AN APPLICATION FOR AN ENVIRONMENTAL PERMIT TO AUTHORISE THE DEPOSITION OF WASTE ON LAND AS A RECOVERY ACTIVITY FOR THE RESTORATION OF PHASES 3A, 3B, 4A, 4B, 5A, 5B, 6A, 6B, 6C AND 7 AT ALREWAS QUARRY, ALREWAS, STAFFORDSHIRE

HYDROGEOLOGICAL RISK ASSESSMENT

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1. Introduction

1.1 MJCA is commissioned by Tarmac Trading Limited (Tarmac) to prepare an application (the application) for a bespoke Environmental Permit (EP) for the deposition of waste on land as a recovery operation in order to restore Phases 3A, 3B, 4A, 4B, 5A, 5B, 6A, 6B, 6C and 7 at Alrewas Quarry, Croxall Road, Alrewas, Staffordshire. This report comprises the hydrogeological risk assessment (HRA) to support the EP application. Throughout this application Phases 3A, 3B, 4A, 4B, 5A, 5B, 6A, 6B, 6C and 7 of Alrewas Quarry are referred to as the site.

1.2 Alrewas Quarry is operated by Tarmac for the extraction of sand and gravel. As explained in the Conceptual Site Model, Environmental Setting and Site Design (ESSD) report presented at Appendix F of the application report and shown on Figure ESSD 2 there are five phases of mineral extraction at the site comprising Phases 3 to 7 inclusive. Phases 3 to 6 are subdivided into smaller areas of operation. The site is the subject of planning permission reference L.19/09/817 MW issued by Staffordshire County Council (SCC) on 21 June 2021 for mineral extraction and restoration. The restoration of the site will necessitate the importation of approximately 3.6Mm^3 of inert materials to restore the site to agriculture, amenity and nature conservation. The approved restoration scheme is shown on drawings references A301-0079-05 and A301-0079-06 copies of which are presented in the ESSD report.

1.3 The HRA is based on the conceptual model presented in the ESSD report. Details of the environmental setting of the site, the geology and hydrogeology, the development design, the history of the site, potential contamination migration pathways and receptors are described in the ESSD report. The acceptance at the site of inert waste materials only will be subject of waste acceptance procedures which are presented at Appendix M of the application report.

1.4 The structure of this HRA report generally is based on Environment Agency (EA) guidance[1] updated in October 2022. The hydrogeological risk assessment and technical precautions sections specified in the EA guidance are presented in Sections

[1] https://www.gov.uk/guidance/landfill-operators-environmental-permits/what-to-include-in-your-hydrogeological-risk-assessment

2 to 4 of this report. All of the relevant subheadings from the guidance are included in these sections albeit in a different order to those presented in the risk assessment. Additional subheadings have been included as appropriate.

1.5 It is concluded in the HRA that there is no significant risk from the proposed deposition of inert waste as a recovery activity to groundwater and surface water quality in the vicinity of the site over the whole life cycle of the site.

2. Hydrogeological risk assessment – Qualitative risk screening (Tier 1)

2.1 The hydrogeological risk assessment is undertaken in accordance with EA guidance[1] and follows a tiered approach to risk assessment[2] with the level of risk assessment proportional to the risks to groundwater and surface water from the proposed recovery operation. Information on the geology, hydrology and hydrogeology of the site is presented in the ESSD report. The information in the ESSD report is used to identify the relationships between the source, pathways and the identified potential receptors.

Nature of the hydrogeological risk assessment

Potential risks presented by the site

2.2 The areas in which imported inert restoration materials will be deposited comprise Phases 3A, 3B, 4A, 4B, 5A, 5B, 6A, 6B, 6C and 7 (Figure ESSD 2). As set out in the ESSD, inert waste is defined in the EU Landfill Directive (Council Directive 1999/31/EC) as:

> *"…waste that does not undergo any significant physical, chemical or biological transformations. Inert waste will not dissolve, burn or otherwise physically or chemically react, biodegrade or adversely affect other matter with which it comes into contact in a way likely to give rise to environmental pollution or harm human health. The total leachability and pollutant content of the waste and the eco toxicity of the leachate must be insignificant, and in particular not endanger the quality of surface water and/or groundwater."*

2.3 The waste types that it is proposed may be accepted at the site are presented in Table ESSD1 comprising inert waste types only. With the exception of Waste Code 01 04 12 ("Tailings and other wastes from washing and cleaning of minerals other than those mentioned in 01 04 07 and 01 04 11") the waste types listed in Table

2 https://www.gov.uk/guidance/groundwater-risk-assessment-for-your-environmental-permit#use-a-tiered-approach-to-your-risk-assessment

ESSD 1 are specified in the guidance[3] as waste types that a producer may not need to test apart from testing for classification purposes.

2.4 Detailed waste acceptance procedures which include for the testing of waste as required will be in place to minimise the risk that unacceptable waste materials are accepted at the site. Procedures will be in place for the rejection of nonconforming loads. The waste acceptance procedures are presented at Appendix M of the application report. The receipt, handling and storage of materials are the subject of the ISO 14001 Environmental Management System (EMS) a summary of which is presented at Appendix K of the application report.

2.5 Consistent with the information presented in the ESSD report it is considered that the waste does not comprise a contaminant source with the potential to have a significant detrimental effect on groundwater quality. It is understood from Tarmac that a significant proportion of the waste which will be deposited will either comprise waste which may be accepted without testing apart from testing for classification purposes or Waste Code 01 04 12 ("Tailings and other wastes from washing and cleaning of minerals other than those mentioned in 01 04 07 and 01 04 11"). The waste which may be accepted without testing must be from a single source, well characterised and described and carry no risk of contamination originating for example from a site that has not been developed previously.

2.6 The material which it is proposed will be deposited under waste code 01 04 12 will originate from Mountsorrel Quarry which is operated by Tarmac and will comprise:-

- Filter cake resultant from silt presses associated with the primary washing of quarried granite materials.
- Dried silt resulting from washing of quarried granite materials where the silt is dried in bays.

2.7 The materials which it is proposed will be deposited under waste code 01 04 12 will be inert and will be the subject of the same waste acceptance procedure as other waste materials accepted at the site and as such will only be accepted if they are

3 www.gov.uk/government/publications/deposit-for-recovery-operators-environmental-permits/waste-acceptance-procedures-for-deposit-for-recovery

chemically and physically suitable. Several results of laboratory testing of samples of the material which it is proposed will be deposited under waste code 01 04 12 were provided to the EA with an e-mail dated 25 November 2021 which is reproduced at Appendix C to the application report. Based on the test results the material comprises inert waste and the leached concentrations of hazardous substances typically are below the respective analytical detection limits and the concentrations of non-hazardous substances are not significantly elevated. Concentrations of the hazardous substance arsenic have been recorded above the detection limit in a small number of samples. Where recorded above the analytical detection limit the concentrations of arsenic are not significantly elevated and are typically recorded at concentrations only slightly higher than the detection limit.

2.8 A proportion of the waste that it is proposed to accept at the site may not meet the relevant criteria set out in guidance for acceptance at the site without testing apart from testing for classification purposes. On that basis and consistent with the waste acceptance procedures provided at Appendix M to the application report it would be necessary to test this waste to ascertain whether it is chemically and physically suitable. Appropriate leaching tests would need to be carried out to confirm that the concentrations of substances present in the eluate do not exceed the limit values specified in Table 3 of the waste acceptance procedures and the total content of specified organic parameters of the waste does not exceed the limit values presented in Table 4 of the waste acceptance procedures.

2.9 Based on consideration of the waste types that it is proposed will be accepted at the site it is considered highly unlikely that the concentrations of hazardous and non-hazardous substances leaching from the waste deposited would be sufficient to cause a discernible discharge of hazardous substances in groundwater or pollution of groundwater by non-hazardous substances. It is considered highly likely that the average concentrations leaching from the waste would be significantly lower than the limit values specified in Table 3 of the waste acceptance procedures and the total content of specified organic parameters of the waste would not exceed the limit values presented in Table 4 of the waste acceptance procedures.

2.10 As the restoration materials imported to the site will comprise inert waste only and based on the waste types which will be accepted it is highly unlikely that there will be significant concentrations of hazardous substances or significant concentrations of non-hazardous pollutants in water that has percolated through the waste mass. Based on the proposed use of inert imported restoration materials and on site materials only it is considered that there will be no significant risks to human health or to the environment from the proposed development.

2.11 Although it is considered highly unlikely that the waste comprises a contaminant source with the potential to have a significant detrimental effect on groundwater quality there is a theoretical possibility that the acceptance at the site of inert waste could leach hazardous substances at concentrations greater that the respective relevant minimum reporting values (MRV) for hazardous substances in groundwater or non-hazardous substances at concentrations sufficient to cause pollution of groundwater. On this basis there is a theoretical possibility of a discernible discharge of hazardous substances to groundwater or pollution of groundwater by non-hazardous substances.

Sensitivity of surrounding water environment

2.12 As set out in the ESSD, the superficial geology at the site comprises Quaternary River Terrace Deposits and/or Quaternary Glaciofluvial Sheet Deposits. The south west of Phase 7 and the west of Phase 6 is underlain by the superficial Quaternary Holme Pierrepont Sand and Gravel Member and part of the east of Phase 7 is underlain by superficial Alluvium deposits comprising clay, silt, sand and gravel. The superficial deposits at the site are designated as a Secondary A aquifer with shallow groundwater typically recorded between 0.5m below ground level (mbgl) and 3mbgl. It is likely that the River Tame is in hydraulic continuity with groundwater in the superficial deposits at and in the vicinity of the proposed extraction area. Locally the degree of hydraulic continuity may be limited by the presence of low permeability horizons comprising the Alluvium deposited by the River Tame. The superficial deposits are underlain by the Triassic Mercia Mudstone Group Secondary B aquifer.

2.13 During excavation and restoration operations at the site the void will be dewatered to facilitate dry working of the sand and gravel deposits and the placement of restoration materials. Dewatering in each phase will be by gravity flow to a sump positioned along a channel in the base of the workings. Fine material will settle out in the channel and the sump prior to consented discharge to surface watercourses and as necessary recharge trenches at and in the vicinity of the site. Based on the Conceptual Site Model the site is in a moderately sensitive setting as the site is located in and on a Secondary A aquifer and the site is sub-water table hence groundwater provides a direct pathway to surface water receptors from the site comprising the River Tame.

Hazards posed and likelihood of the risk happening

2.14 Based on the proposed use of inert waste only that there will be no significant risks to human health or to the environment from the proposed development and waste acceptance procedures will be in place to minimise the risk that unacceptable waste materials are accepted. In addition consideration has been given to the mitigation of residual risk based on the moderate sensitivity of the site setting and taking into account the theoretical possibility that the acceptance at the site of inert waste could result in the leaching of hazardous substances at concentrations greater than their respective MRV.

2.15 If the acceptance at the site of inert waste results in the leaching of hazardous substances at concentrations greater than their respective MRV and in the absence of a suitable geological barrier or attenuation layer there would be a theoretical risk of a direct discharge of hazardous substances to groundwater. We understand that the EA would now expect that an attenuation layer is constructed to physically separate groundwater in the aquifer round the site and any waste deposited below the water table which has the potential to leach hazardous substances at concentrations greater than their respective MRV.

2.16 It is proposed that the attenuation layer is constructed from suitable site won or imported Mercia Mudstone Group (MMG) strata. As MMG strata is present at the site it is considered that quality of groundwater in the attenuation layer would be similar to the quality of groundwater present at the site already and would not contain hazardous substances. As the attenuation layer would physically separate any hazardous substances present in water percolating the waste from groundwater present in the Secondary A aquifer round the site there would be no direct discharge of hazardous substances to groundwater in the unlikely event that acceptance at the site of inert waste results in the leaching of hazardous substances at concentrations greater than their respective MRV. The attenuation layer will also attenuate the discharge of non-hazardous pollutants to groundwater in the unlikely scenario where water percolating through the waste mass includes significant concentrations of non-hazardous pollutants.

2.17 It is proposed that the attenuation layer will be equivalent to a natural geological barrier 1m thick with a maximum hydraulic conductivity of 1 x 10^{-7}m/s and will be constructed in the external side slopes of each area prior to the placement of imported inert restoration materials. It is likely that the MMG strata will have a hydraulic conductivity significantly lower than 1 x 10^{-7}m/s. Further details on the construction of the attenuation layer are outlined in the Stability Risk Assessment (SRA) presented at Appendix I to the application report. Consistent with information presented in the ESSD report where an area of the MMG strata forming the quarry base is determined through Construction Quality Assurance (CQA) procedures at the site to not form a natural attenuation layer then a section of basal attenuation layer equivalent to 1m of in situ material with a hydraulic conductivity no greater than 1 x 10^{-7} m/s would be constructed locally over this area extending beyond it by 3m in all directions.

Qualitative risk screening (Tier 1)

2.18 A qualitative risk screening (Tier 1) is presented above with the Source – pathway – receptor linkages throughout the lifecycle of the site summarised in Table HRA 1 and the indicative hydrogeological cross sections presented on Figure ESSD 12. Based on this qualitative risk screening it is considered highly unlikely that there would be a significant risk from the proposed deposition of inert restoration materials at the site to groundwater quality in the superficial Secondary A aquifers or the surface water quality in the River Tame as it is considered highly unlikely that the waste comprises a contaminant source with the potential to have a significant detrimental effect on water quality. Due to the moderately sensitive setting of the site it is proposed that an attenuation layer equivalent to a natural geological barrier at least 1m thick will be constructed against the external side slopes (and where necessary in parts of the base) of the excavations at the site prior to imported inert restoration materials being placed on which basis there will be no direct discharge of hazardous substances and non-hazardous pollutants will be attenuated in the unlikely scenario that water percolating through the waste mass contains hazardous substances or significant concentrations of non-hazardous pollutants.

Consideration for further tiers of risk assessment

2.19 While it is considered that the Tier 1 qualitative risk screening demonstrates that it is highly unlikely that there would be a significant risk from the proposed deposition of inert restoration materials at the site to surrounding groundwater and surface water quality and that a precautionary approach has been taken with the inclusion of an attenuation layer, a further Tier 2 generic quantitative risk assessment (GQRA) and supplementary attenuation calculations has been undertaken to support these conclusions and is presented at Section 3 to this report. While the Tier 1 qualitative risk screening does not suggest there is an unacceptable risk, it is considered that due to the moderately sensitive setting of the site the Environment Agency will expect a further Tier 2 GQRA.

3. Hydrogeological risk assessment – Generic quantitative risk assessment (GQRA) with supplementary attenuation calculations (Tier 2)

3.1 Although it is determined in the qualitative risk screening presented in the HRA that it is highly unlikely that there would be a significant risk posed to groundwater and surface water quality by the deposition of inert restoration materials at the site, a generic quantitative risk assessment (GQRA) with supplementary attenuation calculations (Tier 2) has been carried out.

3.2 The GQRA is based on the highly unlikely scenario that the concentrations of substances leaching from the waste would be consistent with the waste acceptance criteria set out in Table 3 and Table 4 of the waste acceptance procedures even though, as explained above, it is considered highly likely that the average concentrations leaching from the waste would be significantly lower than the relevant limit values specified in the waste acceptance procedures. On this basis it is considered that the GQRA is highly conservative.

Priority contaminants

3.3 Consistent with the EA guidance[1] the modelled substances have been selected by way of a risk screening exercise. The proposed waste acceptance criteria have been screened against screening assessment criteria. For hazardous substances the relevant screening criterion is the MRV where available or otherwise the limit of quantification provided in the UKTAG Technical report on Groundwater Hazardous Substances. For non-hazardous pollutants the screening assessment criterion is the minimum of the UK Drinking Water Standard (DWS), freshwater Environmental Quality Standard (EQS) or the background groundwater concentrations. For the purposes of the screening assessment groundwater quality monitoring data for boreholes BH1/15 to BH3/15, BH1/20, BH2/20, BH1/21, BH2/21, BH3/21, BH1/97 to BH5/97, BHP02, BHP3 and WH26 have been reviewed for the period December 2015 to May 2022. Groundwater quality monitoring data generally is not available for boreholes BH4/15, BH8/97 which otherwise are located such that background groundwater quality would be considered relevant if it was available. The locations of the boreholes are shown on Figure ESSD 10. The screening assessment sheet is presented at Appendix HRA A.

3.4 As part of the risk screening exercise a risk characterisation ratio (RCR) has been calculated as the assumed source concentration divided by the relevant screening criterion. Based on the risk screening exercise the hazardous substances arsenic, mercury, lead and toluene have a RCR greater than 10 and have been selected for modelling. The non-hazardous pollutants cadmium, copper and zinc have a RCR greater than 10 and comprise substances for which a UK DWS or EQS have been set. The substances with a RCR greater than 10 that are not included in the GQRA have lower RCR than substances that it is considered will behave similarly in the environment as substances included in the GQRA and/or comprise substances for which a UK DWS or EQS have not been set.

3.5 Conservatively the source term concentrations assumed in the GQRA comprise the liquid to solid ratio 10 l/kg leaching limit values presented in the EU Commission document for inert Waste Acceptance Criteria (WAC)[4] expressed in mg/l. The liquid to solid ratio 10 l/kg leaching limit values for inert waste are those with which waste leaching test results are compared prior to acceptance at an inert waste landfill as necessary. The source term concentration for toluene is based on the solid composition WAC for BTEX converted into mg/l. For the purpose of the GQRA it is assumed that the total BTEX concentration comprises toluene.

Review of technical precautions

3.6 As set out in the qualitative risk screening in Section 2 of the HRA, notwithstanding that it is concluded based on the proposed use of inert waste only that there will be no significant risks to the environment from the proposed development consideration has been given to the mitigation of residual risk given the sensitivity of the site setting. It is proposed that an attenuation layer equivalent to a natural geological barrier 1m thick with a maximum hydraulic conductivity of 1×10^{-7}m/s will be constructed against the external side slopes (and in parts of the base as necessary) of each area of excavated quarry prior to the placement of imported inert restoration materials. The attenuation layer will comprise MMG strata available at the site or imported to the site.

[4] Council decision of 19 December 2002 establishing criteria and procedures for the acceptance of waste at landfills pursuant to Article 16 of and Annex II to Directive 1999/31/EC. Official Journal of the European Communities. 2003/33/EC

Modelling approach

3.7 As explained above a GQRA has been undertaken which is supplemented as necessary by detailed calculations of the attenuation of substances migrating through the attenuation layer.

3.8 For the purpose of the GQRA the site has been divided into three areas:

- Phase 7 which is the northernmost phase;
- Phases 3, 6 and 4A located in the centre of the site; and
- the southernmost phases consisting of Phase 4B and Phase 5.

The calculations are presented in separate spreadsheets. A description of the approach to the calculations is provided in this report together with summary tables recording the input parameter values used and the justifications for the parameter values used. The principal aspects of the spreadsheet calculations comprising the water balance, the generic HRA and the supplementary attenuation calculations are described below together with the results of the calculations.

Water balance calculation principles

3.9 The principles of the water balance calculations and similar calculations submitted to the EA in respect of another site in a comparable hydrogeological setting have been reviewed in detail and accepted by the Environment Agency.

3.10 Water flowing through the restoration materials including materials deposited partly or entirely below the water table has the potential to leach substances present in the restoration materials. The mass flux of substances from the restoration materials will depend on the concentrations of substances leached from the restoration materials (the source) and the rate of flow of water through the source.

3.11 The rate of flow of water through the source will depend on the hydraulic properties of the source and the local hydrogeology. Water flowing through the source may originate from rainfall recharge or where material is deposited below the rest groundwater level in an aquifer there may be potential for groundwater already present in the aquifer to flow through the deposited material. The hydraulics of flow through the restoration materials deposited below the groundwater table is potentially complex especially where the relative proportions of recharge flow and groundwater flow through the source needs to be considered. As the restoration materials deposited at the site are expected to comprise predominantly silt and clay sized particles the hydraulic conductivity of the restoration materials and the attenuation layer in the sidewall is likely to be similar and on this basis for the purpose of the water balance calculations the attenuation layer in the sidewall and the deposited restoration materials are considered as a single unit.

3.12 The assumed conceptual models for industry standard hydrogeological modelling tools such as LandSim, ConSim or the EA spreadsheet model for hydraulic containment landfills[5] are not suitable for modelling a combination of groundwater flow and recharge flow through a source deposited below the groundwater table and where necessary modelling attenuation in an attenuation layer located between the deposited restoration materials and the aquifer. On this basis estimates of the relative amounts of groundwater flow and recharge flow passing through a source deposited below the water table have been made using a modified form of the Dupuit equation[6] based on the standard Dupuit assumptions that the hydraulic gradient is equal to the slope of the water table and that flow is horizontal. The deposited restoration materials are modelled as an unconfined aquifer with heads at the up hydraulic gradient and down hydraulic gradient boundaries of the deposit consistent with assumed saturated thicknesses in the aquifer external to the deposit. The base of the deposit which comprises the Mercia Mudstone Group is assumed to be a no flow boundary orientated horizontally.

3.13 The detail of the calculations including the equations used is presented in the *Flow* worksheet of the spreadsheet models. A diagram showing the key geometrical relations relevant to the calculations is also shown on the *Flow* worksheet. For simplicity the flow through the restoration materials and immediate dilution in the aquifer is modelled per unit width perpendicular to groundwater flow. The spreadsheet models are presented at Appendix HRA B.

[5] S. R. Buss, A. W. Herbert, K. M. Green & C. Atkinson. 2004. Contaminant fluxes from hydraulic containment landfills spreadsheet v1.0: User Manual. Environment Agency Science Report SC0310/SR. Environment Agency, Bristol.

[6] Fetter, C.W. 2001. Applied Hydrogeology, 4th Edition. Pages 140 to 144.

3.14 The modified form of the Dupuit equation that is used allows for infiltration or evaporation at the water table. Use of the Dupuit equation facilitates the calculation of the discharge rate per unit width (q'_x) for any section perpendicular to groundwater flow at a distance *x* from the origin which for the purpose of the calculations is a point external to the attenuation layer immediately up hydraulic gradient of the deposited restoration materials. The discharge rate per unit width is calculated based on the recharge rate *ω*, the head at the origin h_1 (where $x=0$) and the head h_2 at a point *L* which for the purpose of the calculations is a point external to the attenuation layer immediately down hydraulic gradient of the restoration materials (where $x=L$). On this basis the rate per unit width of inflow or outflow through both the up hydraulic gradient sidewall attenuation layer and the down hydraulic gradient sidewall attenuation layer can be calculated.

3.15 The physical input parameters relevant to the water balance calculations are summarised in Table HRA 2. Further comments relevant to the calculation of the water balance for each phase are presented below.

Water balance

3.16 Initially the results of the water balance for each model were calculated using an assumed infiltration rate of 51.8mm per year consistent with the site specific water balance calculations presented at Appendix HRA C which is equivalent to a recharge rate of 1.64×10^{-9} m/s. This does not take into account the low permeability substrate of the imported restoration materials which will limit the rate at which water can infiltrate the restoration materials.

3.17 Although the head of water driving the flow of recharge through the restoration materials will build up in the restoration materials as a result of infiltration the maximum head of water which can be reached in the restoration materials will be no higher than the restored ground level on the restoration landform. The maximum head of water in the restoration materials will be unable to increase further as evidently there will be no restoration materials placed above the restored ground levels which can become saturated. Based on the geometry of the restored landform the head would be unable to build up to a value sufficient to drive flow equivalent to 1.64×10^{-9}m/s through the deposit of restoration materials to discharge laterally through the attenuation layer. This finding is consistent with the expectations that over time the generally low permeability restoration materials will accept infiltration until they become saturated. When the restoration materials close to or at the surface of the restored landform become saturated their potential to accept further infiltration will be significantly reduced and on account of this the rate of runoff from the restored landform will increase. On this basis it is unrealistic to assume that the rate of recharge to the restoration materials will be as high as 1.64×10^{-9}m/s.

3.18 An estimate of the rate at which recharge flow could pass through the restoration materials has been made by varying the recharge until the head at the water table divide is equal to the maximum possible head at a groundwater divide in the restored landform. The relevant calculations are presented on the *Flow* worksheet for each model.

3.19 As confirmed by the calculations presented in the *Flow* worksheet the generally low permeability of the restoration materials will result in the build up of a head of water in the restoration materials. Under passive flow conditions following the restoration of the site the head of water in the restoration materials will remain higher than in the surrounding aquifer which will have a significantly greater permeability. On this basis a hydraulic gradient will be maintained outwards from the deposited restoration materials and there will be no flow of groundwater from the aquifer through the restoration materials. It is assumed that there will be outflow through both the up hydraulic gradient and down hydraulic gradient sidewalls and estimates of the magnitude of this flow are calculated in the *Flow* worksheet. The overall water balance is summarised in the *WaterBalance* worksheet and the estimated total flow through the restoration materials and the estimated flow in the aquifer are used in the subsequent generic hydrogeological risk assessment calculations.

Generic quantitative risk assessment

3.20 It is assumed that the whole mass of restoration materials comprises a potential source. The source concentrations assumed comprise generally the liquid to solid ratio 10l/kg leaching limit values expressed in mg/l presented in the EU Commission document for inert WAC[4]. It is considered highly unlikely that the average leached concentrations in the restoration materials would be as high as the inert WAC limit values and on this basis the assumptions made with respect to the source term are considered conservative. The source term concentrations are specified in Table HRA 3.

3.21 Based on a simple dilution calculation using the equation set out on the *GenericAssessment* worksheet the concentrations of the substances at a compliance point in the sand and gravel aquifer are estimated taking into account immediate dilution in the aquifer. It is assumed that groundwater flowing in the sand and gravel aquifer up hydraulic gradient of the phases will be diverted around the low permeability materials comprising the attenuation layer and the deposited restoration materials. On this basis the approach to calculating the groundwater flow is consistent generally with the approach adopted to calculating the steady state dilution in the aquifer presented in the EA spreadsheet model "Contaminant Fluxes from Hydraulic Containment Landfills Worksheet Version 1.0".

3.22 For each of the substances modelled EALs have been specified. The EALs and the basis for their derivation are set out in Table HRA 3. To assess the magnitude of the potential impact on groundwater the predicted concentration of contaminants in the sand and gravel aquifer at the compliance point following immediate dilution are compared with the EALs.

The need for supplementary attenuation calculations

3.23 Based on the GQRA there are several substances for which it is calculated that the concentrations in the aquifer following immediate dilution may exceed their respective EALs if attenuation processes in the attenuation layer are not taken into account. For this reason further supplementary calculations have been undertaken which take into account attenuation processes in the attenuation layer.

3.24 Attenuation of substances passing through the attenuation layer is calculated using solutions to the advection dispersion equation. Two independent but complementary approaches are used to calculate the concentrations at the down hydraulic gradient edge of the attenuation layer comprising an analytical solution to the advection dispersion equation and a numerical solution. The use of two independent approaches facilitates a cross check between the results. The analytical solution to the advection dispersion equation that is used is the analytical solution developed for

LandSim release 1 which takes into account an exponentially declining source[7]. The numerical solution used is consistent with the Laplace Transformation approach used in LandSim release 2 albeit that it is implemented in the spreadsheet in a slightly simplified form because attenuation is modelled in a single pathway only (the attenuation layer at the down hydraulic gradient edge of the superficial deposits) rather than in multiple consecutive pathways as is typically the case when it is used in LandSim (unsaturated pathway, saturated vertical pathway and aquifer pathway). Once the Laplace Transformed concentrations have been calculated a numerical "inversion" algorithm is used to determine the change in concentrations over time. A numerical inversion algorithm has been implemented in Visual Basic for Applications as a macro within the spreadsheet for this purpose. Although it is possible to take into account transverse dispersion occurring in the attenuation layer this has been ignored as each unit width slice of restoration materials modelled may be located adjacent to a similar unit width slice of restoration materials with similar source concentrations hence it may not be conservative to include the transverse dispersion.

3.25 The supplementary calculations take into account source decline. The approach to calculating the declining source is consistent with the approach adopted in LandSim release 2.5[8] whereby the change in concentration of each species in the source through time is based on the initial concentration of these species, K (kappa) which is a species and materials specific constant and the liquid to solid ratio which is the aqueous losses from the restoration materials at any time t divided by the waste mass. It is reported that this approach is similar to that adopted by the EU Technical Adaption Committee during the derivation of the waste acceptance criteria.

3.26 For the purpose of the supplementary attenuation calculations it is assumed that the total calculated outflow from both the down hydraulic gradient attenuation layer and the up hydraulic gradient attenuation layer (where applicable) flows out through the down hydraulic gradient boundary. This simplifying assumption avoids the need to undertake attenuation calculations for both the up hydraulic gradient and down hydraulic gradient attenuation layers but also means that breakthrough of substances may occur significantly sooner than would otherwise be the case because increasing

[7] Environment Agency. 1996. LandSim. Landfill performance assessment: Simulation by Monte Carlo method. R&D Publication 120. Release 2. (LandSim version 2)
[8] Golder Associates. 2003. Addendum to LandSim 2 manual relevant to LandSim 2.5.

the rate of outflow through any single face will also result in a higher mean water flow velocity in the attenuation layer. On this basis the simplifying assumption is significantly conservative.

3.27 The input parameters relevant to attenuation in the flow path and source decay and their justifications are specified in Table HRA 4. The detail of the source decline calculations for each of the substances modelled (parameter P1 to parameter P7) are presented in the *SrcDecline* worksheet and the equation used is set out on the *SourceInputsAttenuation* worksheet. The detail of the numerical solution to the advection dispersion equation including the equations used is presented in the *NumericalSolutions* worksheet. The calculated concentrations for each parameter P1 to P7 using the numerical solution to the advection dispersion equation are presented on worksheets *P1* to *P7*. The calculated concentrations for each parameter P1 to P7 using the analytical solution are presented on worksheets *P1an* to *P7an*.

3.28 On worksheets *P1graph* to *P7graph* individual graphs are provided for each parameter P1 to P7 showing the calculated concentrations at the edge of the attenuation layer and in the aquifer following immediate dilution using both the analytical solution and the numerical solution to the advection dispersion equation. As shown on the graphs there generally is excellent agreement between the results calculated using the two calculation methods.

Model results – Emissions to groundwater or surface water

3.29 The spreadsheet based model which calculates the predicted concentration of contaminants in the sand and gravel aquifer at the compliance point is presented at Appendix HRA B. The results of the GQRA is presented in the *GenericAssessment* worksheet and the results of the supplementary attenuation calculations are presented in the *WithAttenuation* worksheet.

Hazardous substances and non-hazardous pollutants

3.30 As an attenuation layer comprising Mercia Mudstone will be present between the surrounding and underlying aquifers and the inert infill materials there will be no direct discharge of hazardous substances or non-hazardous pollutants from the placement of inert restoration materials at the site. The GQRA model represents the potential indirect discharge of hazardous substances and non-hazardous pollutants from the placement of inert restoration materials at the site.

Results for the "North" model (Phase 7)

3.31 The results of the GQRA for the northern part of the site (Table HRA 5) show that the calculated concentrations of the hazardous substances mercury, lead and toluene are predicted to exceed the EALs in the sand and gravel aquifer after immediate dilution is taken into account. The results of the supplementary attenuation calculations for the northern part of the site show that the calculated concentrations of the hazardous substances and non-hazardous pollutants are lower than their respective EALs with the exception of lead which exceeds the EAL by a factor of 15 approximately.

3.32 As lead is predicted to exceed the EAL even after attenuation in the attenuation layer is taken into account it is proposed that a site specific WAC will be implemented in respect of lead at Phase 7. The proposed limit value for lead at Phase 7 is 0.031mg/kg at a liquid to solid ratio of 10 l/kg compared with the inert WAC for lead of 0.5mg/kg at a liquid to solid ratio of 10 l/kg. Consistent with Table HRA 5 the predicted concentrations of lead are below the EAL for the "North_SWAC" model presented at Appendix HRA B in which a source concentration consistent with a 0.031mg/kg lead leaching limit value is assumed.

Results for the "Centre" model (Phases 3, 6 and 4A)

3.33 The results of the GQRA for the central part of the site (Table HRA 6) show that the calculated concentrations of the hazardous substances lead and toluene exceed the EALs in the sand and gravel aquifer after immediate dilution is taken into account. The results of the supplementary attenuation calculations for the central part of the site show that the calculated concentrations of the hazardous substances and non-hazardous pollutants are lower than their respective EALs.

Results for the "South" model (Phases 4B and 5)

3.34 The results of the GQRA for the southern part of the site (Table HRA 7) show that the calculated concentrations of the hazardous substances lead, mercury and toluene exceed the EALs in the sand and gravel aquifer after immediate dilution is taken into account. The results of the supplementary attenuation calculations for the southern part of the site show that the calculated concentrations of the hazardous substances and non-hazardous pollutants are lower than their respective EALs with the exception of lead which exceeds the EAL by a factor of 5 approximately.

3.35 As lead is predicted to exceed the EAL even after attenuation in the attenuation layer is taken into account it is proposed that a site specific WAC will be implemented in respect of lead at Phases 4B and 5. The proposed limit value for lead at Phase 4B and 5 is 0.09mg/kg at a liquid to solid ratio of 10 l/kg compared with the inert WAC for lead of 0.5mg/kg at a liquid to solid ratio of 10 l/kg. Consistent with Table HRA 7 the predicted concentrations of lead are below the EAL for the “South_SWAC” model presented at Appendix HRA B in which a source concentration consistent with a 0.09mg/kg lead leaching limit value is assumed.

Model verification

3.36 Where possible the input parameters used in the GQRA and supplementary attenuation calculations are based on site specific data or other relevant sources. Where no site specific data are available professional judgement has been used to select appropriate parameter values. Two independent but complementary approaches are used to calculate the concentrations at the down hydraulic gradient edge of the attenuation layer comprising an analytical solution to the advection dispersion equation and a numerical solution. Both approaches have previously been implemented in LandSim albeit that the use of LandSim is not appropriate at this site because waste will be deposited below the groundwater table. The use of two independent approaches facilitates a cross check between the results. Sensitivity analyses have been carried out and are presented in the following section of the report to assess the sensitivity of the model to the assumptions made in the input parameters. It is proposed that verification monitoring is carried out during the operation and post operational phases of the site. The proposed verification monitoring is presented in section 4 of this HRA.

Sensitivity analysis

3.37 It is considered that the results of the water balance calculations, the GQRA and the supplementary attenuation calculations are conservative:

- It is considered highly likely that the average concentrations leaching from the waste would be significantly lower than the limit values specified in Table 3 of the waste acceptance procedures and the total content of specified organic parameters of the waste would not exceed the limit values presented in Table 4 of the waste acceptance procedures.

- As the restoration materials deposited at the site are expected to comprise predominantly silt and clay sized particles the hydraulic conductivity of the restoration materials and the attenuation layer is likely to be significantly lower than assumed in the calculations.

- Other conservative assumptions have been used such as the simplifying assumption that total calculated outflow from both the down hydraulic gradient attenuation layer and the up hydraulic gradient attenuation layer flows out through the down hydraulic gradient boundary.

3.38 Several additional sensitivity scenarios have been modelled the results of which are presented at Appendix HRA D.

- A model in which a constant source is assumed.

- A model in which the waste hydraulic conductivity is a factor of two higher than the already conservative input value of $1x10^{-7}$ m/s assumed.

- A rogue load assessment which is described below under the “Accidents and their consequences” subheading.

3.39 The sensitivity scenario models have been run for the “North_SWAC” model (Phase 7) only as the predicted concentrations of this model generally are higher than for the other models. The relevant models are presented at Appendix HRA D:

- Constant source sensitivity scenario (“North_SWAC_constant”)

- Higher waste mass hydraulic conductivity sensitivity scenario (“North_SWAC_higherK”)
- Rogue load sensitivity scenario (“North_SWAC_rogue”).

The results of the sensitivity scenario modelling are summarised in Table HRA 8.

3.40 The sensitivity assessments confirm that even if a constant source is assumed or the waste hydraulic conductivity is double that assumed in the models at Appendix HRA B the number and magnitude of the exceedances of any EALs generally would be low. Based on the conservative way in which the models at Appendix HRA B have been parameterised and the results of the sensitivity analysis models presented at Appendix HRA D it is considered that the probability that there would be significant discharges of hazardous substances or pollution of groundwater by non-hazardous pollutants is low.

Accidents and their consequences

3.41 While it is considered that using the WAC liquid to solid 10 l/kg leaching limit values is a conservative approach as this assumes that all substances are at the maximum allowable limit, a further sensitivity analysis has been undertaken with respect to the source term concentration used in the model. An additional rogue load assessment has been carried out using the spreadsheet model. It is assumed for the purpose of the rogue load assessment that the concentration of 1 in 100 loads is 100 times higher than the maximum source term concentration assumed in the modelling which is considered highly improbable given the robust WAP which will be in place. It is assumed that the remaining 99% of loads will have a concentration equal to the maximum source term concentration assumed in the spreadsheet model which, as explained above, is considered conservative. For example, if the assumed source concentration of 99% of loads is 100mg/l then the mean source concentration assuming that 1% of loads are 100 times higher is 199mg/l. The equivalent source term for the rogue load assessment is a factor of 1.99 higher than the equivalent maximum source term concentration assumed in the spreadsheet model. The rogue load assessment is considered a highly unlikely scenario.

3.42 The spreadsheet models of the additional rogue load assessment are presented at Appendix HRA D. Based on the rogue load modelling (“North_SWAC_rogue”) the predicted concentrations of lead modelled would exceed the EALs by less than a factor of two and the predicted concentrations of other substances would remain below the respective EALs. The rogue load assessment confirms that even in the unlikely event that rogue loads are accepted at the site there is a low probability that there would be significant discharges of hazardous substances or pollution of groundwater by non-hazardous pollutants.

Conclusions of the GQRA with supplementary attenuation calculations

3.43 Based on the GQRA and supplementary attenuation calculations it is considered that there is no significant risk from the proposed deposition of inert restoration materials at the site to groundwater quality in the superficial aquifer or the surface water quality in the River Tame.

4. Hydrogeological risk assessment – verification monitoring

Hydrogeological leachate completion criteria

4.1 No biodegradable waste materials will be deposited at the site which could result in the generation of leachate. Only inert waste materials will be deposited at the site which have limited potential for leaching of contaminants. As such leachate completion criteria and leachate monitoring are not relevant to deposit for recovery sites.

Monitoring

4.2 A programme of groundwater monitoring is presented in Table ESSD 2. The monitoring will be carried out during the operation of the site and for a limited period following the restoration of the site. The monitoring locations are shown in Figure ESSD 10.

4.3 The proposed groundwater monitoring locations and determinands for which groundwater quality compliance and assessment limits will be set are presented in Table HRA 5. Consistent with Table HRA 9 groundwater quality compliance and assessment limits for groundwater at the down hydraulic gradient boreholes BH2/21, BH1/97, BH2/97, BH3/97, BH4/97, BH3/21 and BH5/97 have been calculated based on the groundwater quality monitoring data where available for the period December 2015 to May 2022. The calculations are presented at Appendix HRA A in the spreadsheets containing information on the background concentrations for individual substances in groundwater. The concentrations of hazardous substances mercury, lead and toluene are generally not recorded above their respective analytical detection limits in the groundwater monitoring data for the site. The groundwater quality compliance and assessment limits are based on minimum reporting values for these determinands.

4.4 No compliance or assessment limits are provided for surface water quality as based on the assessments carried out there is no direct pathway to surface water receptors following restoration of the site. This is consistent with the principles of monitoring the environmental performance of the site in respect of Phase 1 (the currently permitted area). During the operational phase of the site the discharge of water from the water management system to the surface water courses at and in the vicinity of the site will be the subject of discharge limits consistent an Environmental Permit. It is considered that the environmental performance of the proposed operations can be assessed with reference to groundwater quality.

5. Conclusions

5.1 Based on the GQRA and supplementary attenuation calculations it is considered that there is no significant risk from the proposed deposition of inert restoration materials at the site to groundwater quality in the superficial aquifer or the surface water quality in the River Tame.

5.2 As the GQRA is based on the highly unlikely scenario that the concentrations of substances leaching from the waste are consistent with the waste acceptance criteria set out in Table 3 and Table 4 of the waste acceptance procedures it is considered that the GQRA is highly conservative.

TABLES

Table HRA 1

Source – pathway – receptor linkages throughout the lifecycle of the site

Phase of landfill	Source	Pathway	Receptor
Operational	***Water percolating through the inert restoration materials*** Given the inert nature of the waste that will be deposited in the site the potential for the presence of discernible concentrations of hazardous substances or significant concentrations of non-hazardous pollutants is considered highly unlikely. During quarrying and restoration the groundwater table is lowered by groundwater pumping. The inert wastes will be placed above the lowered groundwater level.	Attenuation layer. Unsaturated superficial deposits. Water management system.	Water management system. Groundwater in the superficial deposits. Surface water reaches at and in the vicinity of the site.
Post operational/ completion	***Water percolating through the inert restoration materials*** Given the inert nature of the waste that will be deposited in the site the potential for the presence of discernible concentrations of hazardous substances or significant concentrations of non-hazardous pollutants is considered highly unlikely. The groundwater level will recover following cessation of groundwater pumping upon completion of infilling.	Attenuation layer. Groundwater in the superficial deposits.	Groundwater in the superficial deposits. River Tame.

Table HRA 2

Physical input parameters assumed in the water balance, generic quantitative risk assessment and supplementary attenuation calculations

Parameter		Units	Parameter value	Input worksheet title	Reference/Justification
Aquifer hydraulic conductivity, K_{aq}		m/s	2.31×10^{-5}	*Flow*	Based on information presented in the hydrogeological and hydrological risk assessment (HIA) for the superficial deposits at the site[9]. A value of 2m/d is used to represent the most likely hydraulic conductivity scenario.
Attenuation layer and restoration materials hydraulic conductivity		m/s	1×10^{-7}	*Flow*	It is assumed that the hydraulic conductivity of the restoration materials and attenuation layer is 1×10^{-7} m/s consistent with the upper range estimate for the hydraulic conductivity of clay reported by Kruseman and de Ridder 1994[10].
Attenuation layer thickness		m	1	*Flow*	Proposed minimum thickness.
Distance from origin to h_2, L	North	m	530	*Flow*	The approximate length of the flow path through the restoration materials and sidewall attenuation layers in each phase. Measured from site plans.
	Centre		540		
	South		390		
Head at origin	North	m	4.89	*Flow*	The approximate saturated thickness of the sand and gravel aquifer up hydraulic gradient of Phase 7 based on the log of borehole BH1/21.
	Centre		2.45		The approximate saturated thickness of the sand and gravel aquifer up hydraulic gradient of Phase 3B based on the log of borehole BH1/20.
	South		3.0		The approximate thickness of the sand and gravel aquifer in the up hydraulic gradient part of Phase 4B consistent with the indicative hydrogeological cross section shown on Figure ESSD 12. It is assumed that groundwater levels are approximately 1m below ground level (mbgl) at this location.
Head at L, h_2	North	m	4.71	*Flow*	The approximate saturated thickness of the sand and gravel aquifer up hydraulic gradient of Phase 7 based on the groundwater level recorded in borehole BH2/21 on 19 May 2022 and the base of the sand and gravel deposits recorded in borehole BH2/21.
	Centre		2.28		The approximate saturated thickness of the sand and gravel aquifer up hydraulic gradient of Phase 7 based on the log of borehole BH3/21 and the water level recorded in the same borehole on 17 May 2022.
	South		1.5		The approximate minimum thickness of the sand and gravel aquifer in Phase 5B consistent with the indicative hydrogeological cross section shown on Figure ESSD 12. It is assumed that groundwater levels are approximately 0.5m below ground level (mbgl) at this location.
Recharge rate, ω		m/s	1.64×10^{-9}	*Flow*	This is the starting value used in the calculations referred to as the *CALCULATED* value in the spreadsheet which is equivalent to 51.8mm per year. This is a site specific value which was calculated for the site. The calculations are presented at Appendix HRA C. The starting value does not take into account the low permeability substrate underlying the restoration soils limiting the rate at which water can infiltrate. Further site specific adjustments to the recharge rate based on the geometry of the site are made in the models presented at Appendix HRA B.
Maximum possible head at the groundwater divide in the restored landform	North	m	8	*Flow*	This value is approximate and based on the proposed restoration levels at the approximate centre of the waste mass and on the indicative hydrogeological cross section shown on Figure ESSD 12.
	Centre		4		This value is approximate and based on the proposed restoration levels at the approximate centre of the waste mass and on the indicative hydrogeological cross section shown on Figure ESSD 12.

9 MJCA. 2019. Hydrogeological and hydrological impact assessment for a southern extension to the existing mineral extraction operation and restoration at Alrewas Quarry, Staffordshire. Report reference TAR/AL/CJC/2974/01 dated September 2019.
10 Kruseman, G. p. and de Ridder, N. A. 1994. Analysis and Evaluation of Pumping Test Data. Second Edition. International Institute for Land Reclamation and Improvement Publication 47.

Parameter		Units	Parameter value	Input worksheet title	Reference/Justification
	South		4		This value is approximate and based on the proposed restoration levels at the approximate centre of the waste mass and on the indicative hydrogeological cross section shown on Figure ESSD 12.
Source length	North	m	528	*SourceInputsAttenuation*	The approximate length of the flow path through the restoration materials not including the sidewall attenuation layer.
	Centre		538		
	South		588		
Source thickness	North	m	7.0	*SourceInputsAttenuation*	The indicative thickness of the deposited restoration materials as shown on the indicative hydrogeological cross section shown on Figure ESSD 12. It is assumed that the thickness of restoration soils will be approximately 1m.
	Centre		3.0		The indicative thickness of the deposited restoration materials as shown on the indicative hydrogeological cross section shown on Figure ESSD 12. It is assumed that the thickness of restoration soils will be approximately 1m.
	South		3.0		The indicative thickness of the deposited restoration materials as shown on the indicative hydrogeological cross section shown on Figure ESSD 12. It is assumed that the thickness of restoration soils will be approximately 1m.
Hydraulic gradient in aquifer	North	-	0.0058	*Flow*	Based on Figure ESSD 11.
	Centre	-	0.0038	*Flow*	Based on Figure ESSD 11.
	South	-	0.0064	*Flow*	Based on Figure ESSD 11.
Source porosity and effective porosity		Fraction	0.3	*SourceInputsAttenuation, AttenuationInputs*	Consistent with the value assumed for inert waste in Hjelmar et al (2001)[11].
Source bulk density		kg/l	1.7	*SourceInputsAttenuation*	The midpoint of the range of values specific for clay in the ConSim release 2.5 help file.
Source dry density		kg/l	1.4	*SourceInputsAttenuation*	Calculated assuming a source bulk density of 1.7kg/l. It is assumed that the source is fully saturated with a porosity of 0.3.
Fraction of organic carbon (f_{oc})		Fraction	0.055	*SourceInputsAttenuation*	The midpoint of the range of values specific for clay in the ConSim release 2.5 help file.
Distance along the pathway in the direction of flow		m	1	*AttenuationInputs*	Consistent with the proposed minimum thickness of the attenuation layer.
Saturated thickness in the outflow region	North	m	4.71	*AttenuationInputs*	Assumed consistent with the head h_2 at the down hydraulic edge boundary of the attenuation layer.
	Centre		2.28		
	South		1.5		
Tortuosity		-	5	*AttenuationInputs*	Based on professional judgement. Freeze and Cherry[12] report that tortuosity ranges between 2 and 11.
Longitudinal dispersivity		m	0.1	*AttenuationInputs*	Consistent with the comments in the ConSim manual it is assumed that the longitudinal dispersivity is 10% of the pathway length. It is assumed that the transverse dispersivity is 30% of the longitudinal dispersivity.
Transverse dispersivity		m	0.03	*AttenuationInputs*	

[11] Hjelmar, O., Van Der Sloot, H. A., Guyonnet, D., Rietra, R. P. J. J., Brun, A. and Hall, D. 2001. Development of acceptance criteria for landfilling of waste: an approach based on impact modelling and scenario calculations. Proceedings Sardinia 2001, Eighth International Waste Management and Landfill Symposium. S Margharita di Pula, Calgiari, Italy; 1 – 5 October 2001. CISA, Environmental Sanitary Engineering Centre, Italy.

[12] Freeze, R. A. & Cherry. J. A. 1979. Groundwater. Prentice Hall, New Jersey.

Table HRA 3

Source term concentrations assumed in the generic quantitative risk assessment and supplementary attenuation calculations

Determinand	Environmental assessment limit (EAL) (mg/l) [a]	EAL source	Source term concentration (mg/l)	Assumed background concentrations (mg/l) [f]
Hazardous substances				
Arsenic [g]	North = 0.01 Centre = 0.0075 South = 0.0034	BGC	0.05 [b]	North = 0.0018 Centre = 0.0018 South = 0.0012
Mercury	0.00001	MRV	0.001 [b]	0
Lead	0.0002	MRV	0.05 [b]	0
Toluene	0.004	MRV	0.87 [c]	0
Non hazardous pollutants				
Cadmium [d]	North = 0.03 Centre = 0.027 South = 0.012	BGC	0.004 [b]	North = 0.003 Centre = 0.0017 South = 0.0005
Copper [e]	North = 0.23 Centre = 0.087 South = 0.011	BGC	0.2 [b]	North = 0.022 Centre = 0.0075 South = 0.0049
Zinc [h]	North = 0.071 Centre = 0.11 South = 0.090	EQS	0.4 [b]	North = 0.013 Centre = 0.017 South = 0.011

Notes:
MRV = Minimum reporting value;
EQS = Environmental Quality Standard;
BGC = Background groundwater concentration based on the available water quality monitoring data (calculations are presented in the "Background" subfolder at Appendix HRA A).

[a] The MRVs specified are consistent with MRVs specified at https://www.gov.uk/government/publications/values-for-groundwater-risk-assessments/hazardous-substances-to-groundwater-minimum-reporting-values unless stated otherwise.

[b] Based on the inert waste liquid to solid ratio 10 l/kg leaching limit values[13] expressed in mg/l.

[c] The source term for toluene is based on the solid composition WAC for BTEX converted into mg/l. It is conservatively assumed that the total BTEX concentration comprises toluene.

[d] The EQS for cadmium assuming a water hardness between 100mg/l and 200mg/l $CaCO_3$ is 0.00015mg/l. As the mean background concentration exceeds the EQS the EAL is set at the mean background concentration plus three standard deviations.

[e] The EQS for copper is 0.001mg/l. As the mean background concentration exceeds the EQS the EAL is set at the mean background concentration plus three standard deviations which generally is significantly lower than the maximum background concentration recorded for each area.

[f] It is assumed that mercury, lead and toluene are not present in groundwater at the site albeit that mercury and lead have been recorded above detection occasionally. Background arsenic concentrations are the mean concentrations recorded at the boreholes round area of the site.

[g] The EAL is set at the mean concentration plus three standard deviations which generally is significantly lower than the maximum background concentration recorded for each area.

[h] The EQS for zinc specified in the screening assessment at Appendix HRA A is 0.0109mg/l. As the mean background concentration exceeds the EQS the EAL is set at the mean background concentration plus three standard deviations which generally is significantly lower than the maximum background concentration recorded for each area

[13] Council decision of 19 December 2002 establishing criteria and procedures for the acceptance of waste at landfills pursuant to Article 16 of and Annex II to Directive 1999/31/EC. Official Journal of the European Communities. 2003/33/EC.

Table HRA 4

Input parameters relevant to attenuation in the flow path and source decay

Determinand	Organic carbon partition coefficient K_{oc} (ml/g) [a,b]	Distribution coefficient K_d (ml/g) [a]	Degradation half life $t_{½}$ (years) [a,c]	Free water diffusion coefficient D_w (m^2/s) [d]	Calculation of kappa (κ) constant [e]	
					m (slope) (kg/l)	c (intercept) (kg/l)
Hazardous substances						
Arsenic		25		5.94×10^{-10}	0.0415	-0.0862
Mercury		3835.4		5.94×10^{-10}	0.0767	0.1643
Lead		434.5		5.94×10^{-10}	0.0443	0.0171
Toluene	186.5		0.822	6.2×10^{-10}	0.0298	0.2919
Non hazardous pollutants						
Cadmium		222.2		5.94×10^{-10}	0.0823	0.1589
Copper		126.8		5.94×10^{-10}	0.0664	-0.0488
Zinc		25		5.94×10^{-10}	0.0403	0.0561

Notes:

[a] Parameters derived from ConSim suggested input parameters. For Zinc the K_d is the lowest reported value in the ConSim help file suggested input parameters.
[b] For organic substances K_{oc} values are used to calculate K_d.
[c] For substances which biodegrade.
[d] The default value for the diffusion coefficient assumed in LandSim (p111) is 1×10^{-12} irrespective of contaminant type. The value for toluene is the mean of the range of values reported in the Environment Agency hydraulic containment landfills contaminant fluxes review document[14]. The values for arsenic, mercury, lead, cadmium, copper and zinc are assumed consistent with the value for Cr^{3+} specified in the hydraulic containment landfills review document.
[e] The values are based on the default values in LandSim. It is assumed that the kappa constants for toluene is consistent with the values for chloride.

[14] S. R. Buss, A. W. Herbert, K. M. Green & C. Atkinson. 2004. Contaminant fluxes from hydraulic containment landfills – a review. Environment Agency Science Report SC0310/SR. Environment Agency, Bristol.

Table HRA 5

Results of the GQRA and supplementary attenuation calculations for the "North" model (Phase 7)

Determinand	**Environmental assessment limit (EAL)** (mg/l)	**GQRA results** (Appendix HRA B "North.xlsm" *GenericAssessment* worksheet)	**Supplementary attenuation calculations** (Appendix HRA B "North.xlsm" *WithAttenuation* worksheet)	**Supplementary attenuation calculations** (Appendix HRA B "North_SWAC.xlsm" *WithAttenuation* worksheet)
Hazardous substances				
Arsenic	1.00E-02	5.04E-03	5.02E-03	5.02E-03
Mercury	1.00E-05	**6.72E-05**	4.27E-07	4.27E-07
Lead	2.00E-04	**3.36E-03**	**2.90E-03**	1.95E-04
Toluene	4.00E-03	**5.84E-02**	1.92E-11	1.92E-11
Non hazardous substances				
Cadmium	3.00E-02	3.07E-03	3.04E-03	3.04E-03
Copper	2.30E-01	1.80E-02	1.70E-02	1.70E-02
Zinc	7.10E-02	3.90E-02	3.84E-02	3.84E-02

Note:
Concentrations denoted in bold text exceed the EAL.

Table HRA 6

Results of the GQRA and supplementary attenuation calculations for the "Centre" model (Phases 3, 6 and 4A)

Determinand	**Environmental assessment limit (EAL)** (mg/l)	**GQRA results** (Appendix HRA B "Centre.xlsm" *GenericAssessment* worksheet)	**Supplementary attenuation calculations** (Appendix HRA B "Centre.xlsm" *WithAttenuation* worksheet)
Hazardous substances			
Arsenic	7.50E-03	2.17E-03	2.16E-03
Mercury	1.00E-05	7.59E-06	1.15E-20
Lead	2.00E-04	**3.80E-04**	3.62E-05
Toluene	4.00E-03	**6.60E-03**	5.73E-26
Non hazardous substances			
Cadmium	2.70E-02	1.72E-03	1.70E-03
Copper	8.70E-02	8.96E-03	8.74E-03
Zinc	1.10E-01	1.99E-02	1.98E-02

Note:
Concentrations denoted in bold text exceed the EAL.

Table HRA 7

Results of the GQRA and supplementary attenuation calculations for the "South" model (Phases 4B and 5)

Determinand	**Environmental assessment limit (EAL)** (mg/l)	**GQRA results** (Appendix HRA B "South.xlsm" *GenericAssessment* worksheet)	**Supplementary attenuation calculations** (Appendix HRA B "South.xlsm" *WithAttenuation* worksheet)	**Supplementary attenuation calculations** (Appendix HRA B "South_SWAC.xlsm" *WithAttenuation* worksheet)
Hazardous substances				
Arsenic	3.40E-03	2.31E-03	2.31E-03	2.31E-03
Mercury	1.00E-05	**2.28E-05**	2.06E-07	2.06E-07
Lead	2.00E-04	**1.14E-03**	**9.84E-04**	1.86E-04
Toluene	4.00E-03	**1.98E-02**	1.22E-11	1.22E-11
Non hazardous substances				
Cadmium	1.20E-02	5.80E-04	5.70E-04	5.70E-04
Copper	1.10E-02	9.35E-03	8.99E-03	8.99E-03
Zinc	9.00E-02	1.99E-02	1.97E-02	1.97E-02

Note:
Concentrations denoted in bold text exceed the EAL.

Table HRA 8

Results of the sensitivity scenarios presented at Appendix HRA D

Determinand	**Environmental assessment limit (EAL)** (mg/l)	**Supplementary attenuation calculations** (Appendix HRA B "North_SWAC.xlsm" *WithAttenuation* worksheet) **FOR COMPARISON**	**Supplementary attenuation calculations** (Appendix HRA D "North_SWAC_constant.xlsm" *WithAttenuation* worksheet) **CONSTANT SOURCE**	**Supplementary attenuation calculations** (Appendix HRA D "North_SWAC_higherK.xlsm" *WithAttenuation* worksheet) **HIGHER WASTE PERMEABILITY**	**Supplementary attenuation calculations** (Appendix HRA D "North_SWAC_rogue.xlsm" *WithAttenuation* worksheet) **ROGUE LOADS**
Hazardous substances					
Arsenic	1.00E-02	5.02E-03	5.04E-03	7.81E-03	8.30E-03
Mercury	1.00E-05	4.27E-07	4.39E-07	**2.33E-05**	8.42E-07
Lead	2.00E-04	1.95E-04	**2.07E-04**	**3.65E-04**	**3.79E-04**
Toluene	4.00E-03	1.92E-11	1.92E-11	5.34E-08	3.83E-11
Non hazardous substances					
Cadmium	3.00E-02	3.04E-03	3.07E-03	3.07E-03	3.27E-03
Copper	2.30E-01	1.70E-02	1.80E-02	2.74E-02	2.90E-02
Zinc	7.10E-02	3.84E-02	3.90E-02	6.05E-02	6.44E-02

Note:
Concentrations denoted in bold text exceed the EAL.

Table HRA 9

Groundwater quality compliance limits and assessment levels

Criterion Objective **To confirm that the deposition of inert waste at the site has no adverse effect on groundwater quality**	
Measurement	Arsenic, mercury, lead, toluene, cadmium, copper and zinc
Frequency	Quarterly. To be reviewed annually.
Monitoring points the subject of compliance	Groundwater monitoring boreholes BH2/21, BH3/21, BH1/97, BH2/97, BH3/97, BH4/97, BH3/21 and BH5/97.
Compliance limits[1] for down hydraulic gradient groundwater monitoring boreholes	**Phase 7 (BH2/21)** The concentration of arsenic shall not exceed 0.01mg/l The concentration of mercury shall not exceed 0.00001mg/l The concentration of lead shall not exceed 0.0002mg/l The concentration of toluene shall not exceed 0.004mg/l The concentration of cadmium shall not exceed 0.03mg/l The concentration of copper shall not exceed 0.23mg/l The concentration of zinc shall not exceed 0.071mg/l
	Phases 3, 4A and 6 (BH1/97, BH2/97, BH3/97, BH4/97 and BH3/21) The concentration of arsenic shall not exceed 0.0075mg/l The concentration of mercury shall not exceed 0.00001mg/l The concentration of lead shall not exceed 0.0002mg/l The concentration of toluene shall not exceed 0.004mg/l The concentration of cadmium shall not exceed 0.027mg/l The concentration of copper shall not exceed 0.087mg/l The concentration of zinc shall not exceed 0.011mg/l
	Phases 4B and 5 (BH5/97) The concentration of arsenic shall not exceed 0.0034mg/l The concentration of mercury shall not exceed 0.00001mg/l The concentration of lead shall not exceed 0.0002mg/l The concentration of toluene shall not exceed 0.004mg/l The concentration of cadmium shall not exceed 0.012mg/l The concentration of copper shall not exceed 0.011mg/l The concentration of zinc shall not exceed 0.090mg/l
Assessment levels[2, 3] for down hydraulic gradient groundwater	**Phase 7 (BH2/21)** The concentration of arsenic shall not exceed 0.0074mg/l The concentration of mercury shall not exceed 0.00001mg/l The concentration of lead shall not exceed 0.0002mg/l The concentration of toluene shall not exceed 0.004mg/l

monitoring boreholes	The concentration of cadmium shall not exceed 0.021mg/l The concentration of copper shall not exceed 0.016mg/l The concentration of zinc shall not exceed 0.052mg/l
	Phases 3, 4A and 6 (BH1/97, BH2/97, BH3/97, BH4/97 and BH3/21) The concentration of arsenic shall not exceed 0.0056mg/l The concentration of mercury shall not exceed 0.00001mg/l The concentration of lead shall not exceed 0.0002mg/l The concentration of toluene shall not exceed 0.004mg/l The concentration of cadmium shall not exceed 0.018mg/l The concentration of copper shall not exceed 0.061mg/l The concentration of zinc shall not exceed 0.078mg/l
	Phases 4B and 5 (BH5/97) The concentration of arsenic shall not exceed 0.0027mg/l The concentration of mercury shall not exceed 0.00001mg/l The concentration of lead shall not exceed 0.0002mg/l The concentration of toluene shall not exceed 0.004mg/l The concentration of cadmium shall not exceed 0.0081mg/l The concentration of copper shall not exceed 0.0087mg/l The concentration of zinc shall not exceed 0.064mg/l
Assessment test	Concentrations exceed the assessment limit on three consecutive occasions.

Contingency action	Response time
Advise the environment agency	1 month
Increase the survey frequency to monthly	1 month
Undertake investigation works to identify the source of the contaminants	6 months
Report to the Environment Agency on the re-appraisal of risks and options for corrective measures	12 months
If the risks are acceptable re-evaluate the assessment criteria If the risks are unacceptable implement agreed corrective measures	18 months 18 months

Notes:

[1] The compliance limits are generally set at the mean concentration recorded plus three standard deviations.

[2] The assessment levels are generally set at the mean concentration plus two standard deviations.

[3] The assessment levels for the hazardous substances lead, mercury and toluene are set at the minimum reporting value.

APPENDIX A

RISK SCREENING EXERCISE

APPENDIX B

GENERIC QUANTITATIVE RISK ASSESSMENT MODELS AND SUPPLEMENTARY ATTENUATION CALCULATIONS

APPENDIX C

INFILTRATION CALCULATIONS

APPENDIX D

SENSITIVITY SCENARIO MODELS