of 2 m. (see Drawing D907_220, Appendix A). A histogram summarising the thickness of the reinstated Type B material is presented in Appendix L. However, thicker deposits of the Type B material were present in the south of the site including the borrow pit area in grid squares D22 – D25, - F22-F25 where Type B material was typically up to 5 m thick. A borehole detailed in Atkins (2006) was drilled in the far southeast corner of the site (approximately gridsquare D26) which identified deposits of WMMCF 7.5 m thick, however, this borehole is up hydraulic gradient of the remediated site and therefore not considered representative of conditions with respect to modelling contaminant movement. Therefore, based on the available appropriate data, a triangular PDF has been selected to model the aquifer with minimum and maximum thicknesses of 1 and 5 m and a typical thickness of 2m.

6.5.2 Dry Bulk Density

The dry bulk density of the reinstated Type B material is discussed in section 6.4.1.

6.5.3 Mixing Zone Thickness

The mixing zone thickness has been taken to be equal to the aquifer thickness (see 6.5.1).

6.5.4 Hydraulic Conductivity

111 *in-situ* permeability measurements were made of *in-situ* Type B material over the entire site. Measurements were made in remediated Type B material at a range of depths and locations during reinstatement; and in natural un-disturbed deposits at different levels

during trial pit investigations. The test locations are shown in drawing D907_238, results are presented in Appendix P and summarised as PDFs in Appendix L.

The range of permeabilites in the reinstated Type B was between 1.6 x 10^{-10} and 7.1 x 10^{-6} ms^{-1} with a median value of 2.2 x 10^{-7} ms^{-1}. To provide an indication of variation of permeability/hydraulic conductivity in the Type B material with depth and across the site, the following histograms have also been plotted:

- Zone 1 – PDF = 2 x 10^{-10}, 1.4 x 10^{-7}, 3.2 x 10^{-6} ms^{-1};
- Zone 2 – PDF = 2.3 x 10^{-10}, 2.2 x 10^{-7}, 6.7 x 10^{-6} ms^{-1};
- Zone 3 – PDF = 1.6 x 10^{-10}, 4.5 x 10^{-7} , 7.1 x 10^{-6} ms^{-1};
- 0 – 2 m bgl – PDF = 2 x 10^{-10}, 1.5 x 10^{-7}, 6.7 x 10^{-6} ms^{-1}; and
- Below 2 m bgl – PDF = 1.6 x 10^{-10}, 4.75 x 10^{-7}, 7.1 x 10^{-6} ms^{-1}.

All PDFs listed above are logtriangular, it should be noted that two values that were recorded in the range 10^{-12} ms^{-1} were not considered representative and therefore conservatively discounted. The histograms are presented in Appendix L and give very similar results to the histogram for all 111 permeability values. Therefore, it is considered that the histogram derived for all site data is representative and appropriate for use in the model, the best fit for the histogram was a logtriangular PDF with minimum and maximum values of 1.6 x 10^{-10} and 7.1 x 10^{-6} ms^{-1} with a mid-point (median) of 2.2 x 10^{-7} ms^{-1}.

6.5.5 Effective Porosity

Reinstated soil material at the site has been compacted to a minimum of 95% MDD. Laboratory compaction tests had been undertaken on Type B material (presented in Appendix P) which gives an indication of the minimum air voids percentage which is taken as equal to the effective porosity. The compaction testing indicated that for the upper levels of compaction achievable in the Type B soil material, an air voids percentage of 3 to 7 % would be representative. Therefore, a uniform PDF between 3 and 7% effective porosity has been assumed for the reinstated soil material in the model.

6.5.6 Hydraulic Gradient

As discussed 4.3.4, following the reinstatement of remediated soil material, and subsequent monitoring, a groundwater low is present in the north of the site (see drawings D907_223A, and D907_225). This low may represent a region of groundwater flow towards the centre of the low (and away from the Riddy Brook) or an area of effective negligable flow such that groundwater on site will flow around the negligable flow area. As shown in Drawing D907_236, groundwater levels across the majority of the site generally suggest flow away from the Riddy Brook

However, the potential for recharge in the Type B material over time and a subsequent change of flow direction towards the Riddy Brook cannot be completely discounted at this stage. It is also important to note that groundwater flow in the south of the site still appears to flow towards the Riddy Brook. Therefore, the hydraulic gradient for use in the model has been assessed assuming that the groundwater low is not present and that groundwater flow is towards the Riddy Brook (based on groundwater levels recorded outside of the groundwater low).

Based on the above assumption, hydraulic gradients have been calculated across the site using the groundwater contour plots from all monitoring rounds following completion of remediation (Drawings D907_223A and D907_225). Measurements have been made across the entire site (in the direction of flow as indicated by the contours) to determine the typical range of hydraulic gradients, averaged across the site to account for localised variations in gradient

The measured hydraulic gradients are typically between 0.005 and 0.008 which is broadly similar to the hydraulic gradients recorded at the waste water treatment plant to the east of the A10 (0.007 to 0.009) from the Atkins 2006 groundwater contours (Reference 5).

6.5.7 Groundwater Flow Direction

It should be noted, that the groundwater monitoring undertaken since completion of the remedial works indicates the following flow directions at the site:

- In the north of the site a groundwater low is present (centered around borehole J10), which may (as previously discussed) be indicative of a zone of flow towards the centre of the site or an effective no-flow zone;
- In the south of the site groundwater flow is predominantly towards the northeast, towards the Riddy Brook and the River Cam. In the far southeast of the site, groundwater contours appear to show a more easterly flow, although it is not possible to verify this outside the site boundary; and
- In the northwest corner of the site, groundwater flow is in a northerly direction towards the River Cam and Riddy Brook/River Cam confluence.

For the purposes of modelling, groundwater flow has been conservatively assumed to be towards the northeast. This flow direction, ignores the identified groundwater low and results in the shortest flow paths from the remediated soils to the closest receptor (the Riddy Brook) compared to more northerly or easterly flows.

6.5.8 Dispersivity

Based on the guidance given in the Environment Agency Remedial Targets methodology (References 12) longitudinal dispersivity is assumed to be 10% of the contaminant pathway and lateral dispersivity assumed to be 1%.

Based on the most conservative pathway length, the minimum distance from the buffer zone to Riddy Brook (1 to 2 m), uniform PDF has been used for both longitudinal and lateral dispersivity with values in the range 0.1 to 0.2 m and 0.01 to 0.02 m respectively.

6.5.9 Fraction of Organic Carbon

See section 6.4.2.

6.5.10 Summary

The aquifer pathway parameters are summarised in Table 7 below.

Table 7: Summary of ConSim Aquifer Inputs

Aquifer Property (unit)	PDF (Property value)	Source
Aquifer thickness (m)	Triangular (1.0,2.0,5.0)	Thickness of reinstated Type B material
Dry bulk density (g/cm^3)	Normal (1.8,0.065)	Site specific *In-situ* data
Mixing Zone thickness (m)	Triangular (1.0,2.0,5.0)	Assumed same as aquifer thickness
Hydraulic conductivity (m/s)	Logtriangular (1.e-10, 2.2e-7,7.1e-6)	Site specific *in-situ* permeability testing
Effective Porosity (%)	Uniform (3,7)	Conservative assumption based on low permeability material and results of laboratory testing
Hydraulic gradient	Uniform (0.005,0.008)	Results of groundwater monitoring conservatively discounting the groundwater low in the north of the site

Aquifer Property (unit)	PDF (Property value)	Source
Groundwater flow direction (degrees)	Single (45°)	Based on post remediation groundwater modelling and conservative
Longitudinal Dispersivity (m)	Uniform (0.1,0.2)	10% of distance from Zone 1 to Riddy Brook
Lateral Dispersivity (m)	Uniform (0.01,0.02)	30% of Longitudinal Dispersivity
Fraction of Organic Carbon (%)	Logtriangular (0.75,1.78,4.8)	Site specific data for Type B soil material

6.6 Model Settings

6.6.1 Model Iterations and Time Slices

Both Level 1 and Level 3 models have been run with 1001 iterations. The Level 3a model has been run with the following time slices: 1; 2; 5; 10; 25; 50; 100; 250; 500; 1,000; and 10,000 years.

6.6.2 Level 3a Model Correlations

Several aquifer parameters are directly related to other aquifer parameters. ConSim allows these relationships to be included in the model by enabling the user to set correlations between parameters. Correlations can be set between -1 to +1 where +1 is a total correlation, -1 is an inverse correlation and 0 is equal to no correlation. For the purposes of the model, the following correlations have been set:

- Longitudinal and Lateral dispersivity are both functions of the length of the contaminant pathway with Longitudinal dispersivity set at 10% of the contaminant pathway and lateral dispersivity 30% of the longitudinal dispersivity. Therefore a correlation of 1 between the two values has been selected;
- Hydraulic gradient and hydraulic conductivity are inversely proportional. However, to allow for some natural variation in aquifer properties a correlation of -0.5 was selected; and
- Effective porosity is generally proportional to hydraulic conductivity. Therefore, to model this relationship, but allow for natural variations in the aquifer properties a correlation between the two parameters of 0.5 was selected.

6.6.3 Simulation of Biodegradation

Biodegradation is typically slower in groundwater systems where contaminants become sorbed to the aquifer matrix (no degradation is assumed to occur to sorbed contaminants) compared to water only systems. In modelling the degradation of contaminants, ConSim gives two options:

- Simulate degradation in dissolved phase only; and
- Simulate degradation in dissolved and sorbed phases.

As stated in the ConSim help file (Reference 11), these options distinguish between degradation rates measures in simple aquatic systems (dissolved phase only) and those measured in groundwater systems (dissolved and sorbed phases). Where dissolved phase only is selected, a retardation factor is applied to the degradation rate to simulate the slower degradation rate in groundwater due to contaminants sorbing to the soil.

The selected aquifer half lives used in the models (discussed in Section 6.7) are for groundwater systems and therefore the option to simulate degradation in dissolved and sorbed phases has been used.

6.7 Contaminant Parameters

For the purposes of the risk assessment four physical-chemical properties were required for each CoC:

- Soil Organic Carbon to Water Partition Coefficient - K_{oc} (ml/g);
- Henry's Law Constant (Dimensionless);
- Biodegradation half life in groundwater (days or years); and
- Maximum solubility in water (mg/l).

6.7.1 Data Sources

Together with chemical specific documents, key sources of physical chemical data used to included:

- Compilation of data for priority organic pollutants for derivation of Soil Guideline Values, Science Report SC050021/SR7, Environment Agency, 2008 (Reference 20);

- Physical – Chemical Properties and Environmental Fate for Organic Chemicals, 2nd Edition, Mackay et al, 2006 (Reference 19)*;
- Environmental Degradation Rates, Howard *et al*, 1991, Lewis Publishers (Reference 21);
- Handbook of Environmental Fate and Exposure Data for Organic Chemicals, Volume 1 – Large Production and Priority Pollutants, Howard *et al*, 1989, Lewis Publishers *;
- Handbook of Environmental Fate and Exposure Data for Organic Chemicals, Volume 2 – Solvents, Howard *et al*, 1990, Lewis Publishers *;
- Handbook of Environmental Fate and Exposure Data for Organic Chemicals, Volume 3 – Pesticides, Howard *et al*, 1991, Lewis Publishers *;
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- RCRA Delisting Technical Support Document – Appendix A Chemical Specific Data, United States Environmental Protection Agency, RCRA Delisting Team, October 2008; and
- Regional Screening Levels – Chemical Specific Parameters, United States Environmental Protection Agency website – http://www.epa.gov/region9/superfund/prg/, May 2012 (accessed June 12 2012).

It should be noted that information sources marked * were listed as information sources in the EA document 'Compilation of data for priority organic pollutants for derivation of Soil Guideline Values, Science Report SC050021/SR7' listed above.

6.7.2 Selection of Parameters

In the review of literature values for physical chemical parameters, selection of parameters for use in the models was based on the following preferences:

- Experimental data was given preference over estimated values;
- Environment Agency recommended values, and/or UK and European specific parameters (if available); and
- Where data sources were limited to estimates only, the estimates derived using the most recent recommended approach from reputable data sources (Environment Agency or US EPA) were selected.
- Where no appropriate data was available, property estimations were made using the US EPA Estimations Programmes Interface (EPI) Suite software.

Where sufficient values were available, the range of literature values was assessed using histograms to find the most appropriate PDF and the best fit range of values. For a number of the CoCs, several literature values were significantly higher or lower (generally by orders of magnitude) than the typical range and distribution of values and the Environment Agency recommended values (where available) (Reference 20). These outliers were not considered to be appropriate for use in the PDFs as their inclusion would have significantly skewed the selected PDF such that it would not have been representative of the typical range of values.

Histograms and Justifications for the selection of physical chemical parameters are presented in Appendix M.

6.7.2.1 Aquifer Half Lives

The most conservative biodegradation half lives in groundwater systems were used in the model, typically these were for anaerobic biodegradation but for compounds such as chlorinated solvents these were aerobic biodegradation. Where more than one range of values were available, the two most conservative values in any of the ranges was used as the input.

Very limited sources of contaminant half life data in groundwater systems or water were available and for a number of CoCs, no literature values for half life in water were available. In these cases a conservative anaerobic half life range of 5 to 10 years was assumed.

It should be noted that for ethofumesate, the July 2011 risk assessment assumed a half life range of 5 to 10 years. However, a further review of information provided groundwater half life values of 125 to 285 days. It was unclear if these values were for aerobic or anaerobic degradation and in accordance with the methodology set out in Howard *et al* (1991) (Reference 21) the half lives were conservatively multiplied by a factor of 4 to give a half life range of 500 to 1140 days.

6.7.2.2 Calculating K_d

The values for K_{oc} are multiplied by the fraction of organic carbon to derive K_d, the soil-water partition coefficient (References 11 and 12).

$$K_d = K_{oc} \times FOC$$

K_d was therefore estimated using PDFs of both the K_{oc} and FOC detailed in the sections above.

Non-Polar Organic Chemicals

It should be noted, that the above equation only applies to non-polar organic chemicals. The majority of the 23 CoCs are non-polar, however, phenol, 2,4,6 trichlorophenol, 4,6 Dinitro-o-cresol and 4, chloro-2,methylphenol are polar organic compounds.

For polar (or ionic) organic compounds, values of K_{oc} vary with pH. The recommended equation to calculate K_d given in the EA Remedial Targets Methodology (Reference 10) is as follows:

$$K_d = \{K_{oc,n} \text{ x } (1 + 10^{pH\text{-}pKa})^{-1} + K_{oc,i} \text{ x } (1 - (1 + 10^{pH\text{-}pKa})^{-1})\} \text{ x FOC}$$

Therefore $K_{oc} = K_{oc,n} \text{ x } (1 + 10^{pH\text{-}pKa})^{-1} + K_{oc,i} \text{ x } (1 - (1 + 10^{pH\text{-}pKa})^{-1})$

Where $K_{oc,n} = K_{oc}$ for neutral species;

$K_{oc,i} = K_{oc}$ for ionised species;

pH = pH value; and

pKa = acid dissociation constant.

However, there is no indication of neutral or ionised species in the available literature values of K_{oc}. Therefore, it has been assumed that the literature values represent the total K_{oc} ($K_{oc,n}$ and $K_{oc,i}$) and the standard calculation for K_d can be used.

It should also be noted that for both phenol (Reference 22) and 4,chloro-2,methylphenol, at near neutral pH, based upon the acid dissociation constant, over 99% of the ions present are neutral and therefore the compounds will behave as non-polar compounds.

Hempa, Schradan and Bis(2-chloroethyl)ether in Type B Material

For hempa, schradan and Bis(2-chloroethyl)ether available literature values for K_{oc} were very limited and comprised estimated values only. A large volume of soil analysis and leachate analysis was undertaken on Type B samples for a limited number of CoCs at the site and therefore as an alternative to the calculating K_d using FOC and K_{oc} literature values, based on the Level 1 equation (see Section 5.3), site specific values of K_d were calculated for each sample using:

$$K_{d\,+} (\theta_w + \theta_s.H)/\rho_s = \text{ Soil concentration } (C_s) \text{ / Leachate concentration } (C_l)$$

It should be noted that given the low values of θ_w , θ_s, and H, and to simplify the calculations, $(\theta_w + \theta_s.H)/\rho_s$ has been assumed to be zero.

The results are presented in Appendix N together with histograms of the calculated K_d for to enable PDFs for use in the risk assessment to be generated. Conservatively, soil samples that recorded elevated CoC concentrations in soil but leachate concentrations below detection limits were discounted from the K_d calculations. However, for hempa and schradan to calculate K_d where soil concentrations were below detection limit but elevated CoCs were present in leachate, a soil concentration of half the detection limit was assumed, Additionally, calculated K_d values significantly greater than the typical ranges were discounted.

It should be noted that literature values for Dimefox and a number of the CNPIs were also limited to estimates of $K_{oc.}$ However due to the limited amounts of these CoCs identified at the site, it was not possible to derived site specifc K_d ranges and therefore the literature values have been taken forward in the model. Insufficient data was also available from the Type A material to derive site specific K_d for any CoC and therefore literature values have been used in the assessment of all CoCs present within the Type A.

6.8 Summary of Physical Chemical Properties used in Model

The selected CoC parameters are presented in Appendix M together with justification for the selection of appropriate PDFs. The literature values used to derive the histograms are presented in Appendix P. The chemical parameters are summarised in Table 8 below.

Table 8 - Contaminant Physical-chemical Properties

Contaminant	Parameter	Unit	PDF	Min	Most Likely	Max	S/D
1,2-Dichloroethane	K_{oc}	ml/g	Uniform	11.48	~	76	~
	Henry's Law constant	Unitless	Normal	0.049	~	~	0.025
	Aquifer Half Life	days	Uniform	400	~	720	~
	Maximum Solubility	mg/l	Uniform	8520	~	8680	~
Dicamba	K_{oc}	ml/g	Log triangular	0.1	2.5	42.65	~
	Henry's Law constant	Unitless	Uniform	8.87e-9	~	8.91e-8	~
	Aquifer Half Life	Days	Uniform	151	~	443	~
	Maximum Solubility	mg/l	Single	8310	~	~	~
Schradan	$K_d{}^{\#}$	ml/g	Logtriangular	0.1	11.2	123	~
	K_{oc}	ml/g	Uniform	4.12		20.12	
	Henry's Law constant	Unitless	Loguniform	2.58e-15	~	1.55e-8	~
	Aquifer Half Life	Days	Uniform	1825	~	3650	~
	Maximum Solubility	mg/l	Single	1e6	~	~	~

Contaminant	Parameter	Unit	PDF	Min	Most Likely	Max	S/D
Bis(2-chloroethyl)ether	$K_d^{\#}$	ml/g	Uniform	0.46	12.5	42.5	~
	K_{oc}	ml/g	Uniform	13.8	~	76	~
	Henry's Law constant	Unitless	Uniform	5.34e-4	~	8.71e-4	~
	Aquifer Half Life	Days	Uniform	360	~	720	~
	Maximum Solubility	mg/l	Uniform	10200	~	17200	~
Ethofumesate	K_{oc}	ml/g	Uniform	97	~	245	~
	Henry's Law constant	Unitless	Loguniform	2.74e-7	~	1.5e-6	~
	Aquifer Half Life	Days	Uniform	500	~	1140	~
	Maximum Solubility	mg/l	Single	50	~	~	~
Trichloroethene	K_{oc}	ml/g	Logtriangular	25.12	141	776.24	~
	Henry's Law constant	Unitless	Uniform	0.275	~	0.55	~
	Aquifer Half Life	Days	Uniform	321	~	1654	~
	Maximum Solubility	mg/l	Uniform	1180	~	1370	~
Tetrachloroethene	K_{oc}	ml/g	Triangular	50	296	500	~
	Henry's Law constant	Unitless	Triangular	0.1	0.68	1.21	~
	Aquifer Half Life	Days	Uniform	720	~	1653	~
	Maximum Solubility	mg/l	Triangular	200	225	230	~
Cis 1,2, Dichloroethene	K_{oc}	ml/g	Uniform	35.6	~	69.18	~
	Henry's Law constant	Unitless	LogTriangular	0.129	0.185	0.303	~
	Aquifer Half Life	Days	Uniform	720	~	2875	~
	Maximum Solubility	mg/l	Uniform	4900	~	6410	~
Vinyl Chloride	K_{oc}	ml/g	Triangular	2.99	16.6	57	~
	Henry's Law constant	Unitless	Triangular	0.184	1.085	2.29	~
	Aquifer Half Life	Days	Uniform	720	~	2875	~
	Maximum Solubility	mg/l	Uniform	2700	~	2760	~
Hempa	$K_d^{\#}$	ml/g	Logtriangular	0.17	7.94	50	~
	K_{oc}	ml/g	Uniform	10	~	16.65	~
	Henry's Law constant	Unitless	Single	8.17e-7	~	~	~
	Aquifer Half Life	Days	Uniform	1825	~	3650	~
	Maximum Solubility	mg/l	Single	1e6	~	~	~
1,2 Dichlorobenzene	K_{oc}	ml/g	Triangular	109	379	891	~
	Henry's Law constant	Unitless	LogTriangular	0.049	0.0786	0.151	~
	Aquifer Half Life	Days	Uniform	365	~	720	~

Contaminant	Parameter	Unit	PDF	Min	Most Likely	Max	S/D
	Maximum Solubility	mg/l	Triangular	125	133	156	~
2,4,6 Trichlorophenol	K_{oc}^{*}	ml/g	Logtriangular	109	1513	6918	~
	Henry's Law constant	Unitless	Triangular	5.32e-5	1.176e-4	3.18e-4	~
	Aquifer Half Life	Days	Uniform	169	~	1820	~
	Maximum Solubility	mg/l	Triangular	434	750	800	~
4,6 Dinitro-o-cresol	K_{oc}^{*}	ml/g	Triangular	100	257	602	~
	Henry's Law constant	Unitless	Loguniform	5.77e-5	~	1.74e-2	~
	Aquifer Half Life	Days	Uniform	28	~	42	~
	Maximum Solubility	mg/l	Uniform	150	~	290	~
4-Chloro-2 methylphenol	K_{oc}^{*}	ml/g	Uniform	124	~	700	~
	Henry's Law constant	Unitless	Uniform	4.44e-5	~	5.31e-5	~
	Aquifer Half Life	Days	Uniform	1825	~	3650	~
	Maximum Solubility	mg/l	Uniform	2300	~	4000	~
Dichlorprop	K_{oc}	ml/g	Uniform	34	~	170	~
	Henry's Law constant	Unitless	Loguniform	3.5e-9		1.09e-7	~
	Aquifer Half Life	Days	Uniform	824	~	1235	~
	Maximum Solubility	mg/l	Single	350	~	~	~
Dimefox	K_{oc}	ml/g	Uniform	1.91	~	8.33	~
	Henry's Law constant	Unitless	Uniform	8.17e-7	~	9.12e-7	~
	Aquifer Half Life	Days	Uniform	1825	~	3650	~
	Maximum Solubility	mg/l	Single	1e6	~	~	~
MCPA	K_{oc}	ml/g	Uniform	10	~	154	~
	Henry's Law constant	Unitless	Uniform	1.96e-8	~	1.96e-7	~
	Aquifer Half Life	Days	Uniform	28	~	182	~
	Maximum Solubility	mg/l	Uniform	630	~	835	~
Mecoprop	K_{oc}	ml/g	Uniform	5.3	~	68	~
	Henry's Law constant	Unitless	Loguniform	4.48e-9	~	7.44e-7	~
	Aquifer Half Life	Days	Uniform	28	~	280	~
	Maximum Solubility	mg/l	Uniform	620	~	895	~
Phenol	K_{oc}^{*}	ml/g	Triangular	10	30.19	46.77	~
	Henry's Law constant	Unitless	Uniform	1.29e-5	~	2.9e-5	~
	Aquifer Half Life	Days	Uniform	8	~	20	~
	Maximum Solubility	mg/l	Uniform	82800	~	91000	~

Contaminant	Parameter	Unit	PDF	Min	Most Likely	Max	S/D
Simazine	K_{oc}	ml/g	Triangular	39.81	140	421.7	~
	Henry's Law constant	Unitless	Loguniform	1.37e-8	~	1.37e-7	~
	Aquifer Half Life	Days	Uniform	75	~	174	~
	Maximum Solubility	mg/l	Uniform	3.5	~	7.4	~
Toluene	K_{oc}	ml/g	Triangular	38.9	160	269.15	~
	Henry's Law constant	Unitless	Triangular	0.193	0.266	0.273	~
	Aquifer Half Life	Days	Uniform	110	~	210	~
	Maximum Solubility	mg/l	Uniform	526	~	590	~
Xylenes	K_{oc}	ml/g	Triangular	74	250	616.59	~
	Henry's Law constant	Unitless	Triangular	0.12	0.25	0.636	~
	Aquifer Half Life	Days	Uniform	112	~	360	~
	Maximum Solubility	mg/l	Uniform	161	~	200	~
Dichloromethylphenol (all isomers)	K_{oc}	ml/g	Uniform	805	~	881	
	Henry's Law constant	Unitless	Uniform	1.39e-5	~	2.09e-5	
	Aquifer Half Life	Days	Uniform	1825	~	3650	
	Maximum Solubility	mg/l	Single	6730	~	~	
Trichlorotoluene	K_{oc}	ml/g	Uniform	295	~	832	
	Henry's Law constant	Unitless	Uniform	9.68e-3	~	1.06e-2	
	Aquifer Half Life	Days	Single	2.08e-3	~	~	
	Maximum Solubility	mg/l	Uniform	53	~	370	
2,6-bis(1-methylpropyl)phenol	K_{oc}	ml/g	loguniform	3,189	~	16,250	
	Henry's Law constant	Unitless	Single	1.53e-4	~	~	
	Aquifer Half Life	Days	Uniform	1825	~	3650	
	Maximum Solubility	mg/l	Single	1.8	~	~	
Dinoseb	K_{oc}	ml/g	logtriangular	30.4	124	2720	
	Henry's Law constant	Unitless	Loguniform	1.86e-5		2.06e-2	
	Aquifer Half Life	Days	Uniform	30	~	246	
	Maximum Solubility	mg/l	Uniform	50	~	52	
1,2-bis(2,4,6-trichlorophenoxy) ethane	K_{oc}	ml/g	loguniform	99,200	~	265,400	
	Henry's Law constant	Unitless	Loguniform	1.24e-8	~	1.24e-5	
	Aquifer Half Life	Days	Uniform	1825	~	3650	
	Maximum Solubility	mg/l	Single	6.35e-4	~	~	

Contaminant	Parameter	Unit	PDF	Min	Most Likely	Max	S/D
1-(2-chloroethoxy)-2-(o-tolyloxy)-ethane	K_{oc}	ml/g	Uniform	397.7	~	413.2	
	Henry's Law constant	Unitless	Uniform	1.17e-5	~	1.05e-4	
	Aquifer Half Life	Days	Uniform	1825	~	3650	
	Maximum Solubility	mg/l	Single	84.02	~	~	

* - Polar compound (see Section 6.7.2.2)

- Site specific values of K_d derived for Schradan and Hempa in Type B material

7.0 Risk Assessment

The following sections describe the outputs of the Level 1 and Level 3a models and the overall outcome of the risk assessment.

7.1 Level 1 Risk Assessments

Level 1 risk assessments were undertaken following the methodology set out in Section 5. Risk assessments were undertaken for the CoCs in both the Type A and Type B material. The models are presented in Appendix P and the range of predicted leachate concentrations summarised in Appendix O. The greatest 95th percentile value of predicted leachate concentrations for each CoC is compared with the selected screening criteria in Table 9 below.

Table 9 – Greatest 95th Percentile Predicted Leachate Concentrations

Contaminant	Screening Criteria (ug/l)	Greatest 95th Percentile Predicted Leachate Concentration (ug/l)	
		Type A	Type B
1,2-Dichloroethane	10	25	47
Dicamba	10	2,993	1,570
Schradan	0.35	8,642	503
Bis(2-chloroethyl)ether	1	5,720	2,780
Ethofumesate	30	1,424	2,524
Trichloroethene	10	16.8	986
Tetrachloroethene	10	1538	734
Cis 1,2, Dichloroethene	0.1	10.7	330
Vinyl Chloride	0.5	Not Present	49
Hempa	350	4,656	404
1,2 Dichlorobenzene	0.7	40.5	97
2,4,6 Trichlorophenol	2	566	638
4,6 Dinitro-o-cresol	0.1	Not Present	7,265
4-Chloro-2 methylphenol	50	4,850	1,417
Dichlorprop	0.1	249	388
Dimefox	0.1	Not Present	1,316
MCPA	12	3,960	4,253
Mecoprop	18	11,579	6,358
Phenol	7.7	Not present	481

		Greatest 95th Percentile Predicted Leachate Concentration (ug/l)	
Simazine	1	325	553
Toluene	50	134	492
Xylene	30	193	175
Dichloro methylphenol	1	44.3	891
Trichlorotoluene	1	446	2,062
2,6-bis (1-methylpropylphenol)	1	Not present	33
Dinoseb	0.29	Not present	1,887
1,2-bis(2,4,6-trichlorophenoxy)ethane	0.1	Not present	3.9
1-(2-chloroethoxy)-2-(o-tolyloxy)-ethane	1	60.2	1,374

For all CoCs, the worst case 95th percentile of the predicted leachate concentrations exceeded the selected screening criteria. Therefore, Level 3a assessment was undertaken on all CoCs.

As previously discussed, reinstated Type A material is present in discreet discontinuous layers generally less than 1 m thick overlying Type B material. Therefore, predicted leachate concentrations from the Type A material have been assessed in Level 3a flowing though the Type B.

7.2 Derivation of Leachate Histograms for Level 3a Model

As set out in Section 5.4, PDFs were developed for each CoC zone based on the distribution of leachate concentrations developed in the Level 1 models. Histograms for all CoC zones are presented in Appendix O together with the selected PDF used for the Level 3a inputs.

From the histograms of the normal and logged leachate concentrations, the majority of the predicted leachate distributions appear to be lognormal but the distributions can also be described using the logtriangular function. Where this is the case, ConSim training notes (Reference 24) recommends the use of logtriangular PDFs as they are easier to define in the model.

The logtriangular distribution requires a minimum, maximum and most likely data points. In all cases where this distribution was selected, the minimum and maximum inputs were based on the minimum and maximum predicted leachate concentrations (thus fully replicating the range of predicted values within the model) with the most likely being based on the most commonly occurring values (typically close or equal to the median value of the predicted leachates).

7.3 Level 3a Models and Risk Assessment Outcome

The CoC zones for each CoC and input leachate histograms are presented in Appendix H and O. The full level 3a models are presented in Appendix P, including the input summary and model ouputs.

For all contaminants, the predicted concentrations for all receptor locations at the western bank of the Riddy Brook and/or at the boundary with zone of reinstated clean sand and gravel between Zone 1 and Zone 2S/2N were significantly below the screening criteria. Therefore, based on the full risk assessment, the remediated site conditions, and distribution of CoCs at the site **do not** represent a risk to controlled waters and specifically the Riddy Brook.

A comparison of the greatest 95th percentile groundwater concentrations and the screening criteria is presented in Table 10 below.

Table 10 – Greatest 95th Percentile Predicted Groundwater Concentrations

Contaminant	Screening Criteria (ug/l)	Greatest 95th Percentile Predicted Leachate Concentration (ug/l)
1,2-Dichloroethane	10	0.011
Dicamba	10	5.6
Schradan	0.35	1.3×10^{-3}
Bis(2-chloroethyl)ether	1	7.92×10^{-5}
Ethofumesate	30	0.31
Trichloroethene	10	5.49×10^{-4}
Tetrachloroethene	10	1.33×10^{-4}
Cis 1,2, Dichloroethene	7.6	0.010
Vinyl Chloride	0.5	7.03×10^{-3}
Hempa	350	0.0266
1,2 Dichlorobenzene	0.7	1.87×10^{-3}
2,4,6 Trichlorophenol	2	2.39×10^{-9}
4,6 Dinitro-o-cresol	0.1	No breakthrough at receptors
4-Chloro-2 methylphenol	50	0.705
Dichlorprop	0.1	5.52×10^{-5}

Contaminant	Screening Criteria (ug/l)	Greatest 95th Percentile Predicted Leachate Concentration (ug/l)
Dimefox	0.1	5.65×10^{-2}
MCPA	12	No breakthrough at receptors
Mecoprop	18	1.63×10^{-2}
Phenol	7.7	No breakthrough at receptors
Simazine	1	8.45×10^{-13}
Toluene	50	0.18
Xylene	30	0.23
Dichloro methylphenol	1	4.04×10^{-16}
Trichlorotoluene	1	No breakthrough at receptors
2,6-bis (1-methylpropylphenol)	1	No breakthrough at receptors
Dinoseb	0.29	No breakthrough at receptors
1,2-bis(2,4,6-trichlorophenoxy)ethane	0.1	No breakthrough at receptors
1-(2-chloroethoxy)-2-(o-tolyloxy)-ethane	1	6.21×10^{-10}

8.0 Summary

Following the completion of the remedial works at the former Bayer Crop Science Site, detailed post remediation risk assessments have been undertaken at the site as part of the validation process in accordance with the VertaseFLI remediation method statement.

Building on work undertaken in previous iterations of the risk assessment, the conceptual site model (CSM) was refined to reflect the final post remediation conditions in as much detail and as accurately as possible; and risk assessments were run using the methodology set out in previous reports. Large amounts of site specific data was collected during the remedial works including *in-situ* measurements of permeability/hydraulic conductivity in Type B material; geotechnical properties; and the final distribution of CoCs and their concentrations accurately mapped to enable the final site conditions to be modelled as accurately as possible.

A number of conservative assumptions were also made in the model as follows:

- There is no attenuation of the contaminants as there is considered to be no unsaturated zone;
- There is no dilution of the groundwater/leachate concentrations in the aquifer;
- The remaining CoCs in the remediated soils are non declining sources;
- Groundwater flow across the site has been assumed to be towards the Riddy Brook ignoring the groundwater low in the reinstated soil material in the north of the site (based on current 2012 monitoring data) which suggests either negligable flow through the reinstated soil material or groundwater flow in much of the reinstated soils is currently away from the Riddy Brook;
- Only soil material from treatment beds where elevated CoCs were recorded was used to derive CoC probability density functions for each contaminant zone. Therefore, data from treatment beds where CoCs were below detection limit were conservatively discounted; and
- Where deposits of clean sand and gravel were reinstated in Zone 1, the boundary between Zone 1 and Zones 2S/2N (a minimum of 20 m from the Riddy Brook) has been conservatively set as the receptor.

Of the 23 CoCs and 9 contaminants not previously identified (CNPIs) 4 contaminants (Cyclohexanone, Chlorzaine, Dimethyl nitroanaline and Oxathiane 4, 4-dioxide) were not present in the reinstated soils. Using the revised CSM, all available site specific data and the conservative assumptions listed above, risk assessment models were run for the remaining 28 contaminants. The outcome of the risk assessments for all contaminants confirmed that following the remedial works , the remaining contaminant concentrations do not represent a risk to controlled waters and specifically the Riddy Brook.

9.0 References

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