Validation Completion Report

Former Bayer CropScience Site
Hauxton
Cambridgeshire

December 2012

On behalf of:

Harrow Estates Plc

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1 Introduction

1.1 General

Vertase FLI Limited (VertaseFLI) was appointed by Harrow Estates (Client) to undertake remedial works at the Former Bayer Crop Science Agrochemical Works, Cambridge Road, Hauxton, Cambridgeshire (the Site). The site was used for the storage and production of agrochemicals (pesticides and herbicides) from the 1940's through to ceasing production in 2004. The site was determined as a Special Site under Part 2a of the Environmental Protection Act (EPA) 1990 due to the identified significant pollutant linkages with respect to groundwater and surface water resulting from the former use of the site.

Remedial works were undertaken between March 2010 and December 2011 and comprised the following:

- The excavation of contaminated soil material;
- The treatment of excavated 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.

Condition 10 of the Planning permission for the site (Ref. S/2307/06/F) requires the production of a Verification Report which will:

> *".... address all monitoring and sampling carried out and shall demonstrate that the remediation works has been completed and the effectiveness of the remediation works."*

Owing to the size and complexity of the remedial works undertaken at the site, the following reports have been produced which together with this report comprise the full verification of the site:

- VertaseFLI (2012a) 'Contract Completion Report, Former Bayer Crop Science Site, Hauxton, Cambridgeshire', December 2012 – Revision B")

  Detailing all work undertaken during the remedial works including all chemical analysis results and site conditions on completion.

- VertaseFLI (2012b) 'Post Remediation Quantitative Risk Assessment for Controlled Waters, Former Bayer Crop Science Site, Hauxton, Cambridgeshire', December 2012 – Revision B.
- VertaseFLI (2012c) 'Groundwater Validation – Addendum Report', December 2012 – Revision B.
- VertaseFLI (2012d) 'Contract Completion Addendum Report, Former Bayer Crop Science Site, Hauxton, Cambridgeshire', December 2012 Revision B.

  Including the final post-remediation site model and detailed quantitative assessment of risks to controlled waters (the Riddy Brook) from the reinstated remediated soil material on completion of remediation.

This report presents the results of the six month groundwater monitoring following the formal completion of the site remediation works in December 2011 and also provides assessment and detailed quantitative assessment of the risks to the Riddy Brook from the identified Contaminants of Concern (CoCs) present within groundwater to demonstrate that the remediation works have reduced the extent and level of contamination and removing the previously identified pollutant linkages so that the site no longer represents a significant risk to controlled waters.

1.2 Relevant Reports

It is assumed that the reader is familiar with all relevant reports for the site detailed below:

- VertaseFLI (2009), 'Remediation Method Statement – Former Bayer Crop Science Site, Hauxton Cambridgeshire', April 2009 – Revision 6.
- VertaseFLI (2011a), 'Validation Protocol, Former Bayer Crop Science Site, Hauxton, Cambridgeshire', February 2011 – Revision 4.
- VertaseFLI (2011b), 'Remediation Proposal for the Bentonite Wall, Former Bayer Crop Science Site, Hauxton, Cambridgeshire', April 2011.
- VertaseFLI (2011c), 'Further Quantitative Risk Assessment for Controlled Waters and Preliminary Post Remediation Validation Model, Former Bayer Crop Science Site, Hauxton, Cambridgeshire', July 2011 – Revision B.
- VertaseFLI (2011d) 'Further Quantitative Risk Assessment for Contaminants Not Previously Identified, Former Bayer Crop Science Site, Hauxton, Cambridgeshire', November 2011.

2 Pre Remediation Conditions

2.1 Pre Remediation Ground Conditions

The pre-remediation ground conditions at the site are summarised in Table 1 and discussed in full in VertaseFLI 2012b.

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
West Melbury Marly Chalk Formation (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)
Woburn Sands Formation (Lower Greensand)	Not encountered but typically between 15 – 20 m thick based on the BGS solid and drift map.

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 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.

2.2 Pre-Remediation Conceptual Site Model

The pre-remediation conceptual site model (CSM) for the site was developed by Atkins Ltd (Atkins (2006), ‘Remediation of Former Bayer Site, Hauxton, Preliminary Conceptual Model Report’, August 2006 – Revision 4a). The Atkins CSM presented a detailed model of the sub-surface contaminant pathways prior to remediation based on the understanding of the site at the time. The contaminant source is shown as granular Made Ground and cohesive Made Ground, much of which was located below the water table. The main environmental receptors were groundwater and surface water (Riddy Brook).

The key groundwater contaminant pathways in the model were assumed to be:

- Vertical migration through the unsaturated zone;
- Migration of contaminants through sand and gravel lenses within the cohesive Made Ground and WMMCF; and
- Migration through existing site infrastructure such as sumps and utility trenches.

3 Remediation

3.1 Remediation Approach

The approach to remediation was to:

- Remove all uncertainty relating to soils and groundwater within the site area by excavation, characterisation and treatment of all ground and groundwater;
- Break all preferential contaminant pathways (such as migration through existing site infrastructure); and
- Reduce the contaminant mass within soils as far as the practical limits of cost effective technology permitted to be protective of both the environment (controlled waters) and future users of the site.

The methodology for undertaking the remedial work was set out in the VertaseFLI Remediation Method Statement (VertaseFLI 2009).

3.2 Remediation Works Summary

Full details of the remediation works are given in the completion report (VertaseFLI 2012a). The remedial works comprised the following activities:

- Breaking, uplifting, crushing and sampling of concrete slabs;
- Excavation, breaking crushing and sampling of underground obstructions;
- Pumping and treatment of shallow groundwater and perched waters;
- Services diversions;
- Excavation of contaminated soils;
- Sorting, classification, processing and segregation of soils;
- Preparation of soils for treatment;
- Treatment of contaminated soils;
- Removal of all preferential pathways e.g. pipelines, drainage runs; and
- Re-instatement of soils.

Materials were excavated under and were segregated according to their material type as follows:

- Type A – Granular Made Ground and sand and gravel;
- Type B – Cohesive Made Ground and WMMCF; and
- Type C – Gault Formation

Soils were further segregated based on visual and olfactory evidence of contamination. A total of approximately 171,983 m^3 soil material was excavated during the remediation works. 116,561m^3 of the excavated soils required treatment prior to reinstatement and 2,000 m^3 was not suitable for treatment and exported from site for off-site disposal.

All materials requiring treatment were constructed into treatment beds for biological treatment. Beds were mechanically turned in order to: further homogenise materials by breaking down larger soil clasts, increasing the surface area of material to aeration; and ensure regular aeration of the materials. Spent mushroom compost was added to a number of treatment beds to enhance the remediation process.

Soil material was reinstated in 250 mm layers and compacted to comply with earthworks specification. The placement of soil material was based on the based on maximum threshold targets derived in VertaseFLI 2011c and 2011d.

Following completion of the remedial works of the remediation works, validation boreholes were installed across the site at locations agreed and approved by the Environment Agency (see section 4).

4 Remediation Validation

4.1 Validation Boreholes

Following completion of the remedial works, 16 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 C. All borehole locations were agreed with the Environment Agency prior to drilling.

Details of the borehole response zones are detailed in Table 2 below.

Table 2 – Validation Borehole Response Zones

Borehole	Response zone (m)	Strata	No. of Water Samples Obtained (December 2011 – June 2012) (Max 7)
A18	2-4	WMMCF	7
E14	2-4	WMMCF	2
D20	2-4	WMMCF	0
D25	1.3-3	Type A – Sand and Gravel	0
F12	2-3	WMMCF	0
F23	4-6	Reinstated Type B/WMMCF	0
G10	2-3	Reinstated Type B	0
G21	2.2-4	Type A – Sand and Gravel	7
H7	1-3	Reinstated Type B	4
H15	1-3	Reinstated Type B	0
I18	3-5	WMMCF/Gault Clay	7
I24	3-5	WMMCF	5
J10	2-5	Reinstated Type B and Type C	0
K5	2-5	WMMCF/Gault Clay	0
K14	1-3.5	Reinstated Type B	0
K21	3.7-5.7	WMMCF	7

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. Six groundwater samples were obtained from each of the three boreholes over the seven monitoring rounds to June 2012.

4.2 Boreholes Outside Remediation Boundary

Boreholes were also drilled outside of the remediation boundary to investigation an area of contamination that extended beyond the remediation boundary. The findings of these additional investigations are presented in VertaseFLI 2012c

4.3 Validation of Completed Remedial Works

A detailed quantitative risk assessment (DQRA) with respect to controlled waters was undertaken based on the final site conditions and remaining residual contaminant distribution in soil material using site specific parameters to demonstrate that the remediated site does not represent a risk to the Riddy Brook (VertaseFLI 2012b).

In order to validate the remediation works with respect to the groundwater at the site, this report describes the results of the groundwater monitoring and sampling in the validation boreholes, compares the recorded on-site groundwater concentrations with those predicted in the DQRA and assessed the risks to controlled waters (the Riddy Brook) from the actual groundwater concentrations on site.

5 Monitoring and Sampling

5.1 Boreholes

As described in Section 4, a total of 16 no. boreholes were installed within the remediation boundary of the site for validation purposes. These boreholes are shown on Drawing D907_226A (Appendix A) together with the remaining boreholes (BH9, BH11 and VN3 in the north of the site) from other phases of work at the site.

It is important to note that two contamination sources have been identified beyond the main remediation boundary (located in the vicinity of boreholes H7, G8 and F9, and B16). Therefore, contaminant concentrations in these areas are not considered to be representative of down gradient concentrations resulting from the remediated on site soils and the boreholes have not been considered for the purposes of validating the remediation on site. The off-site contamination in the vicinity of H7, G8 and F9 is discussed further in VertaseFLI 2012c.

On-site monitoring has been undertaken in 19 boreholes remaining on the main remediation site comprising the 19 validation boreholes, and historic monitoring boreholes BH9, BH11 and VN3 in the north of the site. Of the monitored boreholes, it was not possible to obtain groundwater samples on any monitoring round for analysis in nine boreholes due to an absence of recoverable groundwater, these boreholes included all boreholes installed in reinstated soils (with the exception of H7) and borehole D25 installed in natural sand and gravel deposits in the south of the site.
The monitored boreholes are summarised as follows:

- On site boreholes sampled at least once: A18, B21, E14, G21, I18, I24, K21, BH9, BH11 and VN3;
- On site boreholes not sampled due to absence of groundwater: D20, D25, F12, F23, G10, H15, J10, K5 and K14; and
- Boreholes impacted by sources outside of the main remediation site and therefore not appropriate to assess on-site remediation: H7 and B16.

5.2 Monitoring and Sampling

Boreholes were sampled using either a low flow peristaltic pump or disposable bailer in line with all standard procedures and practices. Boreholes were purged to a volume of 3 well volumes per borehole. Borehole purgate was stored in the site lagoon before transfer to the waste water treatment works (WWTW) for treatment as stated in the Completion Report.

In addition, up-stream and down-stream samples of surface water from the Riddy Brook and River Cam were also collected on each monitoring round.
Seven validation monitoring rounds have been completed on the following dates:

1. 07/12/11 – 09/12/11
2. 21/12/11 – 23/12/11
3. 25/01/12 – 27/01/12
4. 22/02/12 – 24/02/12
5. 28/03/12 – 30/03/12
6. 08/0512 – 11/05/12
7. 06/06/12 – 08/06/12

Sampling round 5 was undertaken in the presence of the Environment Agency. It should be noted that dates in summary tables of lab analysis (Appendix D) relate to dates of the laboratory testing certificates (presented in Appendix I) and not the sampling dates.

5.3 Chemical Analysis

Groundwater samples were analysed for the 23 contaminants of concern (COCs) specified in the VertaseFLI (2009), 'Remediation Method Statement – Former Bayer Crop Science Site, Hauxton Cambridgeshire', April 2009 – Revision 6 (hereafter referred to as the RMS).
:

- Organophosphates and Organonitrates: Dimefox, Ethofumesate, Hempa, Schradan and Simazine;
- Phenoxy Acid Herbicides: Dicamba, Dichlorprop, MCPA and Mecoprop;
- Semi Volatile Organic Compounds (SVOCs): 2,4,6-Trichlorophenol, 2-Methyl-4,6-dintrophenol, 4-Chloro-2-methylphenol, bis (2-chloroethyl) ether and phenol; and
- Volatile Organic Compounds (VOCs): 1,2-dichlorobenzene, 1,2-dichloroethane, cis-1,2-dichloroethene (cDCE), cyclohexanone, tetrachlorethene (PCE), toluene, trichlorethene (TCE), vinyl chloride (VC) and xylene.

6 Monitoring results

6.1 Groundwater levels

Drawing D907_223A and D907_225 in Appendix A shows the hydrogeological contour plots for the site on each monthly monitoring round. The results of the monitoring showed a significant low of 6.6 to 6.8 m AOD (approximately centred on borehole J10) in the groundwater levels present in reinstated soil material in the north of the site. As discussed in VertaseFLI (2012b), this low may be indicative of either:

- 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 negligible 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 south of the site groundwater flow is generally to the northeast with an apparent easterly component at the southeast site boundary. Groundwater flow in the northwest corner of the site appears to be towards the north.

Variations in groundwater levels in individual boreholes on-site are shown in Figures 2 to 7 (Appendix B). In the majority of boreholes, groundwater levels have increased over the monitoring period, with the maximum observed increase of approximately 1 m. The principal exception to this is borehole J10 where groundwater levels have remained relatively constant between 6.6 and 6.9 m AOD.

6.2 Comparison of Groundwater levels and Rainfall

Rainfall data for Cambridge is presented in *Figure1* below.

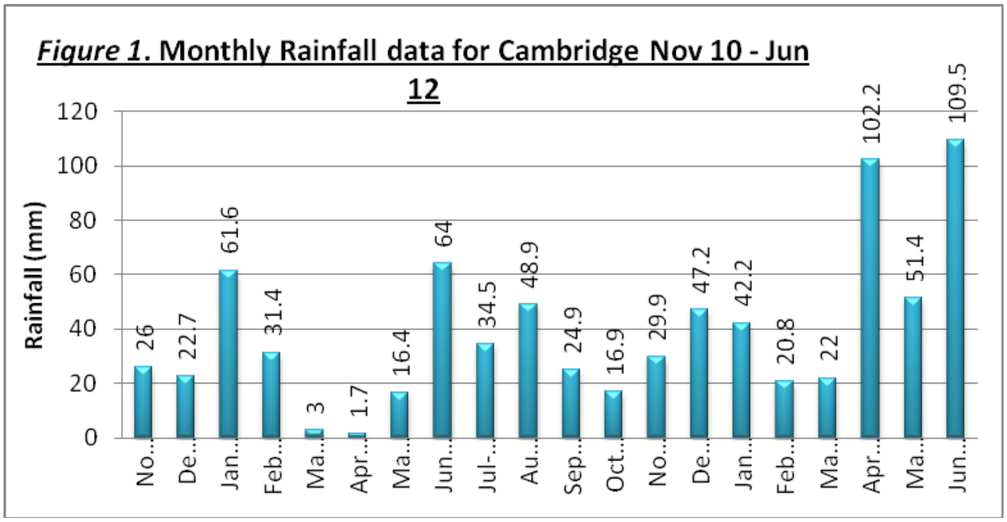

Figure 1 shows that at the start of the post-remediation validation period (Dec 2011) monthly rainfall decreased for three successive months to March. However, significant rainfall was recorded in April (102.2 mm), May (51.4 mm) and June 2012 (105.9 mm) . This initial decline in rainfall followed by a sharp increase closely correlates with groundwater level data. *Figures 2 – 7* in appendix B show the 7 month groundwater data for all site boreholes compared to monthly rainfall data. Generally, there was a rapid recovery of water levels in site boreholes for approximately two months after installation. After this groundwater levels plateau and fall until March 2012. Groundwater levels rose significantly in April 2012, coincident with the high rainfall recorded and remained relatively stable in May.

The groundwater level fluctuation plots included in *figures 2 – 7* show that boreholes J10, H15 and K14 demonstrate limited response to rainfall and have been recovering at a slow rate for the full period of validation. J10 especially demonstrates no obvious response to rainfall, in contrast to the majority of site boreholes.

Groundwater data for boreholes to the south of site indicate recovered water levels and a good correlation between rainfall and groundwater levels.

6.3 Contaminants of Concern observed in Validation Boreholes

The graphs in *figures 8 – 16* in appendix B and validation result data supplied in Appendix D, show that in the majority of boreholes where samples have been obtained, the 23 CoC have generally decreased during the monitoring period and that the recorded concentrations of each CoC have generally been less than 200 ug/l. As discussed above, it was not possible to obtain groundwater samples from the majority of boreholes installed in the reinstated remediated soils due to a lack of recoverable groundwater.

However, concentrations of hempa have increased in four boreholes (A18, BH11, I18 and K21) during the monitoring. Between December 2011 and March 2012 these increases in hempa concentrations were typically less than 20 ug/l, the greatest increases have occurred between April and June 2012 associated with the period of heavy rainfall discussed in Section 7.2. It is important to note that hempa concentrations are below the screening value of 350 ug/l (see Section 8 below) in all samples in A18 and I18 with only one slight exceedance in BH11 and three exceedances in I18.

CoC concentrations in borehole I24 including 2-methyl-4,6-dintrophenol, 2,4,6-Trichlorophenol, ethofumesate and simazine also showed increases coincidental with the heavy rainfall between April and June 2012.

Boreholes VN3, BH11 and BH9 have been used for monitoring for the duration of the remedial works although it should be noted that no borehole construction details or logs were available. Monitoring data from BH9 shows a significant decrease in bis(2-chloroethyl)ether concentrations following the completion of the remediation works and generally lower concentrations of other CoCs. VN3 also showed a decrease in bis(2-chloroethyl)ether concentrations until April 2012 after which concentrations increased back to 460 ug/l.

6.3.1 Boreholes within Sand and Gravel

Two boreholes, D25 and G21 were installed with response zones within deposits of natural sand and gravels in the south of the site. There was insufficient groundwater in D25 to obtain groundwater samples. Analysis results for G21 recorded relatively low contaminant concentrations with only marginal exceedances of the screening criteria (See Section 8) for Schradan and MCPA

6.4 Contaminants of Concern observed in surface water samples

Figures 17 – 18 show residual contamination recorded in the site lagoon (used to retain surface water run-off from the site) and extracted from standing water in grid square K10. Residual contamination in the K10 standing water has consistently declined over a four month period. In the site lagoon (K5 sump), after an initial increase in concentrations in March 2013, the CoC concentrations have decreased.

6.5 Contaminant Levels observed in the Riddy Brook

Figures 20 – 23 show the results of monthly monitoring recorded in the Riddy Brook and River Cam up and downstream samples since November 2010 . Concentrations in the River Cam Upstream sample have remained static since February 2011 with occasional peaks of 3µg/L. Tetrachloroethene has remained present in the River Cam upstream sample at a concentration of between 2 and 3µg/L. As this sample is upstream of the site, it is considered that these represent baseline conditions and are not site influenced. Similar observations can be made for both the River Cam downstream sample and the Riddy Brook upstream sample.

It should be noted that water levels within the Riddy Brook are generally constant with relatively little variation. Level data for the Riddy Brook from 2011 is presented in Appendix E.

Concentrations of the 23 COCs in the Riddy Downstream sample have peaked on a number of occasions. In general peaks in concentrations in this sample can be closely linked to months with high rainfall and high groundwater levels where groundwater levels in the east of the site are greater than levels in the Riddy Brook. It should be noted that the highest concentrations recorded were generally for chlorinated solvents Trichloroethene and Tetrachloroethene, and bis(2-chloroethyl)ether which have generally not been present in the majority of groundwater samples at any significant concentrations. It should also be noted that the contaminant concentrations for the large majority of monitoring were below the screening criteria listed in Section 8. Further detailed discussion of the contaminant levels within the Riddy Brook and potential contaminant sources outside of the remediation boundary is presented in VertaseFLI 2012c. It is also considered likely that the peak concentrations observed in the Riddy downstream samples in December 2011 and January 2012 were contributed to by a historic drainage feature in the north of the site together with the identified off-site sources, the drainage feature has since been decommissioned.

7 Post Remediation Conditions and Site Model

7.1 Post Remediation Ground Conditions

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 250 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 reinstated unit is as follows:

- No Dig Layer – Placed at surface
- 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 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 – Thickness of the reinstated material is between 0.05 to 3.75 thick with an typical thickness of approximately 2.0 m (see Drawing D907_220A). Thickness of WMMCF remaining *in-situ* in the south of the site is in the order of 3 to 5 m, boreholes drilled by Atkins (2006) typically encountered WMMCF deposits 3 – 4 mthick with one borehole in the southeast corner of the site encountering a total thickness of 7.5m. This borehole was up hydraulic gradient of the site and therefore the thickness was not considered representative of site conditions It should also be noted that the excavation and remediation resulted in the homogenisation of the soils and in the case of the WMMCF. As a result the lenses of sand and gravel observed in the WMMCF in the pre-remediation investigations are not present in the reinstated soils. 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 depth to Gault clay across the site (where proven) is shown in Drawing D907_211 and the level of the Gault following reinstatement is shown in D907_212.

It should be noted that prior to the final development and as detailed in the remediation method statement (VertaseFLI 2009), it will be necessary to import a minimum of 1 m thick capping layer comprising subsoil and topsoil onto site.

7.2 Post Remediation Groundwater Conditions

Post remediation groundwater monitoring rounds had been undertaken at the site at monthly intervals. Drawings D907_223A and , D907_225 (Appendix 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 negligible 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. It should be noted that as shown in Table 2 above, it was not possible to obtain sufficient groundwater for chemical analysis boreholes with response zones within reinstated Type B and C material with the exception of borehole H7 indicating the very low flow rates within the reinstated remediated soils.

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.

7.2.1 *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 appears to be more easterly. In the northwest corner of the site, groundwater flows in a more northerly direction.

7.2.2 *Soil Material Aquifer Properties*

Type C Material

As discussed in VertaseFLI(2012b), the natural Gault Formation underlying the site 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 made during trial pitting, drilling of boreholes and subsequent excavations/remediation indicate that in the south of the site (outside the main excavations), the main groundwater body is the WMMCF (see VertaseFLI(2012b)), with negligible groundwater observed in Type A deposits.

To provide detailed data on the Type B material, 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 natural in-situ soils outside of the main excavations. The location of the permeability tests is shown in drawing D907_238 and the results are summarised as histograms in Appendix F. 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 and are considered to be representative of the reinstated and natural WMMCF. The results of the testing are discussed further in VertaseFLI (2012b).

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 of the site (see drawing D907_213A). Natural Type A deposits are between 0.7 and 2.5 m thick, however, the Type A deposits are discontinuous and given the general absence of groundwater (discussed in above) within the natural sand and gravel, the natural Type A material is unlikely to represent a significant groundwater body.

Of the two boreholes (D25 and G21) installed in the sand and gravel deposits in the south of the site, it was not possible to obtain groundwater samples from D25 suggesting that either the deposits of sand and gravel around D25 are relatively impermeable or there is not a significant volume of water present. Chemical analysis results from groundwater from G21 identified relatively low contaminant concentrations compared to adjacent boreholes installed in WMMCF which is considered indicative of the lack of continuity/upward migration between the WMMCF and the sand and gravel.

7.3 Post Remediation Site Model

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

7.3.1 Contaminant Source

The contaminant source in the post remediation CSM comprises the residual CoC concentrations remaining in the remediated soils (see Section 6.3). 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.

7.3.2 Pathways

Potential pathways at the site are limited to leaching of contaminants into groundwater from Type A and Type B material and subsequent horizontal migration via groundwater towards the Riddy Brook through the Type B. As the 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) and placed over Type B material no direct pathway will exist through the reinstated Type A material with the exception of very limited vertical migration through the unsaturated zone.

Based on the low permeability of the Type B material across the site, upwards migration of contaminants into the Type A material has not been considered as a pathway. The relatively low contaminant concentrations observed in the sand and gravel in G21 relative to adjacent boreholes in the WMMCF (K21, I18, I24) also indicates there is not significant connectivity between the two soil types.

Natural sand and gravels are present in the southwest (up hydraulic gradient) and the southeast of the site. Deposits are discontinuous and given the absence of recoverable groundwater from borehole D25 suggesting , located within the sand and gravel deposits to the southeast of the site, this material is not considered to represent a significant migration pathway.

7.3.3 Receptor

The primary receptor is considered to be the Riddy Brook, located between 1 and 6 m from the northeast boundary of the site. 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 i.e. the upgradient edge of the reinstated sand and gravel.

8 Risk Assessment

In order to assess the potential risks to the Riddy Brook from the recorded groundwater concentrations, the following assessments have been undertaken:

- Initial screen of recorded groundwater concentrations with appropriate screening criteria;
- Comparison of groundwater concentrations with leachate concentrations predicted in VertaseFLI 2012b; and
- Detailed quantitative risk assessment using Consim.

The results of the risk assessment are set out in the following sections

8.1 Comparison of Groundwater Contaminant Levels with Selected Screening Criteria

Table 3 sets out the screening criteria and sources used to assess the recorded groundwater concentrations. The screening criteria are discussed further in VertaseFLI 2012b.

Table 3 – Selected Screening Criteria (VertaseFLI 2012b)

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	See VertaseFLI 2012b
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). Considered more appropriate with respect to Riddy Brook than UK Pesticide DWS
Trichloroethene (TCE)	10	UK DWS	
Tetrachloroethene (PCE)	10	UK DWS	

Table 3 – Selected Screening Criteria (VertaseFLI 2012b)			
Contaminant	**Screening Criteria (ug/l)**	**Source**	**Justification**
Cis 1,2, Dichloroethene	6.7	Dutch Freshwater Maximum Permissible Concentration	European Freshwater quality guideline considered appropriate with respect to Riddy Brook – no other guidance values available
Vinyl Chloride	0.5	UK DWS	
Hempa	350	VertaseFLI derived PNEC	See VertaseFLI 2012b
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)
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
Mecoprop	18	Annual mean Freshwater EQS	Environment Agency – River Basin District Typography, Standards and Groundwater Threshold Values
Phenol	7.7	Annual mean Freshwater EQS	Environment Agency – River Basin District Typography, Standards and Groundwater Threshold Values
Simazine	1	Freshwater EQS	Environment Agency – River Basin District Typography, Standards and Groundwater Threshold Values
Toluene	50	EQS Freshwater	
Xylene	30	EQS Freshwater	

It should be noted that there is no screening value in Table 3 for cyclohexanone. Cyclohexanone has not been identified in either the reinstated soils on the site or the groundwater on site and therefore it has not been considered further in the risk assessment.

The following contaminants of concern (CoC) exceeded their respective screening criteria (maximum concentration in brackets) in each borehole during the monitoring period:

- **A18** – Schradan (85 ug/l), Simazine (1.3 ug/l), MCPA (110 ug/l), Dichlorprop (0.4 ug/l) and PCE (20 ug/l);
- **B21** – Schradan (4.5 ug/l) and Simazine (10 ug/l);
- **E14** - Schradan (0.4 ug/l) only;
- **G21** - Schradan (2.8 ug/l), Dichlorprop (0.3 ug/l) and MCPA (33 ug/l);
- **I18** – Ethofumesate (80 ug/l), Hempa (1,300 ug/l), Schradan (470 ug/l), Simazine (16 ug/l), Dicamba (100 ug/l), Dichlorprop (7.2 ug/l) MCPA (220 ug/l), Mecoprop (110, ug/l), 2,4,6 trichlorophenol (50 ug/l), bis(2-chloroethyl)ether (40 ug/l), 1,2 dichlorobenzene (1 ug/l), cis 1,2-dichloroethene (25 ug/l) and vinyl chloride (7 ug/l);
- **I24** – Ethofumesate (840 ug/l), Hempa (430 ug/l), Schradan (6.1 ug/l), Simazine (660 ug/l), Dicamba (100 ug/l), Dichlorprop (27 ug/l), MCPA (1,600 ug/l), Mecoprop (880 ug/l), 2-methyl-4,6-dintrophenol (540 ug/l), bis (2-chloroethyl)ether (38 ug/l) and 1,2 dichlorobenzene (4 ug/l);
- **K21** - Schradan (7.4 ug/l), Simazine (1.1 ug/l), Dicamba (65 ug/l), Dichlorprop (1.9 ug/l) MCPA (12 ug/l) and Mecoprop (18 ug/l);
- **BH9** – Schradan (20 ug/l), Bis(2-chloroethyl)ether (200 ug/l), PCE (120 ug/l);
- **BH11** - Hempa (370 ug/l), Schradan (85 ug/l), Simazine (45 ug/l), Dicamba (23 ug/l), MCPA (72 ug/l), Dichlorprop (1.5 ug/l), 2-methyl-4,6-dinitrophenol (13 ug/l), bis (2-chloroethyl)ether (300 ug/l), Phenol (950 ug/l), PCE (210 ug/l), TCE (23 ug/l) and vinyl chloride (2 ug/l); and
- **VN3** – Schradan (5.3 ug/l), Simzaine (3.4 ug/l), Dichlorprop (0.3 ug/l), Mecoprop (27 ug/l) and bis (2-chloroethyl)ether (490 ug/l).

The greatest exceedances of the screening criteria were typically associated with the greatest CoC concentrations within the reinstated soils (such as I18 and I24). Schradan has exceeded the screening criteria on at least one occasion in all locations. Although the majority of contaminants did not exceed screening criteria in all boreholes, all recorded concentrations have been conservatively taken forward for further assessment to allow for any cumulative effects in the modelling and is discussed in the following sections.

8.2 Comparison of Groundwater CoC Concentrations with Level 1 Risk Assessment Model

As part of the DQRA (VertaseFLI 2012b), the site was split into zones based on the distribution of CoCs within the reinstated soils. Based on the contaminant distributions, and physical chemical data, a Level 1 risk assessment was undertaken which derived a range predicted porewater (leachate) concentrations for each CoC giving a minimum, maximum and most likely together with the predicted 95th percentile worst case concentration. The final outcome of the DQRA following the Level 3a assessment (modelling CoC migration through the Type B material) of the predicted leachate concentrations was that the remediated site did not represent any significant risk to the Riddy Brook.

As an initial screen, the CoC concentrations recorded in groundwater on the site have been compared to the predicted leachate concentrations derived in the Level 1 assessment for eight of the monitoring boreholes (A18, B21, BH9, G21, H7, I18, I24 and K21). A full description of the Level 1 modelling approach including the assessment and zoning of contaminant concentrations in soils is presented in VertaseFLI 2012b. Boreholes BH11, H7, and E14 are not included in the assessment as they were located within 20m of the Riddy Brook. As the reinstated material in zone 1 was subject to stringent chemical criteria (see completion report) and as a consequence, there were no predicted zones within an appropriate area to compare recorded borehole data against. Borehole H7 is considered further in VertaseFLI 2012c.

The tables in Appendix G are a comparison of the minimum and maximum contaminant concentrations recorded in post remediation site boreholes against the maximum, 95th percentile, median and minimum concentration predicted leachate concentrations for the nearest modelled zone in the level 1 models in the Post Remediation Risk Assessment. With the exception of borehole I18, the recorded contaminant concentrations within the ranges predicted by level 1 models in the DQRA for the relevant contaminant zone, and in a number of cases significantly below the ranges predicted by the level 1 models.

Borehole I18 is the only validation borehole (where a comparison is appropriate) that recorded concentrations that exceeded the predicted range from the Level 1 risk assessments. The maximum recorded concentrations of Hempa and MCPA respectively were 1,300 ug/l (maximum predicted 564 ug/l, 95th percentile 31.4 ug/l) and 220 ug/l (maximum predicted concentration 97.6 ug/l, 95th percentile

45.4 ug/l). It should be noted that these concentrations were the maximum recorded to date. Typically recorded MCPA concentrations have been between 0.7 to 58 ug/l and hempa concentrations between 53 and 540 ug/l, all within the predicted ranges.

In general, the comparison of recorded CoC concentrations with the predicted concentrations shows that the recorded concentrations are within the predicted CoC ranges, and in some cases significantly below. Given that the DQRA (VertaseFLI 2012b) shows the reinstated soils at the site do not represent a risk to the Riddy Brook, it can therefore also be seen that with the exception of the maximum concentrations of hempa and MCPA recorded in I18, the recorded CoC concentrations are highly unlikely to represent any significant risk to the Riddy Brook. However, to account for the boreholes located within the 20 m buffer zone, where no comparison of modelled concentrations was possible, and the exceedances of the predicted hempa and MCPA ranges in I18 further risk assessment of the recorded groundwater concentrations has been undertaken (See Section 8.2 below).

It is also important to note, that the comparison between recorded and predicted groundwater concentrations generally validates the range of leachate concentrations predicted in the DQRA as representative of worst case site conditions.

8.3 Risk Assessment of Recorded CoC Concentrations

In order to further assess the risks to the Riddy Brook from the recorded groundwater concentrations including those within the 20 m buffer zone, a level 3a assessment has been undertaken in ConSim using the maximum recorded CoC concentration in each borehole using the same aquifer and CoC parameters used in the DQRA (VertaseFLI 2012b). The Level 3a model models the movement of CoCs already present in the aquifer and conservatively assumes a non declining source.

It is important to note that in modelling risks at the receptors, it is necessary not just to consider the conditions in the aquifer immediately below the soil/groundwater source but also conditions along the entire contaminant flow path through the aquifer. Therefore it is considered appropriate to use the large volumes of data from the entire site to best represent aquifer conditions between the source and receptor. Aquifer parameters for the Type B material are presented in Table 4 below and CoC parameters (partition coefficient Kd and Aquifer Half life) are presented in Table 5. All parameters used in the model are identical to those used in the DQRA. Full justification for the parameters is presented in VertaseFLI 2012b.

The PDF for hydraulic conductivity used in the model is based on 111 *in-situ* permeability measurements undertaken across the site at different depths and in reinstated and natural soils. Full discussion and analysis of the permeability data is presented in VertaseFLI 2012b and it is considered that the selected PDF is representative of the WMMCF.

Table 4 Aquifer Parameters

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 (1.6e-10, 2.2e-7,7.1e-6)	Site specific *in-situ* permeability testing
Effective Porosity (%)	Uniform (3,7)	Conservative assumption based on 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
Groundwater flow direction (degrees)	Single (45^o)	Based on post remediation groundwater modelling and conservative assumptions. Flow to the northeast gives the shortest contaminant pathways to the receptors
Longitudinal Dispersivity (m)	Uniform (0.1,0.2)	Conservatively based on 10% of minimum contaminant pathway between source and receptor (1 – 2 m)
Lateral Dispersivity (m)	Uniform (0.01,0.02)	10% of Longitudinal Dispersivity
Fraction of Organic	Logtriangular	Site specific data for Type B soil

Table 4 Aquifer Parameters		
Aquifer Property (unit)	**PDF (Property value)**	**Source**
Carbon (%)	(0.75,1.78,4.8)	material

Table 5 – CoC Parameters							
Contaminant	**Parameter**	**Unit**	**PDF**	**Min**	**Most Likely**	**Max**	**S/D**
1,2-Dichloroethane	K_{oc}	ml/g	Uniform	11.48	~	76	~
	Aquifer Half Life	days	Uniform	400	~	720	~
Dicamba	K_{oc}	ml/g	Log triangular	0.1	2.5	42.65	~
	Aquifer Half Life	Days	Uniform	151	~	443	~
Schradan	K_d	ml/g	Logtriangular	0.1	11.2	123	~
	K_{oc}	ml/g	Uniform	4.12		20.12	
	Aquifer Half Life	Days	Uniform	1825	~	3650	~
Bis(2-chloroethyl)ether	K_d	ml/g	Logtriangular	0.46	12.5	42.5	~
	K_{oc}	ml/g	Uniform	13.8	~	76	~
	Aquifer Half Life	Days	Uniform	360	~	720	~
Ethofumesate	K_{oc}	ml/g	Uniform	97	~	245	~
	Aquifer Half Life	Days	Uniform	500	~	1140	~
Trichloroethene	K_{oc}	ml/g	Logtriangular	25.12	141	776.24	~
	Aquifer Half Life	Days	Uniform	321	~	1654	~
Tetrachloroethene	K_{oc}	ml/g	Triangular	50	296	500	~
	Aquifer Half Life	Days	Uniform	720	~	1653	~
Cis 1,2, Dichloroethene	K_{oc}	ml/g	Uniform	35.6	~	69.18	~
	Aquifer Half Life	Days	Uniform	720	~	2875	~
Vinyl Chloride	K_{oc}	ml/g	Triangular	2.99	16.6	57	~
	Aquifer Half Life	Days	Uniform	720	~	2875	~
Hempa	K_d	ml/g	Logtriangular	0.17	7.94	50	~

Table 5 – CoC Parameters							
Contaminant	**Parameter**	**Unit**	**PDF**	**Min**	**Most Likely**	**Max**	**S/D**
	K_{oc}	ml/g	Uniform	10	~	16.65	~
	Aquifer Half Life	Days	Uniform	1825	~	3650	~
1,2 Dichlorobenzene	K_{oc}	ml/g	Triangular	109	379	891	~
	Aquifer Half Life	Days	Uniform	365	~	720	~
2,4,6 Trichlorophenol	K_{oc}	ml/g	Logtriangular	109	1513	6918	~
	Aquifer Half Life	Days	Uniform	169	~	1820	~
4,6 Dinitro-o-cresol	K_{oc}	ml/g	Triangular	100	257	602	~
	Aquifer Half Life	Days	Uniform	28	~	42	~
4-Chloro-2 methylphenol	K_{oc}	ml/g	Uniform	124	~	700	~
	Aquifer Half Life	Days	Uniform	1825	~	3650	~
Dichlorprop	K_{oc}	ml/g	Uniform	34	~	170	~
	Aquifer Half Life	Days	Uniform	824	~	1235	~
Dimefox	K_{oc}	ml/g	Uniform	1.91	~	8.33	~
	Aquifer Half Life	Days	Uniform	1825	~	3650	~
MCPA	K_{oc}	ml/g	Uniform	10	~	154	~
	Aquifer Half Life	Days	Uniform	28	~	182	~
Mecoprop	K_{oc}	ml/g	Uniform	5.3	~	68	~
	Aquifer Half Life	Days	Uniform	28	~	280	~
Phenol	K_{oc}	ml/g	Triangular	10	30.19	46.77	~
	Aquifer Half Life	Days	Uniform	8	~	20	~
Simazine	K_{oc}	ml/g	Triangular	39.81	140	421.7	~
	Aquifer Half Life	Days	Uniform	75	~	174	~

Table 5 – CoC Parameters							
Contaminant	**Parameter**	**Unit**	**PDF**	**Min**	**Most Likely**	**Max**	**S/D**
Toluene	K_{oc}	ml/g	Triangular	38.9	160	269.15	~
	Aquifer Half Life	Days	Uniform	110	~	210	~
Xylenes	K_{oc}	ml/g	Triangular	74	250	616.59	~
	Aquifer Half Life	Days	Uniform	112	~	360	~

Each borehole has been modelled based on worst case conditions using the maximum recorded CoC concentrations and the assuming presence of the elevated CoC concentration in the entire grid square surrounding the borehole. Receptors were placed along the Riddy Brook to ensure the worst case predicted concentrations were identified. Additionally, a strip of the buffer zone in the southeast of the site was reinstated with deposits of sand and gravel, where the deposits were present, the receptors for the Riddy Brook were conservatively taken as the boundary between the 20 m buffer zone and the remainder of the reinstated soils.

8.4 Level 3a Results

The Consim model is presented in Appendix H. Conservatively using the worst case recorded groundwater concentrations from the site did not predict any CoC levels that exceeded the selected screening criteria at any of the receptor locations. Therefore the observed groundwater CoC concentrations do not represent a risk to the Riddy Brook. Together with the results of the DQRA (VertaseFLI 2012b) these assessments are considered to show that the reinstated soil material does not represent a risk to the Riddy Brook.

9 Summary

Remedial works were undertaken at the former Bayer CropScience site in Hauxton, Cambridgeshire between March 2010 and December 2011. Following remediation boreholes were installed with response zones in the West Melbury Marly Chalk Formation, reinstated soils and natural sand and gravel (remaining in the south of the site)

As part of the validation of the remediation works, to date seven validation monitoring rounds have been undertaken at the site. The collected monitoring data includes groundwater levels and contaminant concentrations of the 23 COCs.

A groundwater low is present in the north of the site (approximately centred on borehole J10) suggesting either groundwater flow in the north of the site towards the centre of the site and away from the Riddy Brook, or a zone of effective negligible/no flow in the reinstated soils. In the south of the site, groundwater flow is generally towards the northeast, with a more easterly component towards the southeast boundary. Groundwater flow in the northwest corner of the site appears to be towards the north. Due to the low flow conditions in the reinstated soils, it was not possible to obtain groundwater samples from boreholes with response zones in the reinstated soils.

CoC concentrations have been identified in groundwater across the site with the greatest concentrations recorded in I18 and I24, both of which the response zones are located under the greatest CoC concentrations recorded in the reinstated soil material (as detailed in VertaseFLI 2012b) and are as predicted by the Level 1 risk assessment models. Elevated schradan concentrations exceeding the selected initial screening criteria were present in all boreholes on at least one occasion. Outside of I18 and I24, the majority of CoC concentrations other than schradan were below the selected screening criteria. Of the two boreholes installed in sand and gravel, insufficient groundwater was present to obtain a sample from D25 (suggesting either low permeability material or a general absence of groundwater) and contaminant concentrations from G21 were relatively low compared with adjacent boreholes in the WMMCF.

The CoC concentrations were also compared (where appropriate) with predicted CoC leachate concentrations derived in the VertaseFLI Post Remediation Risk Assessment (VertaseFLI 2012b). With the exception of hempa and MCPA concentrations in borehole I18, all recorded groundwater concentrations have been within or below the range predicted confirming that the predicted groundwater concentrations in the model are generally conservative and representative of actual groundwater concentrations. It should also be noted that for both hempa and MCPA in of the seven monitoring rounds only the predicted range was only exceeded on one occasion and that the selected screening criteria was only exceeded on 3 out of 7 occasions for hempa and one occasion for MCPA.

In order to provide further confidence in the Post Validation Risk Assessment and to demonstrate that residual concentrations recorded in post remediation monitoring samples do not pose a risk to the Riddy Brook, a level 3a groundwater risk assessment was undertaken using ConSim and identical parameters to those in VertaseFLI2012b. The parameters used are considered representative and appropriate to model flow through the WMMCF. A northeasterly flow direction was selected as the most conservative (with the shortest contaminant flow paths relative to more easterly or northerly flow directions) The maximum concentration for each CoC in each borehole was conservatively modelled and based on the results all predicted concentrations at the selected receptors were below the screening criteria indicating that the groundwater concentrations identified do not represent a significant risk to the Riddy Brook or controlled waters confirming that the remedial works have removed the former pollutant linkages between the site and Riddy Brook.