



Poyle Quarry Western Extension

Groundwater Quantitative Risk Assessment for Recharge of Abstracted
Groundwater

On behalf of **Summerleaze Ltd**



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Registered Office: Buckingham Court Kingsmead Business Park, London Road, High Wycombe, Buckinghamshire, HP11 1JU
Office Address: Caversham Bridge House, Waterman Place, Reading, Berkshire RG1 8DN
T: +44 (0)118 950 0761 E: PBA.Reading@stantec.com

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	Name	Position	Signature	Date
Prepared by:	Simon Firth	Associate	SF	11/05/2020
Reviewed by:	Kate Riley	Associate	KR	11/05/2020
Approved by:	Richard Thomas	Senior Consultant	RHT	11/05/2020
For and on behalf of Stantec UK Limited				

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1 Introduction

1.1 Report Context

- 1.1.1 This Groundwater Quantitative Risk Assessment (GQRA) has been prepared by Stantec UK Limited for a site in Poyle, near Slough, Berkshire (the Site), known as Poyle Quarry Western Extension. The report has been prepared on behalf of Summerleaze Ltd, in support of an Environmental Permit (EP) application for an inert waste landfill following extraction of sand and gravel from the Site. A Site location plan is presented as Figure GRA 1.
- 1.1.2 The Site boundary for the EP application comprises the area to be infilled with inert waste, and the access/haulage road from Poyle Road to the infill area, and including the weighbridge area, as shown on Figure GRA 2.
- 1.1.3 To enable dry extraction of the sand and gravel, and dry placement of the inert waste, some dewatering of groundwater will be required. A separate application for a groundwater abstraction (transfer) licence has also been submitted. It is proposed that the groundwater abstracted will be returned (recharged) to the sand and gravel aquifer using a number of infiltration basins/trenches located within the Site. There will be no intervening use of the abstracted groundwater.
- 1.1.4 Previous groundwater monitoring has indicated the presence of constituents of potential concern (COPC) in groundwater within the sand and gravel aquifer beneath the Site. As such, the Environment Agency (in their email dated 5th March 2020) has advised that a Groundwater Quantitative Risk Assessment is required to support the EP application, and this report therefore responds to that requirement.
- 1.1.5 The Environment Agency (in their email of 5th March 2020) has requested the following be provided in relation to the proposed discharge of groundwater:
- a. *'A detailed specification of the design of the proposed recharge trench system including its length, width, depth and the depth of unsaturated zone underneath its entire extent.'*
 - b. *'Supporting evidence that the recharge trench has the sufficient capacity, and is of an appropriate design, to provide adequate attenuation for the maximum daily volume and rate of the effluent, at the maximum concentration of pollutants, to protect all groundwater receptors.'*
 - c. *'A site plan showing the exact location and extent of the recharge trench system at every stage of the mineral extraction and infilling operations.'*

1.2 Report Objectives

- 1.2.1 The purpose of this report is to provide the information requested by the Environment Agency in their email dated 5th March 2020 relating to the proposed discharge of abstracted groundwater, as described above.

1.3 Relevant Guidance

- 1.3.1 The GQRA has been conducted in accordance with the following Environment Agency guidance:
- Environment Agency, 2018¹. Infiltration systems: groundwater risk assessments. Available at: <https://www.gov.uk/guidance/infiltration-systems-groundwater-risk-assessments#hazardous-substances-and-non-hazardous-pollutants> Last updated 3 April 2018

- Environment Agency, 2018². Groundwater risk assessment for your environmental permit. Available at: <https://www.gov.uk/guidance/groundwater-risk-assessment-for-your-environmental-permit#detailed-quantitative-risk-assessment> Last updated 3 April 2018.

1.3.2 In accordance with the guidance it will be necessary to demonstrate that the proposed discharge does not cause any of the following:

- A discernible increase in concentration of any hazardous substance in groundwater;
- Pollution of groundwater by any non-hazardous substance;
- A deterioration in status of a groundwater body; or
- An environmentally significant and sustained upward trend in the concentration of pollutants.

1.4 Report Format

1.4.1 Section 2 provides information on the environmental setting of the Site, including geology and hydrogeology. Section 3 provides details on the proposed design of the infiltration basins/trenches and presents the Conceptual Site Model (CSM) of risk for the proposed discharge. Section 4 describes the Quantitative Risk Assessment, including input parameter values and assumptions, results, sensitivity analysis and risk evaluation. Section 5 presents the Conclusions and Recommendations.

1.5 Other Reports

1.5.1 This GQRA report should be read in conjunction with the accompanying and supporting assessments and documents;

- Environmental Setting and Site Design (Ref 35678/EP/R3)³
- Environmental Risk Assessment (Ref 35678/EP/R4)⁴
- Hydrogeological Risk Assessment (Ref 35678/EP/R5)⁵
- Groundwater Risk Assessment (Ref 35678/EP/R8)⁶
- Flood Risk Assessment (Ref 35678/4001/02 Rev B)⁷
- Groundwater Flow Modelling to Assess Quarrying and Restoration Impacts (Ref 1656400.500/A.2)⁸
- Groundwater Control and Mitigation Report (Ref 35678/3501)⁹
- Groundwater, Surface Water and Landfill Gas Monitoring Plan (Ref 35678/EP/R6)¹⁰

2 Environmental Setting

2.1 Site Location

- 2.1.1 The Site is located approximately 6km to the southeast of the town of Slough, Berkshire and approximately 2.5km west of Heathrow Airport.
- 2.1.2 The part of the Site that comprises the extraction and infill area (i.e. excluding the access haul road to the east) has an area of approximately 18 ha and is centred on National Grid Reference TQ 02120 76468.
- 2.1.3 The Site is located to the east of the Queen Mother Reservoir between Colnbrook village to the north, the Colne Valley to the east and Horton village to the south, and is situated in a semi-rural setting composed of farmland, lakes, active gravel quarries and landfills. Horton Brook Quarry and the inert landfill in the quarry void is located to the immediate west of the Site.
- 2.1.4 A Site location plan is presented as Figure GRA 1 and the Site layout plan is presented as Figure GRA 2.

2.2 Geology

- 2.2.1 The geology in the area, as shown on the British Geological Survey 1:50,000 scale geological map Sheet 269 (BGS, 1999)¹¹, and as evidenced by previous mineral investigations undertaken at the Site (for further details see Section 3.1.4 of the ESSD³) is presented in the table below.

Table 2.1 Summary of Superficial and Solid Geology

Formation Name	Thickness (m)	Lithology
Topsoil	0.0-0.2	Gravelly topsoil
Subsoil	0.8-1.2	Dark grey, sandy, gravelly CLAY
Shepperton Gravel Member (Superficial)	1.9-3.3	Medium dense to dense, orange brown, fine to coarse, sandy GRAVEL. Gravel is angular of flint
London Clay (Solid)	>45.9	Stiff and very stiff, grey CLAY
Lambeth Group (Solid)	-	CLAY with variable proportion of silt, sand and gravel
Upper Chalk Group (Solid)	-	CHALK with flints

2.3 Hydrogeology

- 2.3.1 The Shepperton Gravel Member and the Upper Chalk Group are both classified as Principal (formerly Major) Aquifers. The Lambeth Group is also classified as a Principal Aquifer when it is in hydraulic continuity with the Upper Chalk. The London Clay Formation is classified as Unproductive Strata (formerly Non-aquifer). The thick layer of London Clay forms a very low permeability aquiclude between the shallow principal aquifer of the Shepperton Gravel and the deep principal aquifer in the Chalk.

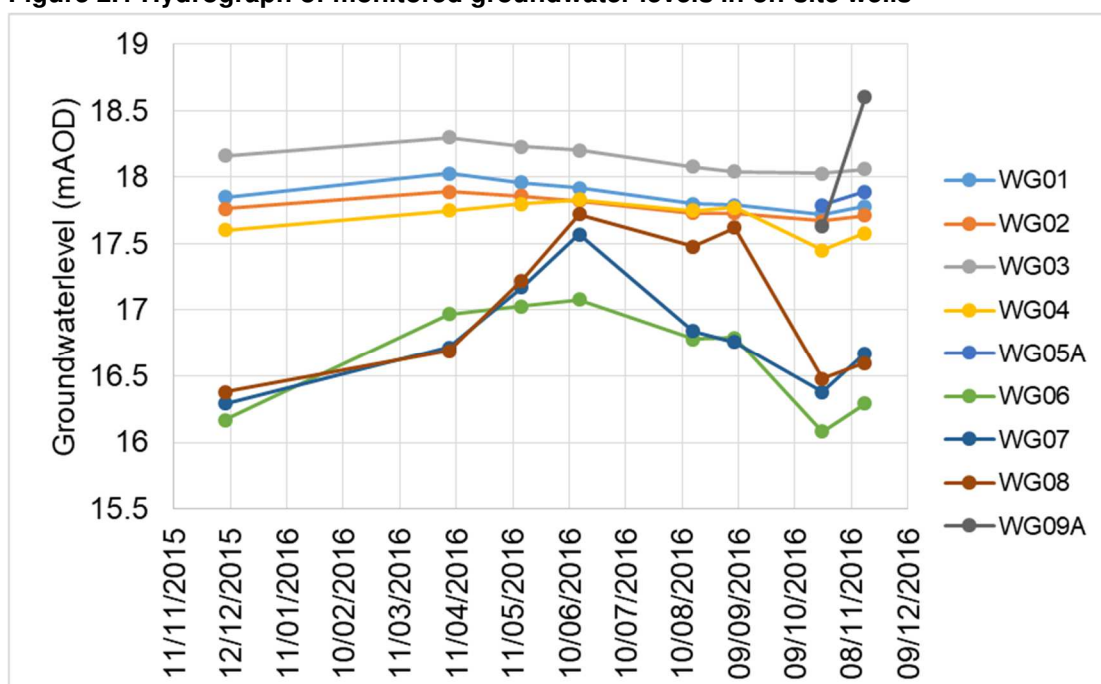
2.3.2 Groundwater levels in the Shepperton Gravels were monitored in on-site monitoring wells between December 2015 and November 2016. The locations of these wells are shown in Figure GRA 2. The monitored groundwater levels are presented in Table 2.2 and as a hydrograph in Figure 2.1 below. Note that the groundwater level reported for WG09A on 16th November 2016 appears erroneously high and is assumed to have been measured or reported incorrectly.

Table 2.2 Monitored groundwater levels in on-site wells

Well	Groundwater level (mAOD)							
	09/12/2015	07/04/2016	16/05/2016	16/06/2016	16/08/2016	07/09/2016	24/10/2016	16/11/2016
WG01	17.85	18.03	17.96	17.92	17.8	17.79	17.72	17.78
WG02	17.76	17.89	17.86	17.82	17.73	17.73	17.67	17.71
WG03	18.16	18.3	18.23	18.2	18.08	18.04	18.03	18.06
WG04	17.6	17.75	17.8	17.83	17.75	17.77	17.45	17.58
WG05A	-	-	-	-	-	-	17.79	17.89
WG06	16.17	16.97	17.03	17.08	16.78	16.79	16.08	16.29
WG07	16.29	16.72	17.17	17.57	16.84	16.76	16.38	16.67
WG08	16.38	16.69	17.22	17.72	17.48	17.62	16.48	16.6
WG09A	-	-	-	-	-	-	17.63	(18.6)*

* assumed erroneous

Figure 2.1 Hydrograph of monitored groundwater levels in on-site wells



- 2.3.3 The monitored groundwater levels indicate a groundwater flow direction to the south / south west. It is possible that this flow direction has been influenced by dewatering operations at the adjacent Horton Brook site. It is likely that the natural hydraulic gradient in the absence of pumping will have a stronger more southerly component.
- 2.3.4 As noted in the Groundwater Flow Modelling Report⁸ extensive quarrying, landfilling and reservoir construction historically carried out in the area has led to the 'truncation' (or partial blockage) of the Shepperton Gravel aquifer, which also affects the flow path and hydrogeological setting of the Site.
- 2.3.5 The hydraulic conductivity of the Shepperton Gravel was estimated from slug tests conducted on the adjacent Horton Brook site to range from 1.5×10^{-4} m/s to 1×10^{-3} m/s. As described in the Groundwater Flow Modelling Report⁸, an acceptable calibration of the groundwater flow model for the Site was produced using a hydraulic conductivity of 1×10^{-3} m/s for the Shepperton Gravel.

2.4 Groundwater Quality

- 2.4.1 Groundwater samples were obtained from monitoring wells screened in the Shepperton Gravels at or in the vicinity of the Site in August, September and November 2016. A total of eleven wells were sampled (WG01 to WG11) with each well sampled on two to four separate occasions. The location of these wells is shown on Figure GRA 2.
- 2.4.2 The samples were analysed for a range of determinants including metals, ammoniacal nitrogen, chloride, sulphate, total petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAHs) and volatile organic carbons (VOCs). The analytical results and laboratory certificates are presented in the Groundwater Control and Mitigation Report⁹.
- 2.4.3 The measured concentrations have been compared with suitable screening criteria in order to assess groundwater quality at the Site. Given that the Shepperton Gravel is classified as a Principal Aquifer UK drinking water standards (DWS) have been used as the screening criteria. Determinants with maximum (detected) concentrations above DWS are listed in Table 2.3 below.

Table 2.3 Determinants with concentrations that exceed drinking water standard

Determinant	Range in concentrations (µg/L)	DWS (µg/L)	No. of exceedances ⁽¹⁾
Arsenic	1.2	10	13 of 32
Cadmium	<0.6 – 12.1	5	2 of 32
Chromium (total)	<2 – 171	50	3 of 32
Iron	580 – 193,000	200	32 of 32
Lead	<6 – 236	10	17 of 32
Manganese	28 – 14,900	50	31 of 32
Nickel	3 – 557	20	18 of 32
Ammoniacal nitrogen as NH ₄	<400 - 1020	500	1 of 32
Benzo(a)pyrene	<0.01 – 0.053	0.01	5 of 32
Sum of PAHs ⁽²⁾	<0.04 – 2.53	0.1	1 of 32
1. Does not include samples with detection limit > DWS 2. Sum of benzo b, k, ghi & indeno123c			

- 2.4.4 The exceedances of arsenic, iron, lead, manganese and nickel are widespread across the Site with no apparent spatial distribution.
- 2.4.5 The exceedances of cadmium and chromium are localised. Cadmium has been detected in two wells: 6.4 µg/L in WG04 on 14th September 2016 and 12.1 µg/L in WG05A on 1st November 2016. Cadmium was below the analytical detection limit in both these wells on the subsequent round of sampling. Chromium was detected above DWS in three wells: 171 µg/L in WG05A on 1st November 2016, 90 µg/L in WG10 on 16th November 2016 and 90 µg/L in WG11 on 1st November 2016. Chromium was below the DWS in these wells on the other sampling events.
- 2.4.6 It is noted that the concentrations of metals are highly variable within each well between sampling events. This is likely a reflection of the fact that samples were analysed for total metals as opposed to dissolved metals. Total metals includes metals in suspended sediment as well as in the dissolved phase. Any naturally occurring metals present within the aquifer matrix that is entrained as suspended sediment in the sample will be included in the analysis and the amount of suspended sediment in the sample will affect the result. It is considered likely that the detected concentrations of total metals in the groundwater samples are due to their naturally occurring presence in the aquifer matrix.
- 2.4.7 The lack of a consistent spatial distribution in the concentrations of metals indicates that the groundwater quality with respect to metals is uniform across the Site, i.e. groundwater quality in one part of the site is no different/worse than in other parts of the Site.
- 2.4.8 Ammoniacal nitrogen has only been detected in one sample: WG01 on 19th August 2016 when 1020 µg/L was detected. Ammoniacal nitrogen was below the analytical detection limit of 400 µg/L in the subsequent two sampling events from this well. This well is located 300m east of the Site (on the eastern side of the Eric Mortimer Rayner memorial lakes).

- 2.4.9 PAHs have been detected in wells WG01 to WG08, but generally only on one occasion in each well. The highest concentrations of PAHs (0.496 µg/L total PAH) were detected in WG07 on 1st November 2016. PAHs were undetected in this well in the previous and following sampling events.
- 2.4.10 There have also been a number of detections of TPH (which does not have a UK drinking water standard), predominantly in the aliphatic C16-35 range. The maximum concentration of this fraction detected was 99 µg/L in WG11 on 1st November 2016. It is noted that TPH was not detected in the subsequent sample from this well on 16th November 2016.
- 2.4.11 VOCs have not been detected with the exception of toluene which was found at concentrations of 10 µg/L and 9.4 µg/L in WG05A on 1st and 16th November 2016, respectively and a trace concentration of 1.4 µg/L toluene in WG10 on 16th November 2016. Both these wells were drilled on 14th October 2016 and it is possible that the occurrence of toluene is related to the drilling works. As discussed in Section 5.2.2 further baseline monitoring will be conducted (see Groundwater, Surface Water and Landfill Gas Monitoring Plan)¹⁰, and this will confirm whether or not groundwater is impacted with toluene at these locations (see further discussion in Section 4.6.4).

3 Conceptual Site Model

3.1 Approach

3.1.1 The underlying principle of the risk assessment is the evaluation of pollutant linkages in order to assess whether the presence of a source of contamination could potentially lead to harmful consequences. A pollutant linkage consists of the following three elements:

- A source of contamination or hazard that has the potential to cause harm or pollution;
- A pathway for the hazard to move along / generate exposure; and
- A receptor which is affected by the hazard.

3.1.2 The risk assessment comprises the following four stages:

- Hazard Identification – identifying potential contaminant sources;
- Hazard Assessment – assessing the potential for unacceptable risks by identifying what pathways and receptors could be present, and what pollutant linkages could result;
- Risk Estimation – estimating the magnitude and probability of the possible consequences (what degree of harm might result to a defined receptor and how likely); and
- Risk Evaluation – evaluating whether the risk needs to be, and can be, managed.

3.1.3 The Hazard Identification and Assessment stages comprise the development of the Conceptual Site Model (CSM). This is described in this section and is used as the basis of the subsequent stages of the risk assessment (described in Section 4).

3.2 Proposed Scheme

3.2.1 The extraction of sand and gravel and construction of the inert waste landfill will be progressed in five phases as shown on Figure GRA 3. Groundwater abstraction will be required to de-water each phase to enable dry extraction of the full thickness of sand and gravel and subsequent construction of the inert landfill.

3.2.2 The abstracted groundwater will be returned to ground via three infiltration basins (A2, B and C) and a trench (A1), the locations of which are shown on Figure GRA 3. The Groundwater Control and Mitigation Report⁹ proposed that recharge trenches would be utilised to discharge groundwater abstracted from the quarry void back to the aquifer, and that conceptually the recharge trench would move around the northern, eastern and southern perimeter of the Site as the different phases were progressed. As part of this report, the concept proposals have been progressed through further stages of detail and therefore it is now proposed to recharge the abstracted groundwater through a combination of infiltration basins and a trench, rather than solely trenches, in order to maximise contaminant transit times through the unsaturated zone and hence maximise the attenuation capacity of the infiltration system. The infiltration basins/trench have been designed in accordance with the principles provided in both the Groundwater Flow Modelling report⁸ and the Groundwater Control and Mitigation report⁹.

3.2.3 The infiltration basins/trench will be utilised as follows:

- Trench A1 and Basin A2 will be used as the infiltration structures for the de-watering of Phase 1 and part of Phase 2

- Basin B will be used as the infiltration basin for the de-watering of part of Phase 2, part of Phase 3 and part of Phase 4
 - Basin C will be used as the infiltration basin for the de-watering of part of Phase 3, part of Phase 4 and Phase 5
- 3.2.4 The approximate location of each of the infiltration basins/trench is provided in Figure GRA 3. The proposed location of the basins/trench may vary slightly within the confines of the Phase they are displayed in, due to operational constraints and practicalities, but they will remain within the boundaries of the Phase they are shown in on Figure GRA 3.
- 3.2.5 Trench A1 will have a nominal length of 150m and width of 10m and Basin A2 will have a nominal length of 200m and width of 42.5m, making a total infiltration area of 10,000m². Basins B and C will both have a nominal length of 200m and width of 50m, giving a total area of 10,000 m² for each basin.
- 3.2.6 The basins/trench will be constructed by excavating to the top of the Shepperton Gravel and then levelling the base to ensure there is a minimum thickness of 1.2m of unsaturated sand and gravel above the groundwater table. The side walls of the basin/trench will be profiled and, if required, raised by construction of a low lying earthen bund/lip to provide a minimum 0.5m depth to the basin/trench. A schematic cross-section of an indicative infiltration basin design/trench is shown in Figure GRA 4
- 3.2.7 The groundwater level data described in Section 2.3 has been used to estimate the maximum groundwater level at each basin location. The basin/trench invert level has then been set at 1.2m above this level. The proposed indicative basin/trench depths and invert levels are shown on Figure GRA 4.
- 3.2.8 It is proposed that as Phase 1 is progressed, the dewatering volumes and infiltration efficiency of Trench A1 and Basin A2 will be carefully monitored and assessed to enable refinements of the dimensions and general arrangement of Basins B and C to be made, to maximise efficiency and suit operational requirements.
- 3.2.9 The abstraction rate required to de-water each phase has been calculated using the following de-watering equation from Preene *et al* (1997)¹²:

$$Q = \frac{\pi K(H^2 - h^2)}{\ln(R_0/r_e)}$$

Where,

Q = abstraction rate (m³/d)

K = aquifer hydraulic conductivity (m/d)

H = saturated thickness of aquifer before de-watering (m)

h = saturated thickness of aquifer in de-watered excavation (m)

R₀ = radius of the zone of influence (m)

r_e = effective radius of the excavation (m)

- 3.2.10 The hydraulic conductivity of the Shepperton Gravels is assumed to be 1 x 10⁻³ m/s (86 m/d) which was the value used by Golders in the calibrated groundwater flow model (see Section 2.3.5).

- 3.2.11 The sands and gravels are assumed to be completely dewatered and therefore h is assumed to be 0m. The value of H is assumed to be 2.3m which is the average saturated thickness of the Shepperton Gravels based on the available groundwater monitoring data and lithological information for the site.
- 3.2.12 The highest de-watering abstraction rates are likely to occur for Phases 1 and 2. However, lower abstraction rates will be required for subsequent phases as the inert landfill cells in Phases 1 and 2 will provide a barrier to groundwater flow from the north into the later Phases.
- 3.2.13 Phases 1 and 2 both have approximate dimensions of 250m x 130m which equates to an equivalent radius (r_e) of 121m using the following equation from Preene *et al* (1997)¹².

$$r_e = \frac{a + b}{\pi}$$

Where,

a = length of excavation (m)

b = width of excavation (m)

- 3.2.14 The radius of influence is estimated to be 218m using the following equation from Preene *et al* (1997)¹²:

$$R_0 = C(H - h)\sqrt{K}$$

Where,

C = empirical calibration factor (according to Preene *et al* (1997)¹² this is usually taken as 3000 when K is in m/s)

- 3.2.15 Using the parameter values described above the required steady state abstraction rate for de-watering the Shepperton Gravels is estimated to be up to 2432 m³/d.
- 3.2.16 Dividing this rate by the footprint area of each infiltration area (10,000 m²) results in an estimated target infiltration rate of 0.243 m/d (2.8 x 10⁻⁶ m/s). This is at least two orders of magnitude below the hydraulic conductivity of the Shepperton Gravels (1 x 10⁻³ m/s) indicating that the discharged water will be easily conveyed to ground via the infiltration basins/trench.

3.3 Sources of Potential Contamination

- 3.3.1 Groundwater monitoring has shown the presence of various constituents of potential concern (COPC) in groundwater at the Site, including PAHs, TPH and toluene. There is therefore a potential for these constituents to be present in the water discharged to the infiltration basins/trench.
- 3.3.2 According to the Joint Agencies Groundwater Directive Advisory Group (JAGDAG, 2018)¹³, PAHs (other than naphthalene), TPH and toluene are all classified as hazardous substances to groundwater. Environment Agency guidance requires that the discharge of water to ground does not result in the discernible entry of hazardous substances to groundwater. PAHs, TPH and toluene are therefore considered as COPC for the assessment.
- 3.3.3 Various metals have been detected in groundwater at concentrations exceeding DWS. However, there is no apparent spatial trend in the measured concentrations with the highest concentrations occurring in different parts of the Site on different occasions. Metals were analysed as total metals (as opposed to dissolved metals) which includes naturally occurring metals in the aquifer matrix that has become entrained as suspended sediment in the sample.

- 3.3.4 Given the observed variability in concentrations of metals it is highly unlikely that the proposed discharge of groundwater would result in a discernible increase in concentrations of metals in groundwater in any part of the Site. Metals are therefore not considered COPCs for this assessment.
- 3.3.5 Ammoniacal nitrogen (as NH_4) was detected at a concentration (1020 $\mu\text{g/L}$) that exceeded the DWS of 500 $\mu\text{g/L}$ in one groundwater well (WG01) on one occasion (19th August 2016). Given the distance of this well from the Site (300m to the east) and the lack of any other detections, ammoniacal nitrogen is not considered a COPC.
- 3.3.6 Based on the above the COPC considered for this assessment are PAHs, TPH and toluene.

3.4 Pathway

- 3.4.1 Water that is discharged to the infiltration basins will infiltrate through at least 1.2m of unsaturated Shepperton Gravels to the water table. This is the minimum unsaturated zone as it is based on the highest seasonal groundwater levels and therefore for parts of the year, the unsaturated zone will be greater than 1.2m, and therefore this introduces conservatism in the model. Retardation and biodegradation will reduce the concentrations of organic constituents reaching groundwater. Infiltrating water will be diluted by groundwater flow beneath the infiltration basin, albeit that this is likely to be limited due to dewatering activities and subsequent aquifer truncation caused by the construction of landfill cells.

3.5 Receptor

The Shepperton Gravel is classified as a Principal Aquifer and is considered to be the key Controlled Waters receptor of concern. The underlying Lambeth Group and Upper Chalk aquifers are protected by at least 45.9m thickness of low permeability London Clay and are therefore not considered to be plausible receptors.

4 Groundwater Quantitative Risk Assessment

4.1 Methodology

- 4.1.1 The Environment Agency's spreadsheet for groundwater risk assessment for treated effluent discharges to infiltration systems (Version 2.0, Environment Agency, 2014¹⁴) has been used to conduct the quantitative risk assessment. This has been used to estimate the concentrations of modelled COPC at a compliance point for comparison with appropriate environmental assessment levels (EALs) in order to characterize risk.
- 4.1.2 As discussed in Section 1.3.2, Environment Agency guidance states that the discharge should not cause discernible entry of hazardous substances to groundwater or pollution by non-hazardous substances.
- 4.1.3 The COPC identified in the CSM (PAHs, TPH and toluene) are all classified as hazardous substances and therefore the modelling has been conducted to determine whether or not there would be entry of these hazardous substances to groundwater. As such, the compliance point is assumed to be the base of the unsaturated zone and the EAL is assumed to be the Minimum Reporting Value (MRV) obtained from Environment Agency (2017)¹⁵, where available, otherwise the analytical detection limit from the baseline monitoring has been used.

4.2 Modelled Contaminants

- 4.2.1 Benzo(a)pyrene and fluoranthene have been chosen as indicator compounds to represent the risk from the hazardous PAHs – fluoranthene being representative of the lighter end, more mobile PAHs and benzo(a)pyrene being representative of the heavier end, less mobile PAHs.
- 4.2.2 Where detected, TPH has predominantly been in the aliphatic >C16-C35 range and so this fraction has been selected as an indicator compound to represent the risk from TPH.
- 4.2.3 As a result, the contaminants selected for modelling are benzo(a)pyrene, fluoranthene, TPH aliphatic >C16-35 and toluene. The maximum measured concentrations of these constituents in groundwater have been used as the source concentrations as shown in Table 4.1 below. It should be noted that the use of the maximum measured concentrations is very conservative because the maximum concentrations measured are not present everywhere within the area from which groundwater is drawn in by the pumping. Therefore, groundwater from areas with the higher concentrations of contaminants will be diluted with water with lower concentrations of contaminants as it is abstracted for de-watering.

4.3 Input Parameter Values

- 4.3.1 The parameter values used for the modelling along with justification for those values are presented in Tables 4.1 and 4.2 below. Table 4.1 shows the contaminant specific parameters and Table 4.2 shows the non-contaminant specific parameters.

Table 4.1 Contaminant specific parameter values and justification

Modelled contaminant	Source concentration (mg/L) ⁽¹⁾	EAL (mg/L)	Organic carbon partition coefficient (L/kg) ⁽⁴⁾	Degradation half-life (days)
Benzo(a)pyrene	5.3×10^{-5}	1.0×10^{-5} ⁽²⁾	1.29×10^5	1060 ⁽⁵⁾
Fluoranthene	5.0×10^{-5}	1.0×10^{-5} ⁽²⁾	1.82×10^4	880 ⁽⁶⁾

TPH ali C16-35	9.9×10^{-2}	1.0×10^{-2} ⁽²⁾	5.75×10^8	1060 ⁽⁷⁾
Toluene	1.0×10^{-2}	4.0×10^{-3} ⁽³⁾	204	200 ⁽⁸⁾
<p><u>Notes to Table 4.1</u></p> <ol style="list-style-type: none"> Maximum measured concentration in groundwater Analytical limit of detection MRV from Environment Agency, 2017¹⁵ Values from Nathanail et al, 2015¹⁶ Maximum value given for aerobic degradation of benzo(a)pyrene in Howard, 1991¹⁷ Maximum value given for aerobic degradation of fluoranthene in Howard, 1991¹⁷ Assumed equal to half-life for benzo(a)pyrene Maximum value given for aerobic degradation of toluene in Environment Agency, 2002¹⁸ 				

Table 4.2 Non-contaminant specific parameter values and justification

Parameter	Units	Value	Justification
Infiltration system			
Discharge rate	m ³ /d	2,432	Estimated dewatering abstraction rate (see Section 3.2.14)
Area of drainage field	m ²	10,000	Based on 200m x 50m infiltration basin
Drainage Layer			
Thickness of drainage layer	m	0.01	Nominal amount chosen as drainage layer is not required
Water filled porosity of drainage layer	-	0.25	Mid-point of suggested range in Environment Agency, 2014 ¹⁴
Bulk density of drainage layer	g/cm ³	1.75	Environment Agency, 2014 ¹⁴
Unsaturated zone			
Thickness of unsaturated zone below drainage field	m	1.2	Environment Agency required minimum thickness of unsaturated zone below infiltration basin ¹
Water filled porosity of unsaturated zone	-	0.18	Calculated using porosity calculator in infiltration spreadsheet using bulk density of 1.8 g/cm ³ and an assumed moisture content of 10% (which is reasonable for sands and gravels). As shown in the sensitivity analysis water filled porosity is not a sensitive parameter.
Bulk density of unsaturated zone	g/cm ³	1.8	Typical bulk density of sand and gravel in River Terrace Deposits
Fraction of rapid flow through unsaturated zone	-	0	Intergranular flow assumed
Fraction of organic carbon in soil	-	0.008	Based on measured soil organic matter content of 1.38% from the Shepperton Gravels in TP102

4.4 Model Results

- 4.4.1 Print-outs of the infiltration worksheets are provided in Appendix A.
- 4.4.2 The predicted concentrations of each modelled constituent at the base of the unsaturated zone are compared with the EALs in Table 4.3 below. Table 4.3 also presents discharge limits which are the concentrations in the water discharged to the infiltration basins predicted to result in a concentration at the base of the unsaturated zone equal to the EAL.

Table 4.3 Model results

Modelled contaminant	Source concentration (mg/L)	Predicted concentration at base of unsaturated zone (mg/L)	EAL (mg/L)	Discharge limit (mg/L)
Benzo(a)pyrene	5.3×10^{-5}	7.85×10^{-7}	1.0×10^{-5}	6.75×10^{-4}
Fluoranthene	5.0×10^{-5}	1.97×10^{-5}	1.0×10^{-5}	2.54×10^{-5}
TPH ali C16-35	9.9×10^{-2}	2.73×10^{-224}	1.0×10^{-2}	3.62×10^{220}
Toluene	1.0×10^{-2}	9.48×10^{-3}	4.0×10^{-3}	4.22×10^{-3}

- 4.4.3 The predicted concentrations of benzo(a)pyrene and TPH aliphatic C16-35 at the base of the unsaturated zone are below the EALs.
- 4.4.4 The predicted concentrations of fluoranthene and toluene at the base of the unsaturated zone are approximately twice the EALs.

4.5 Sensitivity Analysis

- 4.5.1 Sensitivity analysis has been conducted to identify which parameters give greatest sensitivity to the model results. The sensitivity analysis has been conducted by changing potentially uncertain parameters between reasonable minimum and maximum bounds and assessing what effect this has on the predicted compliance point concentrations. Fluoranthene has been chosen as the test constituent for the sensitivity analysis because this is predicted to have moderate attenuation (relative to toluene which has very little and TPH aliphatic C16-35 which is strongly attenuated). The parameters and range of values tested are presented in Table 4.4 and the results of the sensitivity analysis are presented Table 4.5 and Figure 4.1.

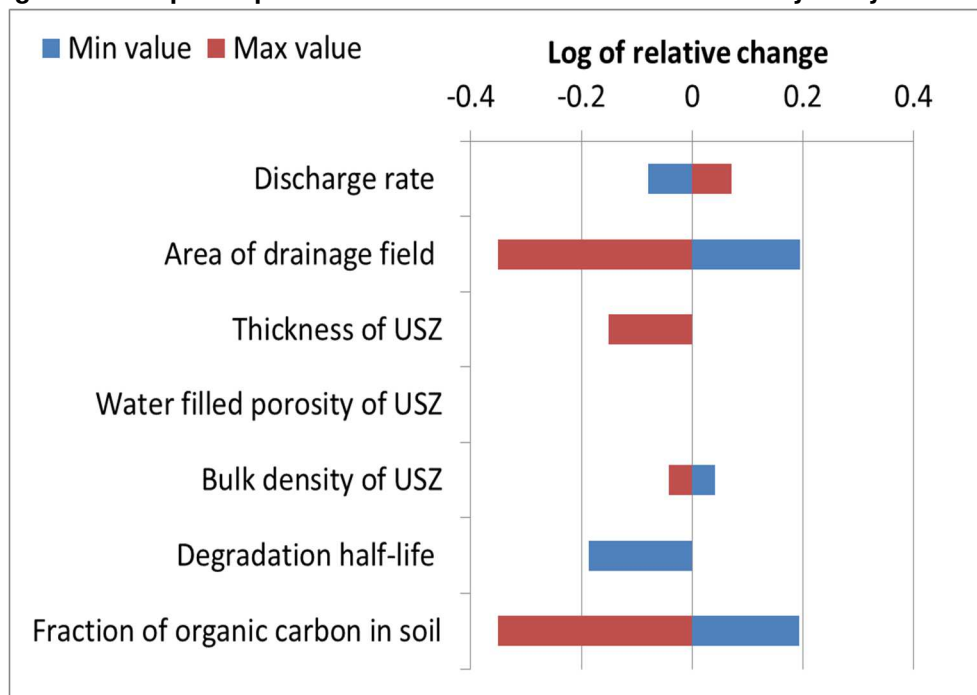
Table 4.4 Parameter values tested in sensitivity analysis

Parameter	Base case	Min	Max	Justification
Infiltration system				
Discharge rate (m ³ /d)	2,432	2,000	3,000	Reasonable range based on uncertainties in calculations
Area of drainage field (m ²)	10,000	5,000	20,000	0.5x and 2x base case value
Unsaturated zone				
Thickness of unsaturated zone below drainage field (m)	1.2	1.2	1.7	Maximum is estimated seasonal average thickness of unsaturated zone beneath infiltration basins
Water filled porosity of unsaturated zone	0.18	0.14	0.27	Calculated range in water filled porosities for moisture contents of 7.5% to 15%
Bulk density of unsaturated zone (g/cm ³)	1.8	1.6	2.0	Reasonable range for sand and gravel
Degradation half-life (days)	880	580	880	Minimum is mid-point of range given for aerobic degradation in Howard (1991) ¹⁷
Fraction of organic carbon in soil	0.008	0.004	0.016	0.5x and 2x base case value

Table 4.5 Results of sensitivity analysis

Parameter	Predicted concentration of Fluoranthene at base of unsaturated zone (mg/L)		
	Base case	Min	Max
Discharge rate	1.97 x 10 ⁻⁵	1.64 x 10 ⁻⁵	2.32 x 10 ⁻⁵
Area of drainage field		3.08 x 10 ⁻⁵	8.80 x 10 ⁻⁶
Thickness of unsaturated zone below drainage field		1.97 x 10 ⁻⁵	1.39 x 10 ⁻⁵
Water filled porosity of unsaturated zone		1.97 x 10 ⁻⁵	1.97 x 10 ⁻⁵
Bulk density of unsaturated zone		2.17 x 10 ⁻⁵	1.79 x 10 ⁻⁵
Degradation half-life		1.28 x 10 ⁻⁵	1.97 x 10 ⁻⁵
Fraction of organic carbon in soil		3.07 x 10 ⁻⁵	8.80 x 10 ⁻⁶

Figure 4.1 Graphical presentation of the results of the sensitivity analysis



- 4.5.2 Figure 4.1 shows the log relative change in the predicted concentration at the base of the unsaturated zone (USZ) using the minimum and maximum values of each parameter tested. A log change of -0.3 represents a halving of the predicted concentration whilst a log change of +0.3 represents a doubling of the predicted concentration.
- 4.5.3 The results of the sensitivity analysis show that a very conservative approach has been adopted for the modelling with the majority of parameter changes leading to a decrease in predicted concentrations at the base of the unsaturated zone.
- 4.5.4 In addition, as discussed previously, the maximum measured concentrations in groundwater have been used as the source concentrations. This is highly conservative as groundwater with higher concentrations of contaminants will be diluted with water with lower concentrations of contaminants as it is abstracted for de-watering.

4.6 Risk Evaluation

- 4.6.1 The sensitivity analysis has shown that a highly conservative approach has been adopted for the modelling. As such, the concentrations at the base of the unsaturated zone have more likely been over-predicted than under-predicted and the calculated discharge limits in Table 4.3 can be considered very cautious and will provide a very high level of groundwater protection.
- 4.6.2 The maximum measured concentrations of benzo(a)pyrene and TPH aliphatic C16-35 in groundwater are below their calculated discharge limits. Given the conservative approach adopted for the risk assessment it can be concluded that the proposed discharge of water via the infiltration basins will not result in discernible entry of these constituents to groundwater.
- 4.6.3 The discharge limit for fluoranthene was exceeded in one groundwater sample taken from WG07 on 1st November 2016. The measured concentration of fluoranthene on this occasion was approximately twice the discharge limit. PAHs were undetected in both the previous and following samples from this well. Given that the discharge limit is conservative and that the concentrations of fluoranthene are below the discharge limit in all other 31 groundwater

samples tested, it is concluded that the proposed discharge of water via the infiltration basins would not result in discernible entry of fluoranthene to groundwater.

- 4.6.4 The discharge limit for toluene was exceeded in two groundwater samples taken from WG05A on 1st and 16th November 2016. The measured concentrations of toluene on both occasions were approximately twice the discharge limit. No other VOCs have been detected in groundwater at the Site and there is no obvious reason why toluene would be present in groundwater at this location but absent everywhere else. The groundwater samples were taken shortly after the well was drilled and it is considered that the occurrence of toluene in these two water samples is most probably related to contamination introduced locally during the drilling works. The concentrations measured are unlikely to reflect the pre-existing presence of toluene at this concentration in the groundwater in the general area of WG05A. As discussed in Section 5.2 additional baseline monitoring will be conducted and this will ascertain whether or not any localised toluene contamination is present.

5 Conclusions and Recommendations

5.1 Conclusions

- 5.1.1 Groundwater monitoring has shown the sporadic presence, both spatially and temporally, of various organic constituents in groundwater at the Site, namely PAHs, TPH and toluene. There is therefore a possibility (albeit unlikely due to dilution as groundwater is abstracted) for these constituents to be present in the water discharged to the infiltration basins and to present a risk to groundwater below the Site. This risk has been further assessed using the Environment Agency's infiltration spreadsheet with benzo(a)pyrene, fluoranthene, TPH aliphatic >C16-35 and toluene selected as indicator compounds.
- 5.1.2 Various metals have also been detected in groundwater but these are considered to be naturally occurring and have been discounted as COPC.
- 5.1.3 PAHs, TPH and toluene are classified as hazardous substances to groundwater and, as such, the discharge should not result in their discernible entry to groundwater. This has been assessed by comparing the modelled concentrations at the base of the unsaturated zone with MRVs, where available, or method detection limits. The model has also been used to derive discharge limits, which are the concentrations in the discharged water predicted to result in concentrations at the base of the unsaturated zone equal to the MRVs/method detection limits.
- 5.1.4 Sensitivity analysis has shown that a highly conservative approach has been adopted for the risk assessment.
- 5.1.5 The maximum measured concentrations of benza(a)pyrene and TPH aliphatic > C16-35 are at least one order of magnitude below the discharge limits and indicate that these constituents do not present an unacceptable risk to groundwater with the proposed discharge.
- 5.1.6 The discharge limit for fluoranthene is exceeded (by a factor of 2) in one groundwater sample from WG07. The concentrations of PAHs in the previous and following sample rounds from this well were below method detection limit. Given the conservatism in the modelling and the isolated exceedance, fluoranthene is not considered to pose an unacceptable risk to groundwater with the proposed discharge.
- 5.1.7 The discharge limit for toluene is exceeded (by a factor of 2) in both samples from WG05A. No other VOCs have been detected in groundwater at the Site and there is no obvious reason why toluene would be present in groundwater at this location. The groundwater samples were taken shortly after the well was drilled and it is possible that the occurrence of toluene is related to the drilling works. As discussed in Section 5.2 further baseline monitoring will be conducted and this will ascertain whether or not toluene is still present in this locality.
- 5.1.8 The Groundwater Quantitative Risk Assessment indicates that the proposed discharge of groundwater from the dewatering operations via the infiltration basins and trench, does not present an unacceptable risk to groundwater. In the highly unlikely event that localised toluene contamination is confirmed to be present around WG05A, and depending on the extent of dilution with groundwater containing very low or no toluene, the assessed discharge limit could be exceeded indicating, in theory, a low potential risk. If additional pre-operation baseline monitoring indicates that toluene is still present around WG05A, then treatment of the discharge water in this Phase may need to be considered to mitigate the potential low risk to groundwater from toluene.

5.2 Recommendations

- 5.2.1 Further baseline groundwater monitoring and testing will be conducted prior to works commencing, as described in the Groundwater, Surface Water and Landfill Gas Monitoring Plan¹⁰. The analysis will include dissolved metals in addition to the previously monitored parameters.
- 5.2.2 The measured concentrations of benzo(a)pyrene, fluoranthene, TPH aliphatic >C16 to 35 and toluene will be compared with the calculated discharge limits to re-evaluate the risks from the proposed discharge. Should the measured concentrations exceed the discharge limits then consideration may need to be given to treatment of water prior to discharge.

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Appendix A: Infiltration Spreadsheet Print Outs