January 2024

London Luton Airport Expansion

Planning Inspectorate Scheme Ref: TR020001

Volume 8 Additional Submissions (Examination)

8.164 Gas Mitigation Measures Technical Note

Infrastructure Planning (Examination Procedure) Rules 2010

Application Document Ref: TR020001/APP/8.164

The Planning Act 2008

The Infrastructure Planning (Examination Procedure) Rules 2010

London Luton Airport Expansion Development Consent Order 202x

8.164 GAS MITIGATION MEASURES TECHNICAL NOTE

Deadline:	Deadline 7
Planning Inspectorate Scheme Reference:	TR020001
Document Reference:	TR020001/APP/8.164
Author:	Luton Rising

Version	**Date**	**Status of Version**
Issue 1	January 2024	Additional Submission – Deadline 7

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1 INTRODUCTION

1.1.1 This technical note has been developed by Luton Rising (a trading name of London Luton Airport Limited) (‘the Applicant’) to support the application for a Development Consent Order (DCO) for the expansion of the airport to 32 million passengers per annum (mppa) (the Proposed Development). The type and scale of the airport expansion proposal meets the thresholds to be classified as a Nationally Significant Infrastructure Project (NSIP) for the purposes of the Planning Act 2008. Therefore, an application has been made to the Secretary of State for Transport for development consent.

1.1.2 The note has been produced to satisfy items LBC118, and120 in the Statement of Common Ground (SoCG) with Luton Borough Council (LBC) **[REP6-027]**, their related comment is presented below:

“LBC request feasible options with regards to gas mitigation measures in regard to potential for off-site mitigation, and request details covering the means to secure these and when they will be incorporated into construction. Also query whether the gas monitoring frequency is sufficient due to the character of the landfill changing quickly once construction commences.”

1.1.3 LBC requested further information on an earlier version of the SoCG dated 31/05/2023 which was issued to them as part of the ongoing engagement (via email correspondence) on the following:

a. demonstration of the effectiveness of the proposed passive ventilation system in the mitigation of landfill gas migration off-site;
b. reference to case studies where this technique has been used;
c. identification of worst-case assumptions; and
d. detail of further gas monitoring including continuous gas monitoring which is most appropriate for measuring changes in landfill gas conditions, during construction.

1.1.4 This technical note seeks to respond to LBC’s request for additional information and:

a. present a summary of baseline gas conditions in the landfill;
b. outline the potential method of gas control measures outlined in the Outline Remediation Strategy (ORS) (**Appendix 17.5** of the **ES [APP-125]**);
c. explain the principles by which the outlined gas control technique works; and
d. present case studies of this control technique.

2 SUMMARY BASELINE GAS CONDITIONS

2.1 Baseline monitoring 2018 to 2019

2.1.1 **Appendix 17.3** to **Chapter 17** of the ES **[APP-123]** includes a detailed assessment of the risk to human health from landfill gas based on an assessment of the results of continuous gas monitoring, spot monitoring and purge and recovery testing. Modelling of future landfill gas generation potential was completed using GasSim 2.5[1]. A summary of the assessment is provided here:

a. The continuous and spot gas monitoring data suggests the landfill is still capable of generating gas in localised areas, particularly where the landfill is at its deepest (central area) and in areas where there are more recent wastes which still contain some degradable organic matter.

b. In the north of the site where the waste is not as thick and comprises predominately construction waste, it was concluded that there is a lower potential for generation of landfill gas and the level of gas flow is likely to be low.

c. While there are high concentrations of bulk landfill gases (carbon dioxide and methane) present within the waste, gas flow rates are relatively low, indicating low rates of continued biodegradation of residual organic matter. Gas flow rates are influenced by barometric pressure variations, with short duration peaks in flow when there is a fall in barometric pressure, this is an indication that overall the quantities of gas being generated are low.

d. The monitoring results are consistent with the waste types encountered during the ground investigation and the level of degradation observed within the waste.

e. The landfill is beyond the end of its peak gas generation period in its current condition and is likely to be in its residual gas generation phase.

f. There is no evidence that gas is migrating a significant distance off-site based on the gas monitoring undertaken to date (**Appendix 17.2 [APP-121 and APP-122]** and **Appendix 17.3 [APP-123]** of the **ES**. A review of the ground model demonstrates that although there is no engineered base or sides, the landfill sits within a valley with low permeability clays and silts to the base and sides

g. The gas screening value (GSV)[2] assessment indicates that as a worst-case, the landfill site should be classified as Characteristic Situation (CS) 4 (with

[1] GasSim 2.5 was developed with and endorsed by the Environment Agency for active landfills. The modelling package is also used by landfill operators and consultants, to provide a standard risk assessment methodology for landfill gas management, to meet EU Directives (Waste Framework and Landfill Directives) which have been translated into UK legislation. GasSim considers the uncertainty in input parameters using a Monte Carlo Simulation to quantitatively evaluate risks and the magnitude of the impacts.

[2] Gas monitoring results were assessed using the classification system presented within CIRIA C665 (Ref. 1). The classification system uses gas concentrations and recorded flow rates for methane and carbon dioxide to determine a gas screening value (GSV). The GSV is used to determine the Characteristic Situation (CS) for the site, which is a qualitative method of defining risk to a proposed development

moderate to high risk) and areas outside of the landfill should be classified as CS2 (Low Risk) (Ref. 1). This is considered a precautionary assessment which allows for short and sporadic spikes in gas generation. The spot monitoring and continuous gas monitoring suggest that for most of the time the landfill site is more typically CS2 and outside the landfill CS1 (very low risk) (current airport to the west and Wigmore Valley Park and agricultural land to the east).

h. Modelling of future gas generation potential using GasSim[1] also indicates the landfill in its current state is past the peak gas generation.

i. A simulation of lateral flow of gas for 2019 indicated the potential for lateral migration of landfill gas across the landfill boundary is limited. The worst-case was identified as migration of landfill gas from waste deposited in the 1970s and 1980s which indicated limited concentrations could travel up to 10m, at the boundary of the 'cell'[3], beyond which any concentration would be insignificant **(Section 4.4, paragraph 4.4.20, Appendix 17.3 [APP-123]** of the **ES)**. This is supported by the monitoring results (**Appendix 17.2 [APP-121 and APP-122]** and of the **ES)**.

j. Offsite migration could be encouraged by the presence of preferential pathways such as old drains/service corridors, these will be detected and treated to prevent such an eventuality.

2.2 Summary of off-site gas migration risk

2.2.1 Based on the evidence presented above, the landfill is past its peak gas generation potential and has entered its residual gas generation phase. In this condition there:

"*is no sustained pressure within them and the risk of landfill gas migration off-site is reduced".* (Ref. 2)

2.2.2 In its current state there is no evidence of significant landfill gas migration beyond the landfill with recorded gas concentrations generally classed as very low risk. The risk to off-site receptors (e.g., neighbouring airport buildings and residential areas) is considered to be very low. However, it is possible that the Proposed Development on the landfill could increase the risk of gas migration to off-site receptors due to surcharging the surface of the landfill.

2.2.3 Work completed on other sites (Ref. 3) has indicated that a 3-6 m surcharge of shallow made ground containing ground gases increases soil gas pressure and seals the gas surface which has the effect of causing increased lateral migration from the gas source. It has been predicted that in low to moderate permeability soils increased surface emissions will occur within 5-10 m from the edge of the surcharged area.

2.2.4 It is not possible to predict the impact surcharging of the landfill will have on the gas migration off-site. Although, the greater depth of surcharging will occur over

constructed on gassing ground. Characteristic Situation (CS) 3 is considered a moderate risk and typical of a gas source being generated from old landfill, inert waste, or flooded mine workings.

[3] For the GasSim model each era of waste deposition were assumed to be 'cells.

the central and southern area of the landfill, at a distance more than 10m from off-site receptors, therefore the risk is considered to be low. However, to be prudent it was concluded that gas control measures will be first installed along the boundaries of the landfill with off-site receptors as part of the Proposed Development.

2.3 Baseline monitoring 2023

2.3.1 Data from the ongoing programme of monitoring in 2023 (Ref. 4) has shown that the monitoring locations in the landfill recorded methane and carbon dioxide concentrations ranging from 0.0% to 75.38% and 0.1% to 29.3%, respectively. Flow rates in boreholes were negligible, recorded values were between 0.0 and -0.41 l/hr.

2.3.2 Recorded concentrations of methane and carbon dioxide are similar to concentrations from previous monitoring (2018 to 2019). Flow rates appear to have slightly increased across all wells which resulted in a nominal change in characteristic situation, most of the landfill can be categorised as CS2 or CS3 (previously the classification was typically CS2). However, this does not impact the conclusions of the previous assessment which adopted a worst-case approach.

2.3.3 Gas monitoring in the wells located in the northern and western extents of the landfill exhibited the following gas concentrations, see **Table 2.1**.

Table 2.1 Summary of gas monitoring results at locations in proximity to landfill boundaries

Borehole ID (BHID)	Location on landfill	Steady CO2 (%)	Peak CO2 (%)	Steady CH4 (%)	Peak CH4 (%)	Steady Flow (l/hr)	Peak Flow (l/hr)	Atm. Pressure (mbar)
2023 Monitoring								
AEC18-LF-BH210	West	4.7	11.2	1.7	3.6	-0.5	-0.5	999
AEC18-LF-BH227	West	0.1	1.0	0.00	0.00	-0.11	-0.10	998
AEC18-LF-GW207A	West	17.8	18.1	17.2	17.9	0.0	0.0	998.0
AEC18-LF-BH232	West	8.1	8.1	75.38	75.60	0.21	0.40	999
AEC18-LF-BH201	North	6.5	8.3	8.59	12.00	0.19	0.20	1001
AEC18-LF-BH202	North	7.9	18.2	3.73	14.70	-0.01	0.00	1021

Borehole ID (BHID)	Location on landfill	Steady CO2 (%)	Peak CO2 (%)	Steady CH4 (%)	Peak CH4 (%)	Steady Flow (l/hr)	Peak Flow (l/hr)	Atm. Pressure (mbar)
2023 Monitoring								
AEC18-LF-BWS212	North	8.3	9.3	7.5	8.7	0.3	0.3	1007.0
PFCPRC40/SP	North	12.4	13.6	17.41	19.70	0.08	0.10	1022
AEC18-LF-PFWS58A	North	5.1	6.2	0.0	0.0	-0.3	-0.3	1000.0
Boundary wells								
AEC18-LF-BBH204	North-east	2.1	2.3	0.00	0.00	-0.02	0.00	1021
AEC18-LF-BBH209	East	1.2	2.5	0.01	0.20	0.17	0.20	1020
AEC18-LF-BWS211	East	1.7	1.9	0.00	0.00	0.29	0.40	1022

2.3.4 Gas monitoring wells along the north eastern and eastern boundary of the landfill show similar conditions to those recorded during the 2018-2019 monitoring rounds. The results support the findings from the previous assessment (**Chapter 17 Soils and Geology** of the **ES [APP-043]**) that there is currently a low risk to off-site receptors. See **Drawing 1**.

2.3.5 The proposed monitoring scope included continuous monitoring units, which were installed in three wells, however these were vandalised within 48 hours and were not reinstalled to avoid further vandalism.

3 INDICATIVE GAS CONTROL MEASURES

3.1.1 The ORS (**Appendix 17.5** to **Chapter 17** of the **ES [APP-125]**) presents potential gas control measures which will provide protection to the Proposed Development and to off-site receptors from landfill gas produced by the former Eaton Green Landfill.

3.1.2 A range of gas control measures have been outlined including:

a. Sealing/removing of existing preferential pathways i.e., drainage runs – Thames Valley Drain.

b. Gas management in buildings and to protect the Luton DART tunnel from gas ingress. Currently it is proposed to design protection measures to protect against a worst-case scenario of CS4. However final design would depend on building type/use and results of continued gas monitoring.

c. Across the top of the landfill in hard paved and landscaped areas proposed measures consist of high permeability 'gas pathway/venting layer', which will collect and direct landfill gas to a network of venting posts.

d. Beneath the aviation platform a high permeability 'gas pathway/venting layer' is proposed vented via a network of gravel trenches, located in areas away from the stands and taxiways and would diffuse gases away preventing build up.

e. As a precautionary approach, installation of gas control measures to the western and northern landfill boundaries is proposed to prevent lateral off-site migration to off-site receptors; airport buildings and residential properties, respectively. On the northern boundary the landfill material in the western part will ultimately be removed by the construction of a new access road (denoted with cross hatching in **Figure 3-1** below); and to the east where landfill will remain, by passive venting. In the interim period this area will be protected by the provision of a gas barrier to the south i.e., to deal with any potential increased gas generation or increased flow from the works area further to the south. The potential technique presented in the ORS is a Passive Dilution Gas Migration Barrier (denoted with pink line in **Figure 3-1**).

f. To the east and south of the landfill, the measures proposed across the top of the landfill are considered sufficient. The proposed gas control measures are indicative and the final design is dependent on results of continued monitoring and the detailed design of the Proposed Development. The measures to the external areas currently propose venting to atmosphere, based on current flow rates and concentrations it would not be feasible to utilise the gas emissions, which would be a more sustainable option. However, the Applicant will review the situation if the gas monitoring completed during construction indicates that utilising gas for energy production is feasible, based on the technology available at the time.

Figure 3-1 Gas protection measures proposed in the ORS **Appendix 17.5** to **Chapter 17** of the **ES [APP-125]**

4 PRINCIPLES OF PASSIVE DILUTION

4.1.1 It is concluded, based on available monitoring, that the current gassing conditions would be insufficient to enable energy generation. This is based on a review of currently available technologies, and therefore the proposal is to passively dilute the landfill gas and vent to atmosphere.

4.1.2 Passive dilution barriers, or Virtual Curtain (a trade name) systems, are an efficient way of controlling gas migration. The passive dilution principle is an accepted industry standard described in numerous guidance documents/technical standards describing control measures to protect buildings from landfill gas/ground gases and prevent migration of gases. Landfill gas will migrate from a site as a result of diffusion (moving from a high concentration of gas to a lower concentration) and flow due to pressure differences. This process is effective where concentrations are high combined with low emission rates, (Ref. 5) which are the conditions currently recorded in the former Eaton Green landfill. A passive inground venting system would be successful in diluting gas concentrations and dispersing to the atmosphere. There are several passive gas control systems:

a. venting trenches;
b. venting wells;
c. Virtual Curtain; and
d. drainage layers.

4.1.3 The Virtual Curtain has advantages over conventional venting trenches and venting wells and makes this system preferable for the Proposed Development.

4.1.4 The following is taken from a technical note ‘Design and performance of a passive dilution gas migration barrier’ (2001) (Ref. 6) (**Appendix A**) which sets out design guidance for the construction and operation of the system:

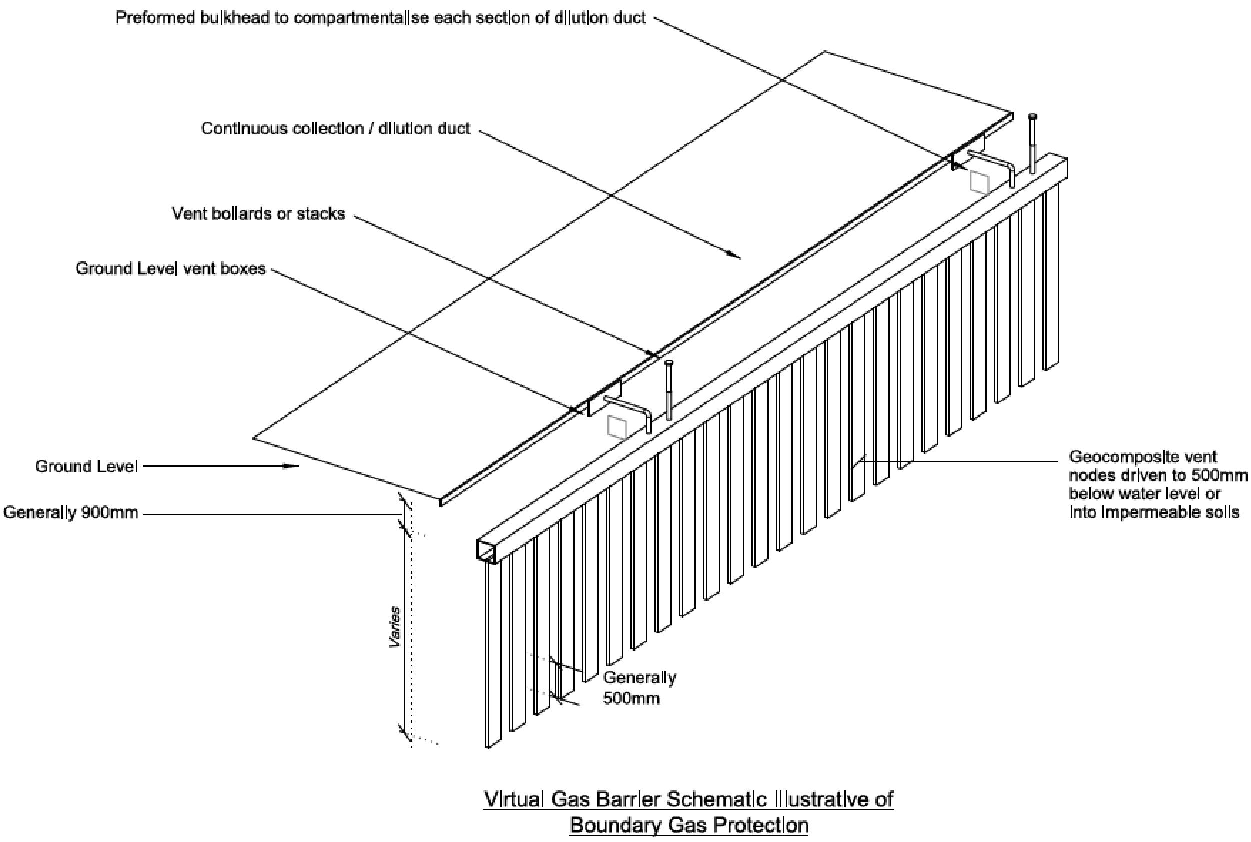
4.1.5 The discrete geocomposite vent nodes are driven into the ground along the boundary of the landfill to 500mm below the water table or into impermeable soils. This creates a perimeter of low pressure that draws in landfill gas via a pressure differential. The vents are connected via an overlying dilution duct which contains a continuous high flow of fresh air to dilute the gases before they are vented to the atmosphere using a combination of vent stacks, bollards or ground level boxes. The key advantages are:

a. dilutes gas emissions to acceptable levels; and
b. causes a venturi effect[4] in the geocomposite vents which enhances gas flow from the ground towards the vents.

4.1.6 A schematic diagram of the Virtual Curtain is shown below in **Figure 4-1.**

[4] Pressure gradients can be formed between gas in the ground and that in the atmosphere by the effects of wind (the Venturi effect). High wind flows across a surface cause a pressure difference, resulting in the movement of gas from the soil to atmosphere (Ref. 1)

Figure 4-1 Schematic diagram of a Virtual Gas Curtain (Ref. 6).



4.1.7 A Virtual Curtain system presents advantages over alternative methodologies as noted below (Refs. 6 and 7), also see **Appendix B**:

a. A lack of any requirement for surface infrastructure for the system makes the ventilation more discrete.
b. Installation of the vents requires no dewatering and will not impact the hydrogeological regime or nearby foundations.
c. The vents are installed using a no-dig methodology, meaning no open excavation resulting in minimal contact between construction workers and the contaminated ground. Works can be carried out in locations with restricted access, such as in close proximity to businesses, without causing much disturbance.
d. The lack of excavation reduces site traffic and minimises the need to dispose of excavated material as the soil remains in place.
e. The vents can be installed in quick succession which will benefit the site programme and mean shorter disturbance time.
f. Can be implemented with recyclable and recycled materials to reduce environmental impact, whilst minimising carbon dioxide emissions due to the lack of topsoil excavation and heavy machinery for material movement.

4.1.8 The Virtual Curtain is designed to be a part of a number of gas control measures as described in **Section 3** and would be installed prior to any disturbance of the historical landfill (assessment Phase 1) with the other measures being added as the Proposed Development progresses (**Appendix 17.5** of the ES **[APP-125]**).

4.1.9 The contractor will design the system based on the calculations presented in the technical note (Ref. 6) to ensure the system can deal with the volume of landfill gas based on the most recent monitoring data and that it will be adequately diluted. This will include factors of safety to address effects of uncertainty in the gas regime, constructions to flow in the system and blocking of vents.

4.1.10 The Contractor would use an experienced subcontractor with a proven track record in installing Virtual Curtains.

4.1.11 A gas management plan would be produced for the environmental permit application for the works on the landfill. The plan will include measures to protect and maintain the system with description of verification monitoring outside the Virtual Curtain.

5 CASE STUDY EXAMPLES

5.1 The Environmental Protection Group (EPG) Ltd. Gas Mitigation Design Report. V1 (2020) (Ref. 2)

5.1.1 Steve Wilson is the technical director at EPG and is a foremost expert in monitoring ground gases and assessment of risk.

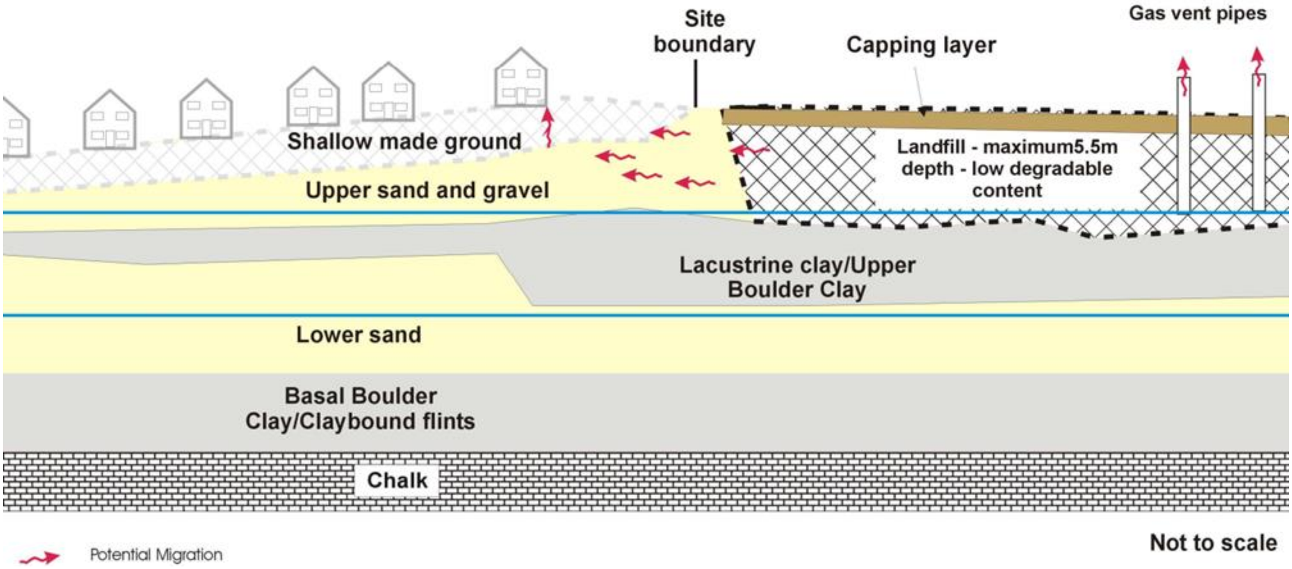
'*Steve is a Chartered Engineer and Registered Ground Engineering Advisor with over 25 years' experience in the investigation and assessment of ground gas risk (including landfill gas), as well as design of mitigation systems. He is a SoBRA (Society of Brownfield Risk Assessments) Accredited Risk Assessor for Permanent Gas and Vapour Intrusion. He has written numerous technical papers on the subject and contributed to much of the recent guidance, including British Standards. He has acted as an expert witness on ground gas risk in court cases around the world. This demonstrates compliance with the competency requirement of BS8485 (Ref. 8).'* (Ref. 2)

5.1.2 EPG has contributed to the development of much of the current guidance relating to ground gas risk assessment and mitigation design including the recently updated NHBC guidance (Ref. 9). This case study is based on work undertaken by EPG which included investigation into the efficacy of a passive venting system, see **Appendix C**.

5.1.3 This project demonstrates the effectiveness of a Virtual Curtain as a method of mitigating landfill gas migration from a landfill with similar attributes to the former Eaton Green Landfill, including the gas generation stage and waste types as presented in **Appendix 17.3** of the ES **[APP-123]**.

5.1.4 The aim of the project was to prove the gas protection measures installed in a housing development in proximity to an historical landfill were suitable to deal with the gas risk. An element of the works was to determine the efficacy of a Virtual Curtain installed in an earlier phase of development. As with the former Eaton Green Landfill site, the landfill was operational during the 1960s and received industrial, inert and domestic waste. At the time of the development proposal, the site was estimated to be within the residual phase of gas generation, similar to that of the former Eaton Green Landfill. The geology assumed for the Virtual Curtain design is shown in **Figure 5-1** below.

Figure 5-1 Geology assumed for Virtual Curtain design (Ref. 2).



5.1.5 In 2005, a Virtual Curtain was installed to prevent gas migration to the residential properties, located approximately 20m to 35m from the landfill. At the time of installation of the curtain the landfill gassing conditions were as follows:

a. maximum gas concentrations of 98.5% methane and 12% carbon dioxide, however the concentrations were highly variable;
b. maximum flow rates were up to 11.5 l/hr, again this was highly variable much lower flow rates of 2l/hr and 3l/hr were also recorded;
c. this equates to a gas generation rate of 26m^3/hr (equivalent to a Characteristic Situation (CS) 3 in accordance with BS8485 (Ref. 10);
d. beyond the landfill boundary methane and carbon dioxide concentrations of 24% and 7.3% respectively were recorded and maximum flow rate of approximately 1.9l/hr; and
e. the virtual gas curtain was designed to protect against an assumed flow rate of 12l/hr at the landfill site boundary.

5.1.6 The Virtual Curtain design was for a series of ‘high capacity’ vent nodes driven to an average depth of 6.5m below ground level (bgl) at 1.062m centres connected to a shallow ventilation duct connected to vent bollards.

5.1.7 The curtain was operational in 2005, methane concentrations in monitoring boreholes, now separated from the landfill by the gas curtain, did not detect any methane over the monitoring period from 2005 to 2019. The flow rates recorded at these boreholes became negative within 35m of the curtain, demonstrating the effectiveness and area of influence covered by the system.

5.1.8 The gassing conditions present were similar to the current state of the Eaton Green landfill which is predicted (based on the Gassim 2.5 modelling) to have a maximum gas generation rate of ~23.4m^3/hr and methane up to 80.6% v/v (worst case monitoring result from 2018/2019) (**Table 4.3**, **Appendix 17.3** of the ES **[APP-123]**). The most recent monitoring results indicate gas flow rates of up to -0.5l/hr (Ref. 4), maximum flow rate previously recorded was 9l/hr. Although the Conceptual Site Model (CSM) is different due to the greater depth of landfill waste and the presence of low permeability geological barrier at the former Eaton Green Landfill (**Appendix 17.2** of the ES **[APP-121]**).

5.2 S.A. Wilson & A. Shuttleworth, Design and Performance of a passive dilution gas migration barrier (2001) (Ref. 6)

5.2.1 This paper was also written by Steve Wilson whose professional credentials are described in Section 5.1.

5.2.2 The paper describes the design and construction of a Virtual Curtain to a landfill site in North West England, see **Appendix A**. The landfill was a former brickwork that began waste deposition in 1981 and ceased operation in 1995. During its operational period, 2.5 million tonnes of domestic waste was disposed of to a depth of 33m. On closure of the landfill an engineered cap was constructed and an operational gas extraction system installed and the landfill gas was flared. A routine ground investigation identified landfill gas migrating offsite and this necessitated the installation of the Virtual Curtain.

5.2.3 Before installation of the Virtual Curtain, gas monitoring identified methane and carbon dioxide concentrations in excess of 30% v/v and 10% v/v respectively, at 20m from the landfill site.

5.2.4 The ground conditions comprised relatively impermeable clays (Glacial Till) which were considered to act as a natural barrier against landfill gas migration. The landfill gas concentrations recorded off site were suspected of migrating along a granular lens within the superficial deposits.

5.2.5 The Virtual Curtain was designed with 14 vent nodes, reaching a depth of 5m bgl and separated by a 1.4m spacing. The dilution duct was positioned above at a depth of 0.45m bgl.

5.2.6 As shown below in the graphs in **Figure 5-2** and **Figure 5-3**, all subsequent monitoring readings after the implementation of the gas curtain found the concentrations of both methane and carbon dioxide to have been reduced significantly to values generally less than 1%.

Figure 5-2 Reduction in carbon dioxide concentrations after installation of the Virtual Curtain (Ref. 6)

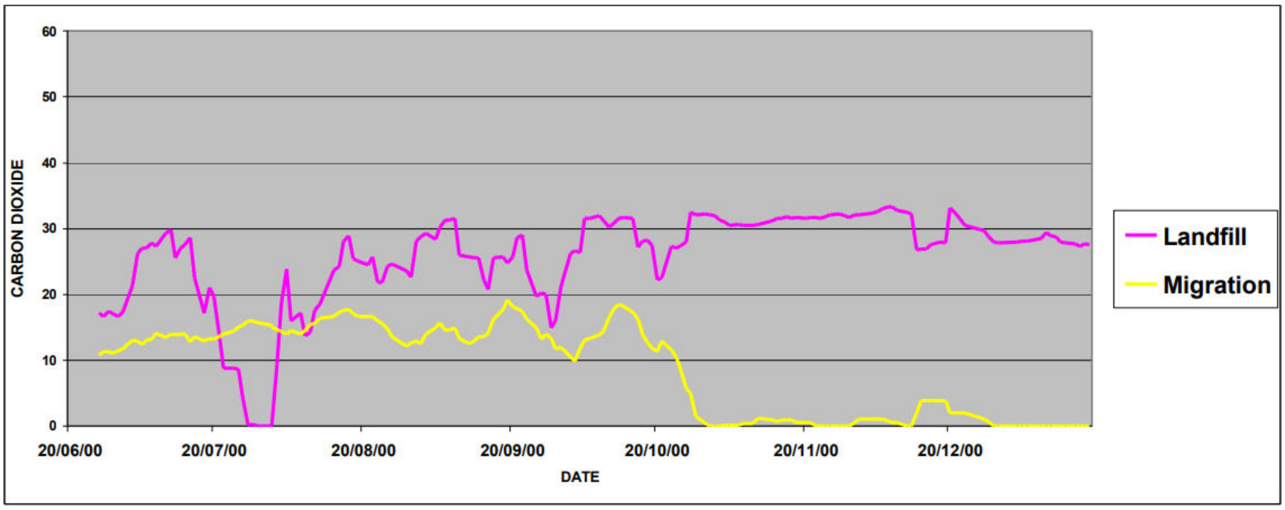
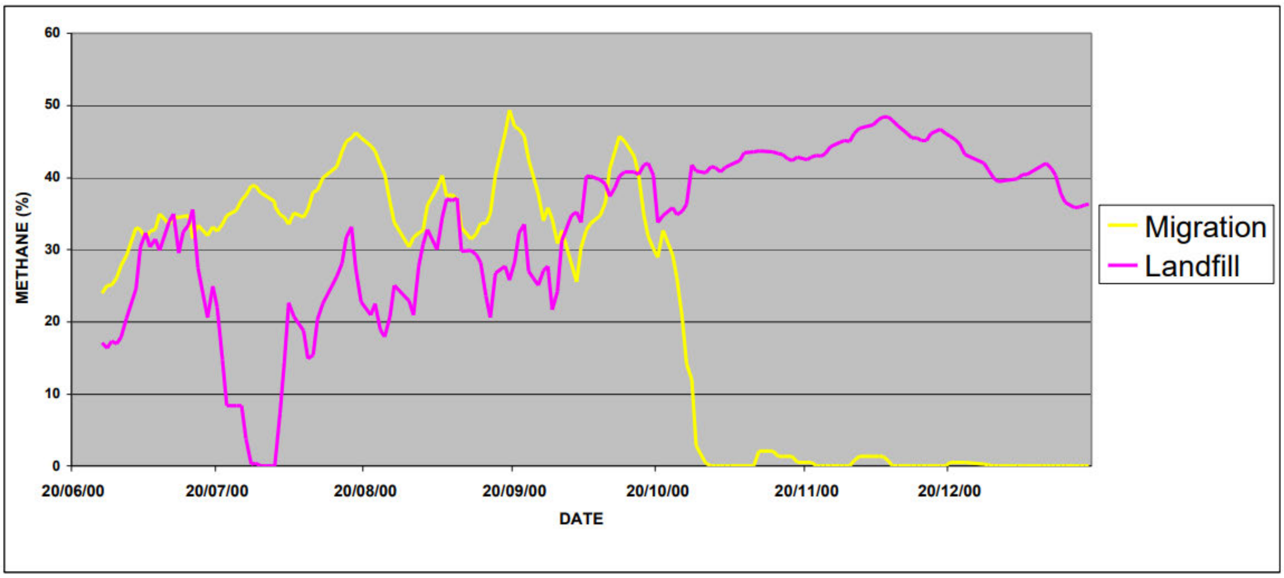


Figure 5-3 Reduction in methane concentrations after installation of the Virtual Curtain (Ref. 6)



5.2.7 In this case study the conditions were worse than those recorded in the former Eaton Green Landfill with higher gas concentrations coupled with high flow rates and a naturally occurring pathway, however, the Virtual Curtain proved to be an efficient mitigation measure to prevent gas migration. The clay with flints and weathered chalk in which the former Eaton Green Landfill sits form a natural relatively impermeable barrier around the landfill waste to reduce potential for off-site migration.

6 POTENTIAL IMPLEMENTATION FOR THE FORMER EATON GREEN LANDFILL

6.1.1 All works within the landfill will require Environmental Permits, including a Deposit for Recovery Permit. This permit will require ongoing baseline and long-term monitoring of conditions including gas monitoring, on and off the landfill. All proposals will be presented to the Environment Agency, with monitoring data reviewed by the Agency also.

6.1.2 It is recognised the Proposed Development could impact the current gassing situation of the former Eaton Green Landfill by stimulating gas generation and potentially migration of landfill gas off-site. Therefore, gas protection measures are proposed. The installation of a Virtual Curtain around the landfill will provide additional mitigation in combination with the other measures described in Section 3.

6.1.3 As presented in **Figure 3-1**, various measures including the installation of a Virtual Curtain would be installed along the western and northern boundaries of the landfill to mitigate the risk to the airport and residential area to the north.

6.1.4 The case studies demonstrate the efficacy of the Virtual Curtain for conditions which are comparable to/worse than those recorded currently in the former Eaton Green Landfill. The examples presented have highlighted the longevity of the vents and wide radius of influence, as well as the effectiveness of landfill gas extraction and dilution, reducing methane concentrations to undetectable levels. The landfills had some comparable conditions to the former Eaton Green landfill, including gas generation rates, waste types and gas compositions.

6.1.5 The second case study highlights the efficacy when installed to prevent migration from an actively gassing landfill, which is the worst-case assumption for future conditions in the former Eaton Green Landfill.

6.1.6 The proposed Virtual Curtain will be installed prior to any earthworks within the landfill (this would be an expected environmental permit pre-commencement condition). The efficacy will be determined by ongoing monitoring including use of continuous units. It should be noted that the disturbance to the landfill is minimal during the initial stages of the Proposed Development. The monitoring data collected would be used to monitor the effectiveness of the Virtual Curtain and determine the risk of ground gas migration during the more intrusive later works.

6.1.7 Although the landfill will be disturbed, the effect of surcharging is likely to be exhibited over a distance up to 10 m (Ref. 3). The surcharging during initial development works is at the south of the landfill this would be at a considerable distance from the nearest off-site residential receptor to the north.

6.1.8 The gas management plan will be prepared for the environmental permit. This would include failure scenarios for each component of the gas management system (Ref. 11) and appropriate action values should be assigned to specific monitoring locations for elements of the gas control system. It would also include requirements for emergency actions, changes to gas management techniques and changes to the monitoring strategy to address failure scenarios.

6.1.9 The ongoing monitoring of the gas management system will be undertaken throughout the preparatory works on the site including the earthworks, processing and compaction trials. If the gas flows or concentrations detected during the monitoring resulted in action values being reached (as to be outlined in the gas management plan), the likely additional measures considered would depend on:

a. Verification of proper installation of virtual curtain
b. Gas source (local or widespread)
c. Receptors impacted.

6.1.10 If further gas mitigation was required to be incorporated into detailed design, this may include consideration of:

a. Excavation or elimination of localised source
b. Re-evaluation of gas collection for use in energy generation (currently not considered feasible due to current low flow and concentrations)
c. Consideration of active gas control measures

6.1.11 Further details of the design of the gas mitigation system will be confirmed during the detailed design stage.

REFERENCES

Ref. 1 CIRIA, "Publication C665: Assessing the risks posed by hazardous ground gases to buildings", 2007.
Ref. 2 The Environmental Protection Group Ltd., "Gas Mitigation Design Report," 2020.
Ref. 3 Wilson, S. Screening approach for landfill gas migration around landfill sites. Ground Gas Information Sheet No.3. Presented at the Scottish Contaminated Land Forum Conference 2018, 5 September 208, Glasgow, Scotland. EPG Ltd. 2018.
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Ref. 5 Card, G.C., 'Protecting development from methane', 1995. CIRIA Report 149.
Ref. 6 Wilson, S.A and Shuttleworth, A., Design and performance of a passive dilution gas migration barrier. 2001.
Ref. 7 SEL Environmental Ltd, "Virtual Curtain System - Lateral Gas Migration Barrier," 2017.
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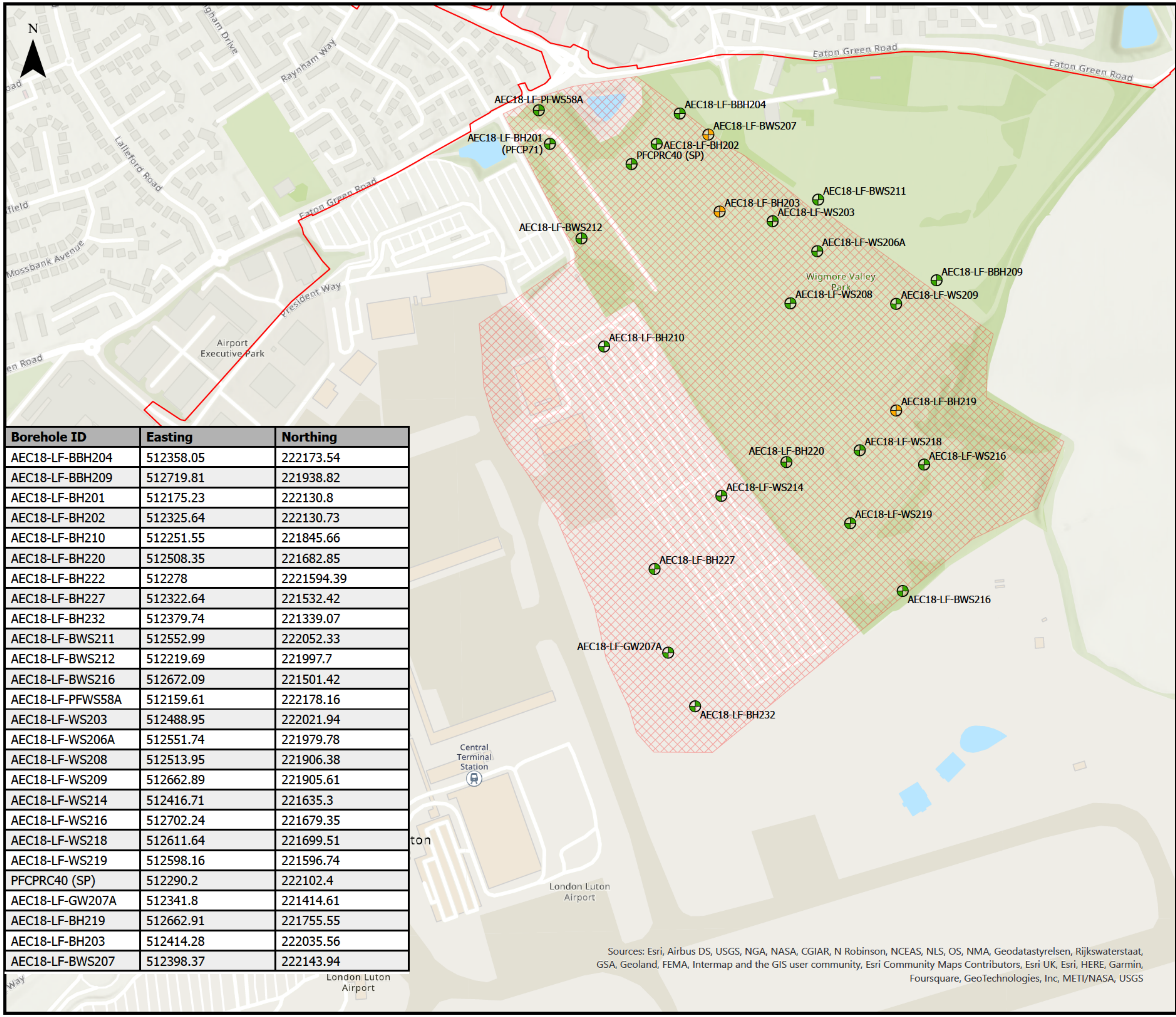
Ref. 11 Environment Agency (2020) Landfill operators: environmental permits. Available at https://www.gov.uk/guidance/landfill-operators-environmental-permits/manage-landfill-gas.

DRAWING 1



Borehole ID	Easting	Northing
AEC18-LF-BBH204	512358.05	222173.54
AEC18-LF-BBH209	512719.81	221938.82
AEC18-LF-BH201	512175.23	222130.8
AEC18-LF-BH202	512325.64	222130.73
AEC18-LF-BH210	512251.55	221845.66
AEC18-LF-BH220	512508.35	221682.85
AEC18-LF-BH222	512278	2221594.39
AEC18-LF-BH227	512322.64	221532.42
AEC18-LF-BH232	512379.74	221339.07
AEC18-LF-BWS211	512552.99	222052.33
AEC18-LF-BWS212	512219.69	221997.7
AEC18-LF-BWS216	512672.09	221501.42
AEC18-LF-PFWS58A	512159.61	222178.16
AEC18-LF-WS203	512488.95	222021.94
AEC18-LF-WS206A	512551.74	221979.78
AEC18-LF-WS208	512513.95	221906.38
AEC18-LF-WS209	512662.89	221905.61
AEC18-LF-WS214	512416.71	221635.3
AEC18-LF-WS216	512702.24	221679.35
AEC18-LF-WS218	512611.64	221699.51
AEC18-LF-WS219	512598.16	221596.74
PFCPRC40 (SP)	512290.2	222102.4
AEC18-LF-GW207A	512341.8	221414.61
AEC18-LF-BH219	512662.91	221755.55
AEC18-LF-BH203	512414.28	222035.56
AEC18-LF-BWS207	512398.37	222143.94

Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community, Esri Community Maps Contributors, Esri UK, Esri, HERE, Garmin, Foursquare, GeoTechnologies, Inc, METI/NASA, USGS

All structure positions are indicative. The proposed works will be subject to detailed design development. The changes will be within limits of deviation specified in the Development Consent Order.

Legend

Order Limits

Interpreted Landfill Extent

Ground Gas Monitoring Positions

Continuous Ground Gas Monitoring

Ground Gas Spot Monitoring

0 0.040.07 0.15 0.22 0.3

Kilometers

Revision History	Drawn	Checked / Approved	Date	Rev.
	OB	RB / HLO	06/12/23	P01

Luton Rising
Our airport. Our community. Our planet.

Luton Rising
Hart House Business Centre
Kimpton Road, Luton, LU2 0LA
www.lutonrising.org.uk

London Luton Airport Expansion
Development Consent Order

Drawing Title

Drawing 1:
Round 1 Ground Gas
Monitoring Positions

Purpose of issue	Suitability
Additional Submissions - Deadline 7	Issue

Drawn	Checked	Approved	Date	Scale	Size
OB	RB	HLO	01/24	1:5,000	A3

DCO Application Ref.	APFP Regulation	DCO Document Ref.
TR020001	N/A	TR020001/APP/8.164

	Revision
LLADCO-4-ARP-WHS-GEN-DR-EN-0011	P01
Project - Phase - Originator - Asset/Zone - Sub Asset - Type- Disc. - Number	

APPENDIX A - WILSON, S.A AND SHUTTLEWORTH, A., DESIGN AND PERFORMANCE OF A PASSIVE DILUTION GAS MIGRATION BARRIER. 2001

Design and performance of a passive dilution gas migration barrier

S A Wilson and A Shuttleworth

16 May 2001

S A Wilson, MSc, BEng, CEng, MICE, FGS, Associate Director.

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Key words

Landfill gas, contamination, remediation, gas barriers

No of words - 2297

Introduction

The use of in ground barriers, particularly vent trenches, is a common method used to protect development from landfill gas migration. A new system for installing passive venting barriers is described which overcomes many of the disadvantages associated with conventional trench systems. It uses highly efficient geocomposite vent nodes, which are driven into the ground and connected to a collection/dilution duct, to allow safe venting to atmosphere. The system minimises spoil and contact by installers with contaminated soils and can be installed in restricted spaces.

There is little design guidance available for such barriers. A method is described which allows the spacing of vents and the ventilation requirements to be determined. This should ensure that gas vented to atmosphere from the system is at acceptable concentrations.

A monitored trial of the system has been undertaken which demonstrates the barrier is effective in reducing migration of landfill gas.

Conventional gas migration barriers

Vertical in ground barriers are used extensively to prevent gas migration from landfill sites to below susceptible targets (usually a nearby development).

There are two common methods of forming a barrier to gas migration:

- Using very low permeability materials to resist gas flow,
- Using highly permeable materials to allow the gas to vent to the surface.

Current methods of forming a gas resistant barrier usually involve the excavation of a trench and backfilling with either an impermeable material such as bentonite, or the inclusion of a gas resistant membrane. Vent trenches are normally constructed using trenches backfilled with either gravel or geocomposite venting media to promote gas flow to the surface. An alternative method is to provide a series of discrete vent wells at regular spacings. These methods allow the gas to exhaust directly to atmosphere without any dilution in the system.

Legislation

Recent European legislation[1] suggests that the primary method of gas management from heavily gassing landfill sites should comprise enclosed flaring or energy utilisation. This prevents emissions of methane (a greenhouse gas) to atmosphere. Control contingencies to support the primary gas management system may include perimeter gas barriers as a secondary method of preventing off site migration.

In the past it has also been common to manage gas in the ground by uncontrolled venting to atmosphere. The Pollution Prevention and Control (England and Wales) Regulations (2000)[2] implemented the Landfill Directive and apply to all new landfills and all existing ones from 2003. This requires the use of best available technology (BAT) and therefore the venting of undiluted gas to atmosphere should be avoided wherever possible.

It is, therefore, now considered unacceptable to passively vent gas to atmosphere which contains greater than 1% v/v methane or 1.5% v/v carbon dioxide, on both environmental and health and safety grounds. One implication of this is that vent trenches must dilute gas to tolerable levels before discharge to the atmosphere.

Passive dilution barrier

Concept

The concept of the passive dilution barrier is to form a low pressure area relative to the surrounding gassing ground, to encourage gas to flow towards the barrier. This is achieved by driving discrete vent nodes into the ground, which are connected to a collection/dilution duct running along the top of the strips. The nodes comprise highly efficient geocomposite strips. The duct has a high flow of fresh air through it by means of passive ventilation. This is one of the key advantages of the system as it:

- dilutes gas emissions to tolerable levels,
- causes a venturi effect in the geocomposite vents which enhances gas flow from the ground towards the vents.

Ventilation of the duct can be achieved using a combination of vent stacks, bollards or ground level boxes, depending on the gas regime and wind conditions at a particular site. A schematic layout for the barrier is shown in Figure 1.

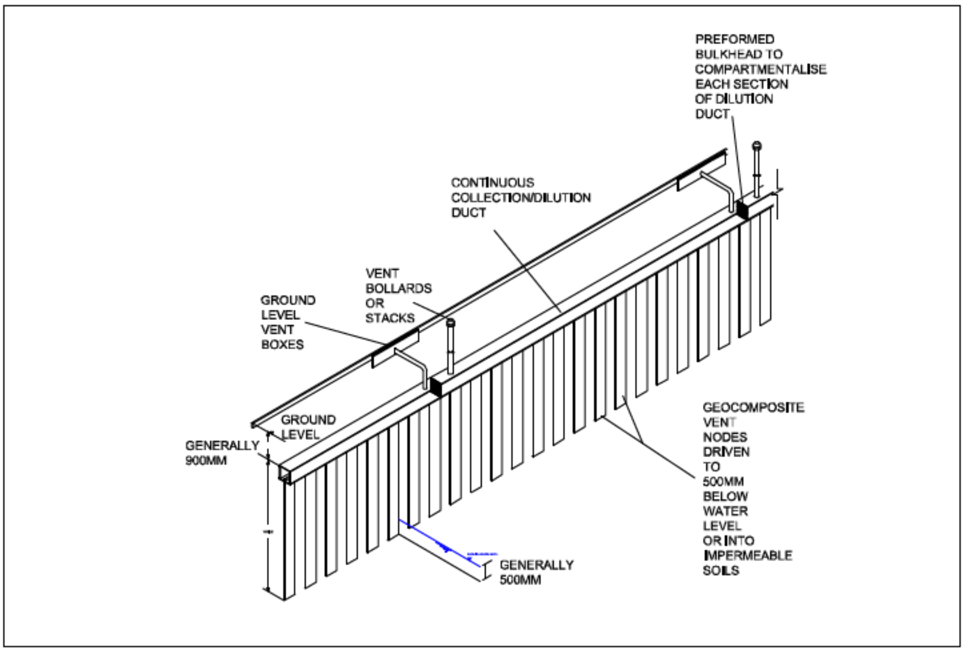

Figure 1 Schematic layout of passive dilution barrier

Theory

Gas flow to barrier

Generally the flow of gas of gas in the ground towards a well or barrier can be modelled using the equations for planar flow of fluids based on D'Arcy's law. One of the most common situations is shown in Figure 2, where a permeable layer is overlain by an impermeable barrier (a capping layer or hard cover). A relatively shallow groundwater table or impermeable clay layer typically provides a lower confinement to gaseous flow. In this situation we may use the equation for flow of fluids in a confined aquifer towards a horizontal slot based on work by Chapman (1959)[3] and the United States Environmental Protection Agency (1975)[4].

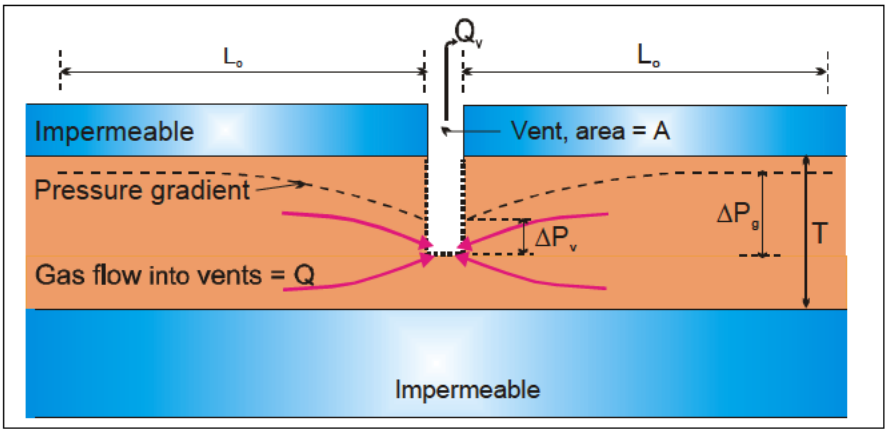

Figure 2 Flow to a slot penetrating a confined aquifer

Flow to a slot in a confined aquifer is given by

$$Q = \frac{\left[\frac{2K_I\gamma}{\mu}\right] TL\Delta P_g}{L_o} \qquad (1)$$

(Based on D'Arcy flow), where:

Q = flow in m/s from both sides of barrier

K_I = intrinsic permeability of the ground in m^2.

γ = bulk density of methane in N/m^3

μ = viscosity of gas being considered in Ns/m^2

T = thickness of confined aquifer or migration layer in m

L = length of section of barrier being considered in m

ΔP_g = driving pressure of gas from ground Pa

L_o = distance of influence of barrier (decreases as spacing of nodes decreases) in m

The calculated flow of gas towards the barrier is very sensitive to the chosen value of the distance of influence of the barrier. Evidence[5, 6, 7] suggests the radius of influence for passive vent wells is likely to vary between 2m and 30m, depending on ground conditions, type of well, etc, and it seems reasonable to use similar values for L_o.

However because the calculated value of gas flow is sensitive to any variation in L_o a sensitivity analysis should usually be carried out.

Using these equations and the measured pressures from monitoring wells, the flow of gas to the line of vent wells can be estimated. The peak values of pressure recorded when a borehole tap is first opened should be used, as this represents the pressure in the surrounding ground that has achieved equilibrium with the borehole and is the driving pressure for gas towards the vent curtain. It is therefore vital for this design method that both peak and steady state borehole flow and pressures are recorded when undertaking gas monitoring. This calculated gas flow from the ground is the volume that requires dilution in the duct.

Flow capacity of geocomposite vents

The flow capacity of a single geocomposite vent can be calculated directly using D'Arcy's law, and the value of intrinsic permeability, K_i, for the particular geocomposite used. In this case the pressure difference causing the flow can be assumed to be the equilibrium or steady state recorded from boreholes.

The flow in the vents is given by;

Total flow capacity of vents $$Q_v = \left[\frac{K_i g A i}{m} \right] x\, N \qquad (2)$$

Where

K_i = intrinsic permeability of geocomposite in m^2

A = area of vents in m^2

N = number of vents

i = pressure gradient = ΔP_v/length of vent node.

The sum of the flows from all the vents must be greater than the flow into the system from the surrounding ground.

Dilution

The flow of fresh air through the collection/dilution duct, required to dilute the methane to less than 1%, can be calculated using the gas flow calculated in (1) and the guidance in CIRIA Report 149[8] and British Standard BS 5925[9].

Using: $Q_{duct} = Q \, x \, c_{max} \, x \left(\frac{1 - c_e}{c_e} \right)$ from CIRIA 149 (3)

Where c_e = design equilibrium concentration in %

Q_{duct} = fresh air flow through system in l/hr

Q = flow of soil gas into the system for each 25m length in l/hr

C_{max} = design concentration of methane in soil gas, %

The ventilation area required to provide this flow can be calculated using the guidance for designing natural ventilation provided in British Standard BS 5925. Using these design criteria the arrangement and type of ventilation can be determined.

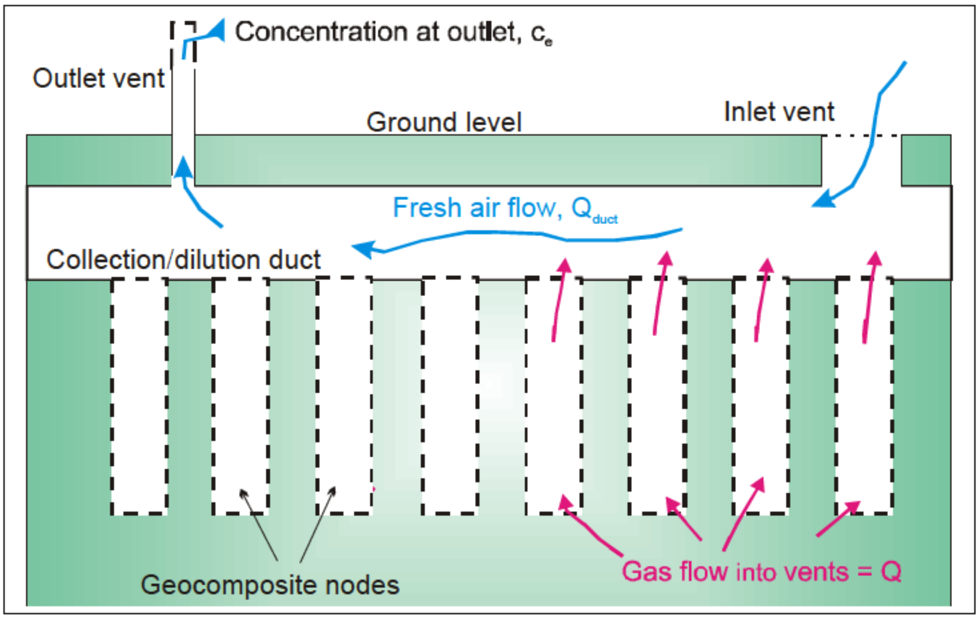

figure 3 Fresh air flow in collection/dilution duct

Factors of safety

The calculations require a factor of safety to be incorporated to allow for the effects of:

- uncertainty in the gas regime,
- constrictions to flow in the system,
- blocking of vents or other breakdowns of the system.

It is usual to apply the following factors of safety in gas ventilation design

- the use of maximum concentrations, flow rates and pressures regardless of spacial or temporal variation across a site gives an inherent factor of safety, because the calculations assume constant flows from the ground across the whole site, at the design values,
- design gas values - apply a factor of safety of between l and 5 depending on the amount and reliability of the gas monitoring data and site investigation data,
- on ventilation air flow - apply a factor of safety of between l and 5 depending on the sensitivity of the development , risk, what management systems will be in place, how critical the dilution barrier is, etc,
- on ventilation outlets - apply factor of safety of between l and 3 on the same basis as the air flow.

Installation

The passive dilution barrier is installed using a unique no dig method in which a steel mandrill is vibrated up to 5m into the ground, using a vibrating piling hammer supported by a 360^{o} excavator. (Figure 4). Once the hollow mandrill is in the ground the central cutting shoe can be removed (see Figure 5) and a geocomposite strip inserted. The mandrill is then withdrawn, leaving the vent in the ground.

Figure 4 vibrating mandrill into ground

The key advantages of this method of installation are:

- speed – up to 30 vents per day can be installed,
- cost – there is a reduction in excavation costs and disposal of spoil that is frequently contaminated,
- safety – contact with contaminated materials by the installers is minimised.

A further advantage is that walls can be constructed very close to site boundaries and in areas where access is restricted and conventional barriers could not be constructed, as shown in Figure 4.

Figure 5 Inserting geocomposite vents into ground

Site trials

Background

A site trial of the new system was undertaken at a landfill site in North West England. The site was formally a brickworks which ceased operations in 1975, leaving open clay pits. Filling of the site began in 1981, with approximately 2.5 million tonnes of domestic refuse being placed. The site was completed in 1995 leaving depths of waste up to 33m, which was covered by a capping layer.

The site is underlain by Glacial Till overlying Millstone Grit and the Till generally comprises relatively impermeable clays which act as a natural barrier to landfill gas migration. The site has been retro fitted with a gas extraction system which collects the gas and burns it off at flares. Routine monitoring by the landfill operator and the

Environment Agency identified one area where gas appeared to be migrating off site. The monitoring borehole in question was approximately 20m outside the landfill, beyond the influence of the extraction system.

The migration is thought to be occurring along a granular lense or infilled glacial overflow channel within the Glacial Till, which comprises sand and gravel. These features are common in the area. The conceptual gas migration model is shown in Figure 6.

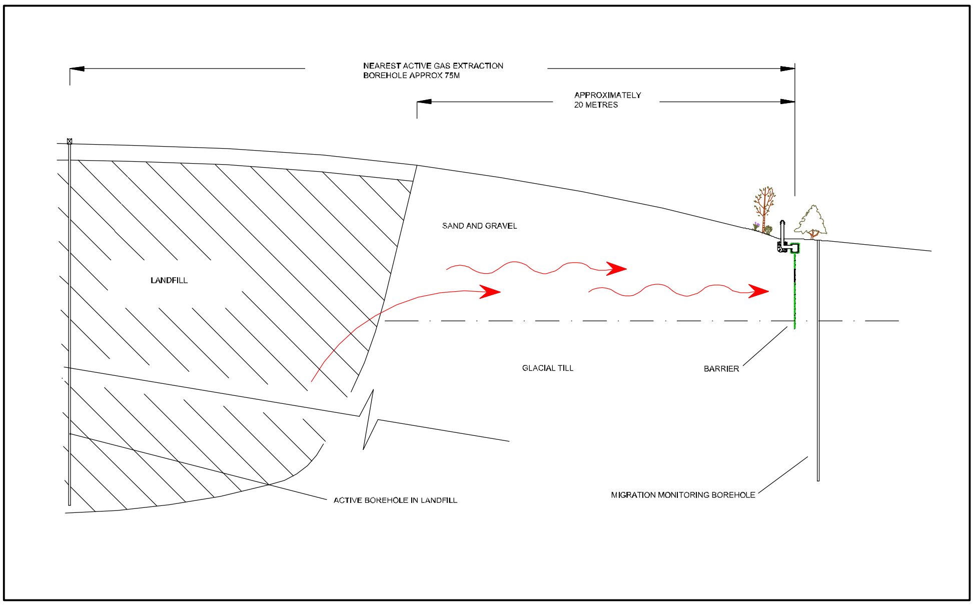

Figure 6 Conceptual gas migration model

Before installation of the barrier methane concentrations in one monitoring borehole were consistently in excess of 30% v/v with peak levels of 50% v/v. Carbon dioxide concentrations were typically between 10% v/v and 20% v/v.

Installation

The passive barrier was installed over a length of 20m offset from one of the affected borehole by 1m. It runs 10m either side of the borehole, between it and the centre of the landfill. It is 75m from the nearest extraction well within the landfill and 20m from the landfill boundary.

The passive dilution barrier comprises 14 No vertical geocomposite vent nodes (410mm by 30mm) spaced at 1400mm centres. They are driven to a depth of 5m below ground level. A collection/dilution duct has been placed over the nodes and is 450mm deep by 410mm wide. It is vented via a 3m vent stack at one end and a 0.9m high venting bollard at the opposite end, which provides 18,000mm^2 ventilation area.

The system was installed over a period of 4 days and was commissioned on 18 October 2000.

Performance

Gas monitoring has been undertaken on a daily basis before and after installation of the barrier. The results presented in Figures 7 and 8 show a clear and dramatic reduction in gas concentrations after the barrier was commissioned. Both methane and carbon dioxide concentrations have dropped to generally less than 1% v/v in the ground. This demonstrates the effectiveness of the system.

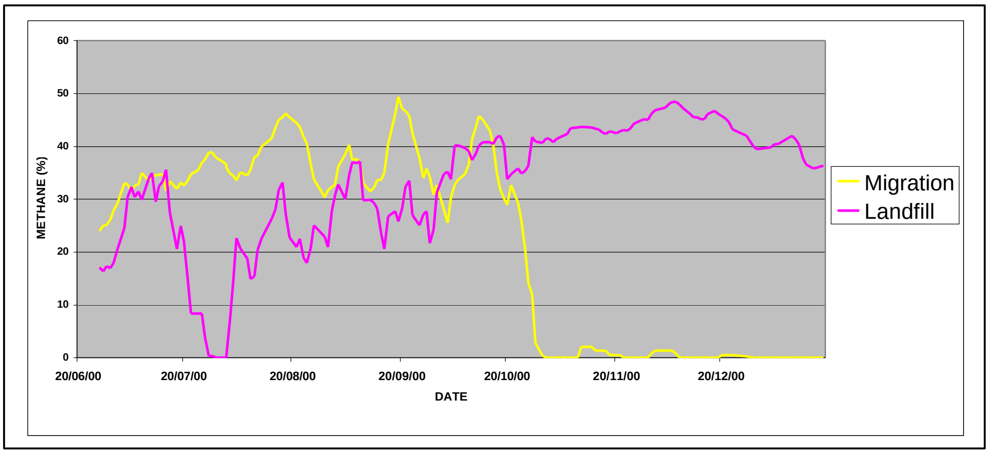

Figure 7 Reduction in methane concentrations after installation of barrier

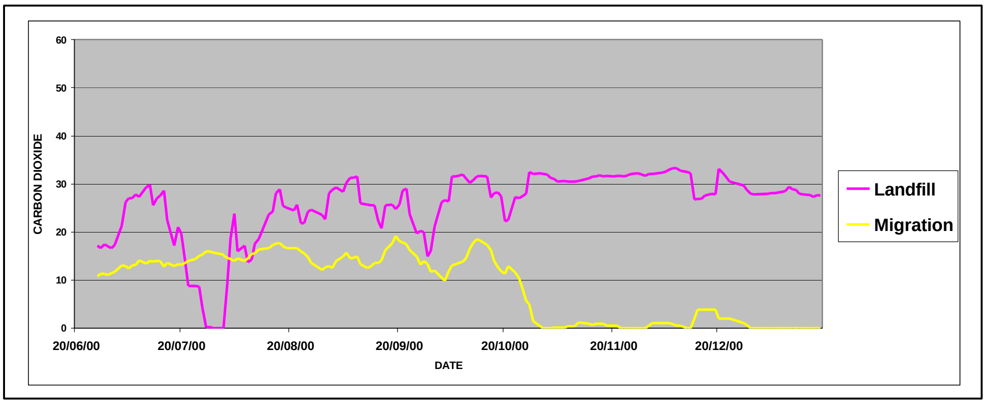

Figure 8 reduction in carbon dioxide concentrations after installation of barrier

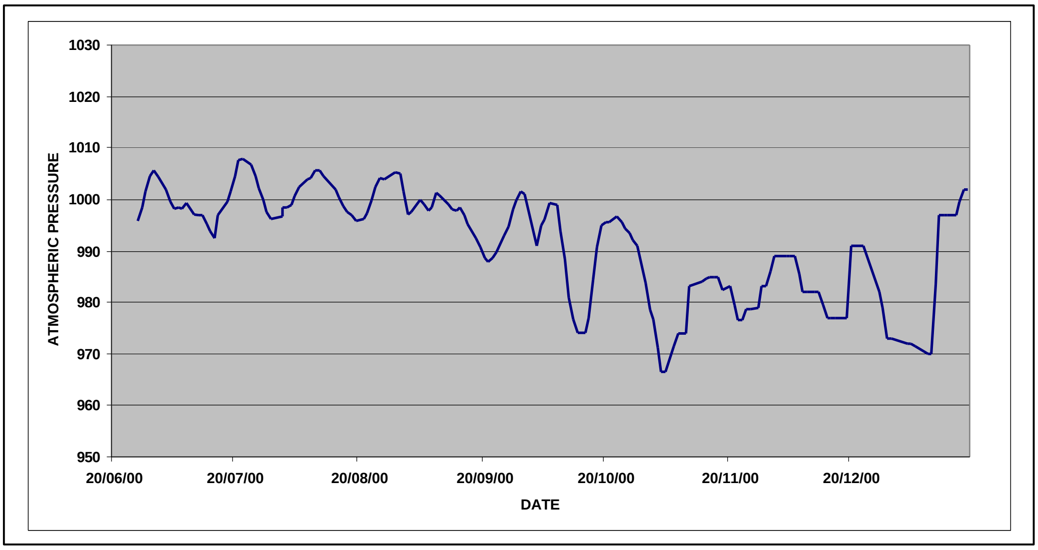

Figure 9 Atmospheric pressure during monitoring

Conclusions

The passive dilution gas migration barrier offers several advantages over conventional vent trenches and vent wells:

- speed of installation,
- reduced costs,
- increased safety as contact with contaminated materials by the installers is minimised,

- efficient ventilation dilutes gas emissions to tolerable levels,
- can be installed in restricted areas.

The system can be designed to deal with different ground conditions, gas regimes and wind conditions to ensure the safe venting of gases at tolerable concentrations, using accepted principles of fluid flow in the ground.

A monitored site trial has demonstrated the effectiveness of the barrier in reducing landfill gas migration.

References

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[1] Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste. Official Journal of the European Communities, L182, Volume 42, 16 July 1999. PHOTOCOPY PG 14 and 17 OF TECH GUIDANCE

[2] Pollution Prevention and Control (England and Wales) Regulations, 2000, SI 2000 No 173. The Stationary Office.

[3] Chapman T G (1959). *Groundwater flow to trenches and wellpoints*. Journal of the Institution of Civil Engineers, Australia, October – November, 1959, pp275 to 280.

[4] United States Environmental Protection Agency (1975). *An evaluation of landfill gas migration and a prototype gas migration barrier.* Produced by City of Winston-Salem N C and Enviro-Engineers Inc. Grant No S-801519. 1975.

[5] Harries C R, Witherington P J and McEntee J M (1995). *Interpreting measurements of gas in the ground*. CIRIA Report 151, Construction Industry Research and Information Association

[6] Pecksen G N (1985). *Methane and the development of Derelict Land*. London Environment Supplement, No 13, Summer 1985. Greater London Council.

[7] Department of the Environment DoE (1991). *Waste Management Paper No 27*, *Landfill gas*. Second Edition. Department of the Environment, HMSO, London

[8] Card G B (1995). *Protecting development from methane*. CIRIA Report 149, Construction Industry Research and Information Association.

[9] British Standards Institution, BS 5925:1991, *Code of Practice for ventilation principles and designing for natural ventilation*.

APPENDIX B - SEL ENVIRONMENTAL LTD, VIRTUAL CURTAIN SYSTEM - LATERAL GAS MIGRATION BARRIER, 2017

SEL Ground Gas Protection

Virtual Curtain System

Lateral Gas Migration Barrier

SEL Ground Gas Protection

KEY ADVANTAGES

Engineering & Environmental

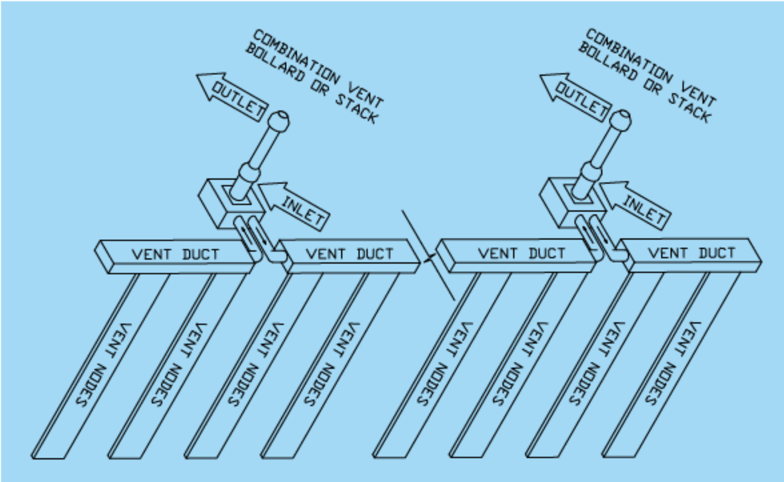
- Predominantly a no-dig solution with a minimal generation of excavated material that is generally from the upper inert capping layer.
- Contaminated ground remains in place.
- Any arisings are used to backfill over the top duct with any surplus arisings regraded to suit original ground levels.
- No dewatering requirements.
- No impact on site hydrogeology.
- No impact on existing foundations.
- Replaces the requirement for aggregate venting media.
- Reduces site traffic on existing roads as the venting composites used are up to 100 times more efficient that gravel venting media.
- Uses recycled and recyclable materials.

Health & Safety / CDM

- Minimal exposure to contamination (e.g. asbestos) for workforce and public.
- Gas dispersal is controlled and diluted with fresh air prior to dispersal.
- Reduced risk from less vehicle movements and lower plant requirement.
- Shallow excavations, less than 0.65m deep.
- Minimal open trench required as the installation progresses.
- Small working zone made fully secure at the end of each shift.
- Robust, vandal resistant dedicated vent terminations, designed for a school environmental.

Financial Benefits

- Low mobilisation / start-up costs.
- Rapid installation will enhance site programme.
- Negates the off-site disposal of contaminated material.
- Minimises importation of granular materials.
- Low maintenance requirements post installation.
- Minimal site disruption of other trades.
- Can be installed while other earthwork operations take place, such as ground improvements.



Sustainability

- Reduces the environmental impact of your development as it uses recycled and recyclable materials.
- Reduces impact of quarrying through low reliance on aggregates.
- Reduces impact of tipping / landfill through no-dig installation method.
- Requires significantly less lorry movements than alternatives considerably reducing your carbon emissions.

Virtual Curtain System

SEL Ground Gas Protection

'NO-DIG' GAS MIGRATION BARRIER

The SEL Virtual Curtain Gas Migration System is the ideal solution to intercept, treat and control lateral migrating ground gases. The system has been used on numerous commercial and residential projects, on and near brownfield development sites over the last 20 years and is a realistic alternative to gas barriers and gravel vent trenches.

This unique patented system comprises a series of vertical vent nodes connected together to create a zone of low pressure within the ground that attracts and dilutes ground gases to acceptable levels, provide an appropriate pathway break and conduit for controlled and safe passive venting to atmosphere. The virtual curtain system can form a fundamental part of any remediation strategy to satisfy the requirements of Part 2A of the Environmental Protection Act (1990) determination and enable developments on contaminated land or near it.

Containments

The Virtual Curtain System is devised to mitigate ground gases such as:

- Methane (Ch4)
- Carbon dioxide (Co2)
- Carbon monoxide (CO)
- Diesel range organics (DRO)
- Petroleum range organics (PRO)
- Volatile organic hydrocarbons (VOCs)

Design Requirements

To develop a site specific designed solution for your project the following information would be required:

- All site investigation data, including historical investigations to enable us to undertake a comprehensive review and desk study.
- All gas monitoring and groundwater monitoring information including all historical monitoring information.
- Detailed site survey.
- All details of services, drainage or any other manmade structures that exist on or beneath the site.
- Any other relevant information, anecdotal or otherwise that may affect or influence our proposals.
- A copy of the part 2A determination document.

CPD MEMBER The CPD Certification Service

SEL offer a CPD accredited seminar which reviews a new methodology for migrating gas protection from landfill and brownfield sites. The seminar comprises a 30 minute presentation followed by questions and answers.

SEL Ground Gas Protection

Telephone: +44(0)1254 589987
Email: sales@selenvironmental.com
Web: www.virtual-curtain.com

www.virtual-curtain.com

Technical Services

To support architects, engineers and contractors in designing and installing ground gas protection systems, our design services department offers computer aided scheme details and advice on solutions.

Other Services

- Permeable Paving Optimisation
- Commercial SuDS
- Attenuation Tanks
- Gas Protection
- SELSports Rooftop Sports
- MUGA & Sports Pitches
- Cloud Water Control
- Modular Paving

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BB2 4DD

Virtual Curtain System

Lateral Gas Migration Barrier

APPENDIX C - THE ENVIRONMENTAL PROTECTION GROUP LTD., GAS MITIGATION DESIGN REPORT, 2020

Gas Mitigation Design Report

Chequersfield, Welwyn Garden City

Planning Reference 6/2018/1519/MAJ

April 2019

The Environmental Protection Group

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Company Number: 3506162

Reference	EPG/Chequers/Q1/20120/R1	**Version**	1.0	**Issue Date**	February 2020

CONTENTS

SUMMARY

Taylor Wimpey Ltd (TW) have developed a residential site with flats. It is referred to as Chequersfield and is located in Welwyn Garden City. The development has been constructed next to an old landfill site. Gas resistant membranes have been incorporated into the building floor construction and a ventilated sub-floor void has also been provided as part of the gas mitigation system.

The development lies to the north of a previous housing development constructed around 2004 to 2007 by George Wimpey North London Limited and Persimmon Homes Limited. As part of that development a gas venting barrier (known as a Virtual Curtain) was installed along the northern boundary of that site to prevent any potential gas migration from the landfill. This current development lies outside the venting barrier on the landfill side.

The landfill adjacent to this site is over 44 years old and it is 15 years since the Virtual Curtain gas barrier was installed at the site.

Gas monitoring data and other evidence from the site show that current gas generation rates in the landfill adjacent to this site will be very low and at residual levels. Improved understanding of landfill gas risk since 2007 suggest that the gas generation will be insufficient to support large scale gas migration out of the landfill site.

Gas monitoring data in this site shows carbon dioxide concentrations have the same signature as those in the development site to the south and are caused by biological respiration rather than landfill gas migration.

A very cautious approach would classify the current site as Characteristic Situation CS3.

The development has been provided with a gas resistant membrane and underfloor ventilated void. The assessment has shown the design and installation is adequate to deal with the gas risk on this site and would meet the requirements of CS3.

The membrane provided is sufficient to deal with any minor and localised VOC contamination.

Ongoing gas monitoring in relation to the Virtual Curtain is no longer required.

1. INTRODUCTION

1.1 Background

Taylor Wimpey Ltd (TW) have developed a residential site with flats. It is referred to as Chequersfield and is located in Welwyn Garden City. The development has been constructed over the edge of an old landfill site. Gas resistant membranes have been incorporated into the building floor construction and a ventilated sub-floor void has also been provided as part of the gas mitigation system.

The development lies to the north of a previous housing development constructed around 2004 to 2007 by George Wimpey North London Limited and Persimmon Homes Limited. As part of that development a gas venting trench was installed along the northern boundary of that site to prevent any potential gas migration from the landfill. This development lies outside the venting barrier on the landfill side.

Taylor Wimpey has appointed the Environmental Protection Group Limited (EPG) to complete the following:

- Undertake a risk assessment to determine if the scope of protection is adequate to deal with the gas and VOC vapour hazards;
- Determine whether the development will have any adverse effect on the gas venting barrier and the gas risk to the development to the south;
- Determine the mitigation measures necessary to manage gas risks; and
- Provide a design report to confirm that the as built protection is adequate to allow safe occupation of the development.

In relation to gas risk, EPG's report supersedes all previous documents. The report addresses the concerns raised by LQM about previous assessments prepared by Soiltechnics.

This report has been prepared in general accordance with UK guidance and good practice documents, including (but not limited to):

- BS8485: 2015 + A1: 2019 - Code of Practise for the Design of Protective Measures for Methane & Carbon Dioxide Ground Gases for New Buildings (BSI, 2019);

- CIRIA Report C735 - Good Practice on the Testing and Verification of Protection Systems for Buildings Against Hazardous Ground Gases (CIRIA, 2014); and

- CLR 11 - Model Procedures for the Management of Land Contamination (DEFRA and the EA, 2004).

A copy of this report should be submitted to the relevant regulators for their review and comment.

1.2 Author and competence

The foreword to British Standard BS8485: 2015 + A1: 2019 states that “it has been assumed in the preparation of this report that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced”. This report has been prepared by Steve Wilson. Steve is a Chartered Engineer and Registered Ground Engineering Advisor with over 25 years experience in the investigation and assessment of ground gas risk(including landfill gas), as well design of mitigation systems. He is a SoBRA Accredited Risk Assessor for Permanent Gas and Vapour Intrusion. He has written numerous technical papers on the subject and contributed to much of the recent guidance, including British Standards. He has acted as an expert witness on ground gas risk in court cases around the world. This demonstrates compliance with the competency requirement of BS8485.

2. SUMMARY OF DESIGN INFORMATION

2.1 Information for the current development

The following information has been provided to EPG by Taylor Wimpey.

Soiltechnics, Residential development, Chequersfield, Welwyn Garden City, Remediation Strategy Report, STM3370A-RS01, March 2019
Soiltechnics, Letter dated 19th July 2019, Soil leachate testing at Chequersfield, Welwyn Garden City
Soiltechnics, Proposed development, Land at Chequersfield, Welwyn Garden City, Ground Investigation Report, STM3370A-G02, June 2019, Revision 03
Land Quality Management (LQM), Review of land contamination reports relating to a site at Chequersfield, Welwyn Garden City, LQM Report 1474-0/1, February 2020

2.2 Information from the Virtual Curtain design

In addition, EPG was responsible for the design of the gas venting system (known under its trade name of Virtual Curtain) that was installed to the north of the existing housing development. EPG no longer holds all the base information used in the design but does have a summary of it and extracts of borehole records and gas monitoring data in the landfill site. The following documents were used to inform the design of the Virtual Curtain barrier.

Stats report – Former Holy Trinity School Site, Welwyn Garden City, Geotechnical and Geoenvironmental Report, Volumes 1 to 3 of 3, 30 July 1999.
Stats report – Quarterly report on groundwater chemistry and landfill gas monitoring, Chequersfield (closed) landfill site, Welwyn Garden City, Herts, February 2004, Report No 33405/06.
Geotechnical Engineering report – Ground investigation, Land adjacent to Chequersfield, Welwyn Garden City, Proposed housing development, Report No 15634, 2 March 2004.
Letter from Vertase Limited to SEL Environmental, 17 March 2004.

Vertase FLI Limited – Environmental site assessment, Herts Country Club. March 2007, Ref 738 GWN Rev A
Vertase Limited – Drawing No D430/B, Chequersfield, Welwyn Garden City, Herts, Investigation location plan.
EPG Limited, Design Summary for Gas Protection Design, Virtual curtain system, Rev 1 27 April 2004, Chequersfield
EPG Limited, Design Report for gas migration barrier at Chequersfield, Hertfordshire Country Club Site, Welwyn Garden City, for Vertase Limited, Revision 1.0, May 2007

EPG also has construction and as built drawings for the venting system and the design calculations/report for it (Appendix A) as well as post construction gas monitoring records (Appendix B).

3. BACKGROUND INFORMATION

3.1 Site location

The site is located on the northern side of a road known as Chequersfield. It is approximately 1.8km to the south of Welwyn Garden City centre. The National Grid reference for the site is 523619, 211325. The location of the site is shown in Figure 1.

Approximate site boundaries are edged in **RED**.

Figure 1 Site location

The site is approximately triangular in shape. To the west is undeveloped land which continues beyond the western site boundary to the East Coast Mainline railway line. The Welwyn Grid Substation is to the north west. A road (Chequersfield) forms the southern boundary, beyond which lay residential houses. Open rough grass land borders the site to the north.

3.2 Site history

The history of the site is summarised in the Soiltechnics Ground investigation report, based on historical maps. Information was also obtained during the design of the existing gas barrier. In summary the following is relevant with respect to landfill gas:

- The majority of the site was open fields and then disused land. A small part of the site (northern edge) was open fields until it was part of a sand or gravel pit that encroached onto it from the north in around 1937 to 1939). This gravel pit formed part of the larger Twentieth Mile Gravel and Brick Works, with six settling beds bordering the site to the northwest.

- It is known that the area to the north of the site was used as a landfill. The exact dates are not clear and there is conflicting data. Council records indicate that on 8th February 1963 a proposal for school playing field on tip was made and stated "*tip is almost full*". A record from 16th July 1963 indicates the pit would be full in 6 weeks. However, based on the design reports for the Virtual Curtain it could have been filled as late as 1976 and it accepted industrial, domestic and inert waste. The uncertainty regarding the final closure dates makes no difference to the gas risk assessment. It is a minimum of 44 years old and gas generation will be in the residual phase. The landfilling is discussed in more detail in Section 4; and

- A vertical gas barrier was installed along the southern side of Chequersfield and around the former Herts Country Club to prevent landfill gas migration to the housing development to the south of this site. It was installed around 2005 to 2007. This is discussed in more detail in Section 4.

3.3 Geology and groundwater

The Soiltechnics report indicates that the site is underlain by Superficial deposits of the Kesgrave Catchment Subgroup and Lowestoft Formation Subgroup which are between 5m to 12m and up to 20m deep respectively (these are Glacial deposits). The solid geology comprises Lewes Nodular Chalk Formation and Seaford Chalk Formation.

Previous investigations have identified that there is an upper Sand and Gravel layer and this has been quarried for sand and gravel. This is underlain by Lacustrine Clay or Boulder Clay and then a lower

Sand Gravel layer. Finally, the lowest drift deposits comprise a basal Boulder Clay or Claybound Flints. The anticipated geology taken from the previous Virtual Curtain design is shown in Figure 2.

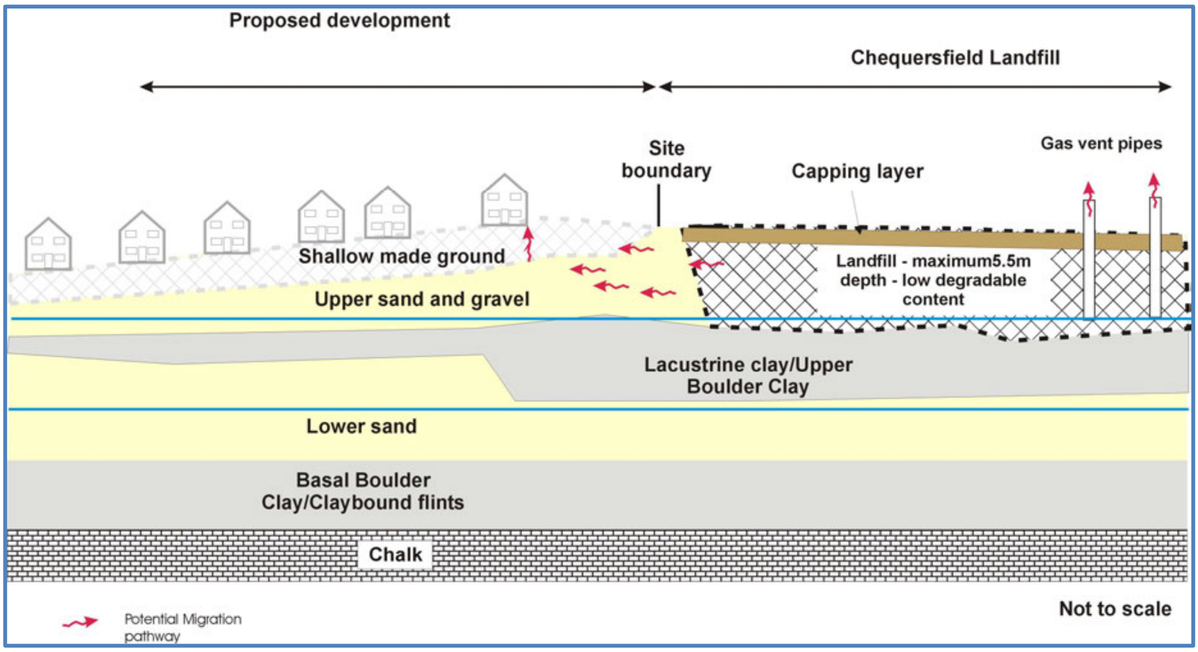


Figure 2 Geology assumed in Virtual Curtain design

4. INFORMATION ON THE LANDFILL SITE

4.1 Extent of landfill and investigations

The landfill to the north of the site was investigated by STATS in 1999 and a further investigation to locate the southern boundary was completed by Vertase FLI in 2003. An extract from a Vertase FLI Drawing No D430/N produced in 2003 is shown in Figure 4a and this indicates the likely extent of the landfill. It covered an area of some 33,000m^2. The plan also shows the locations of the STATS monitoring wells installed in and around the landfill site. A full version is provided in Appendix C.

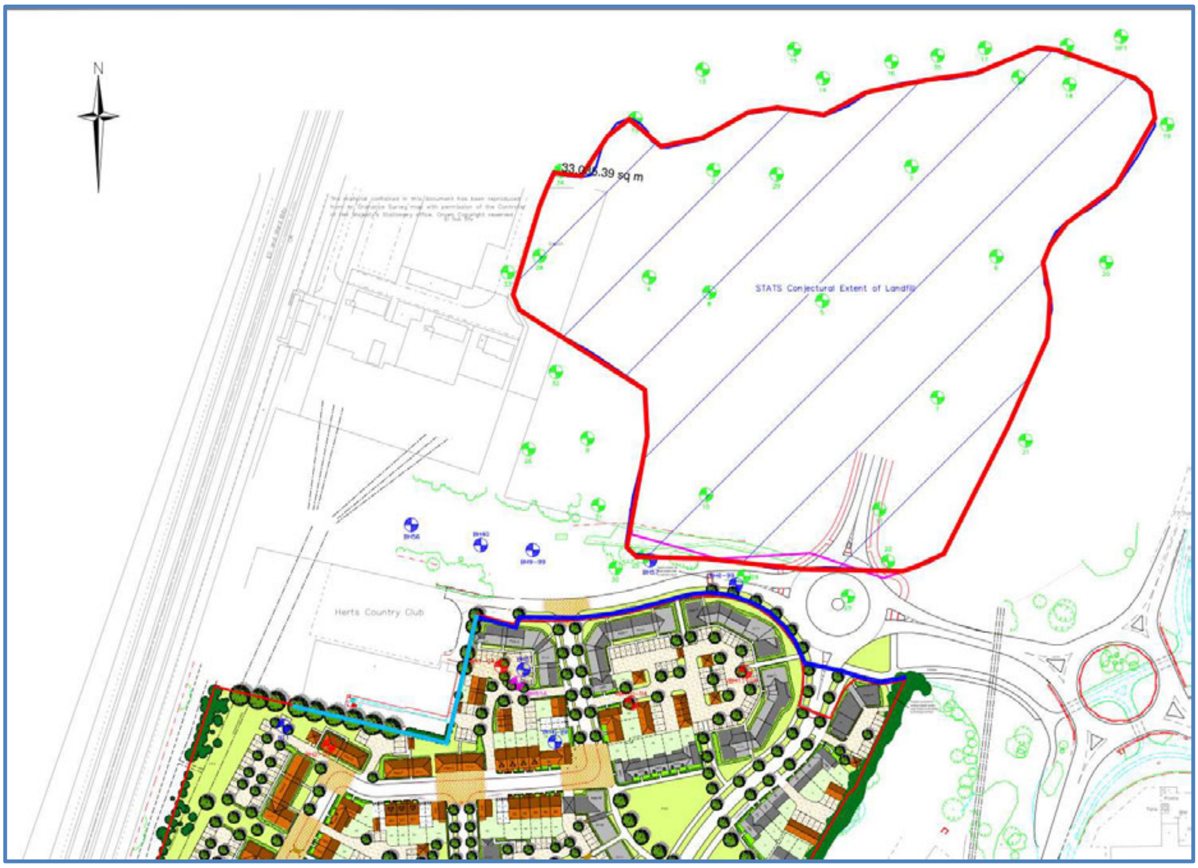


Figure 3 Conjectured extent of landfill site based on STATS site investigation in 1999

Soiltechnics has taken the information from the Vertase FLI drawings (Figure 4a) and superimposed it on the topographical survey for this site (Figure 4b). As can be seen the landfill encroaches the site at the eastern end of the site.

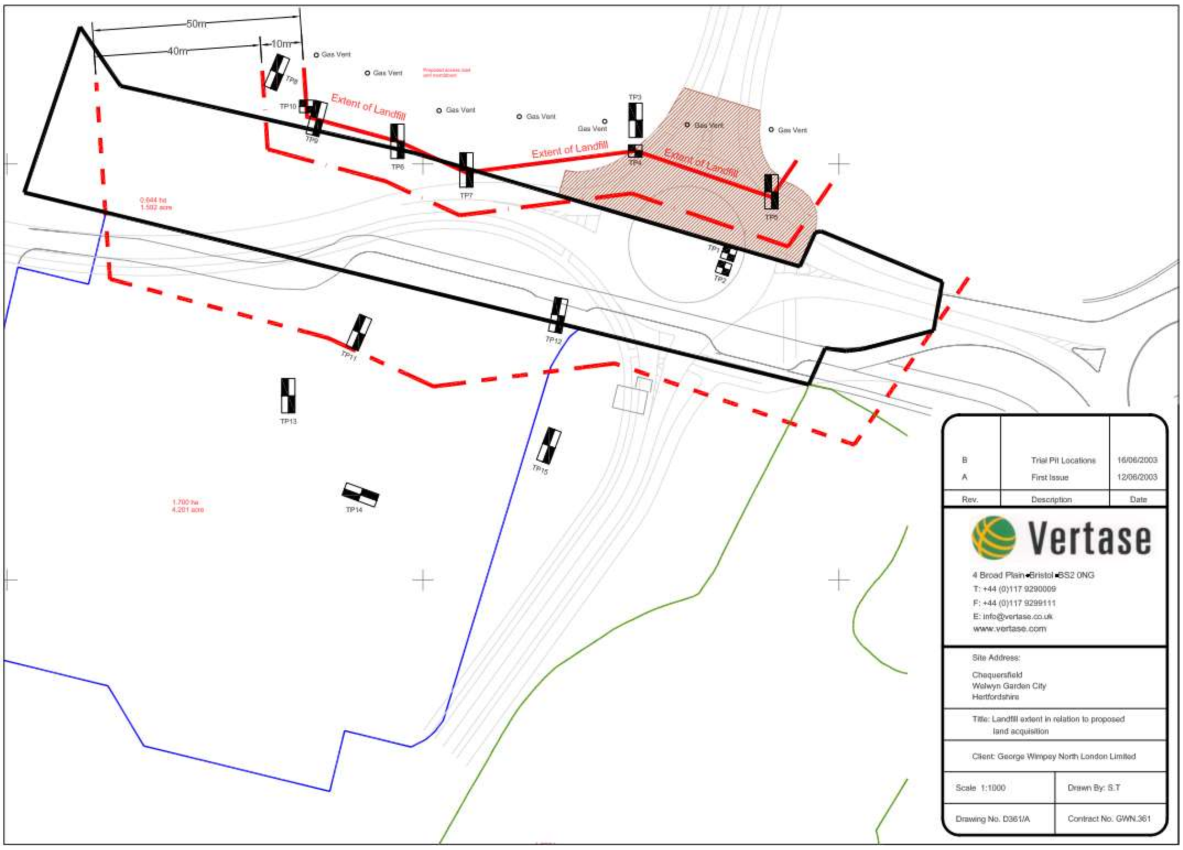


Figure 4a Vertase investigation of landfill boundary 2003

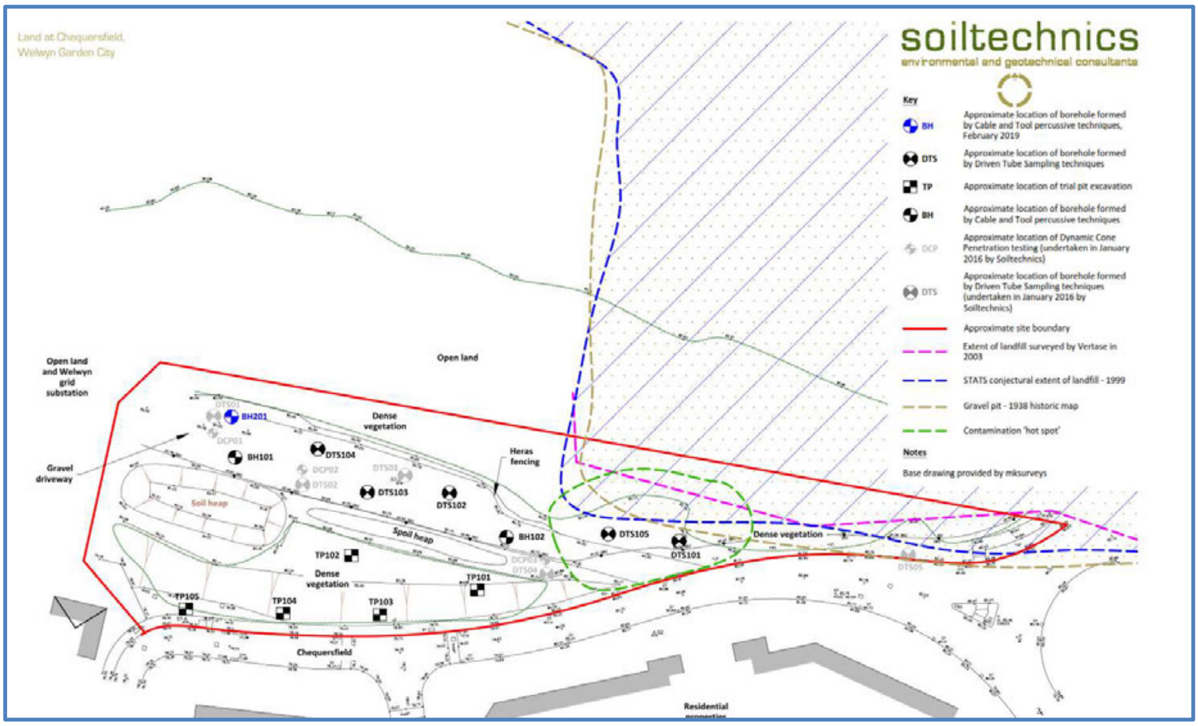


Figure 4b Site survey and landfill area

The surface of the landfill is covered by capping layer that is 0.8m thick on average and comprises a very gravely clay (reworked Brickearth). It is not an engineered capping layer and will not form a barrier to either water ingress or gas egress from the landfill material.

4.2 Gas barrier

In March 2005 a vertical gas venting barrier (known by the trade name of Virtual Curtain) was installed along the southern side of Chequersfield. Temporary vent bollards were installed which were replaced with the permanent vent bollards in December 2006. A subsequent extension was installed around the former Hertfordshire Country Club in 2007. The barrier is essentially a very effective vent trench and it was installed to the base of the upper layer of sand and gravel in order to reduce the risk of landfill gas migration towards the development site to the south.

The location of the main barrier is shown in Figure 5 and the approximate location of the extension in Figure 6.

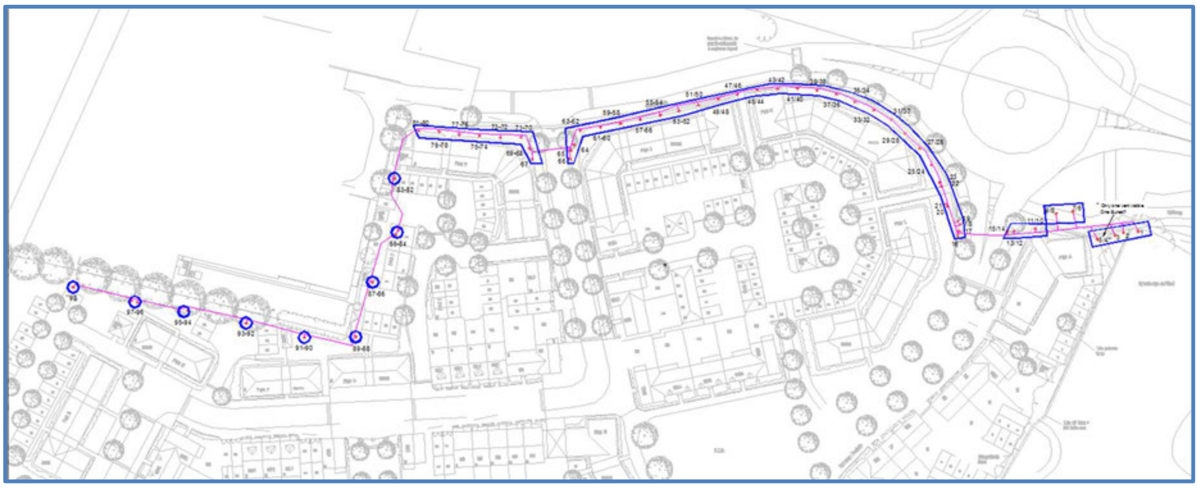


Figure 5 Location of Virtual Curtain gas barrier

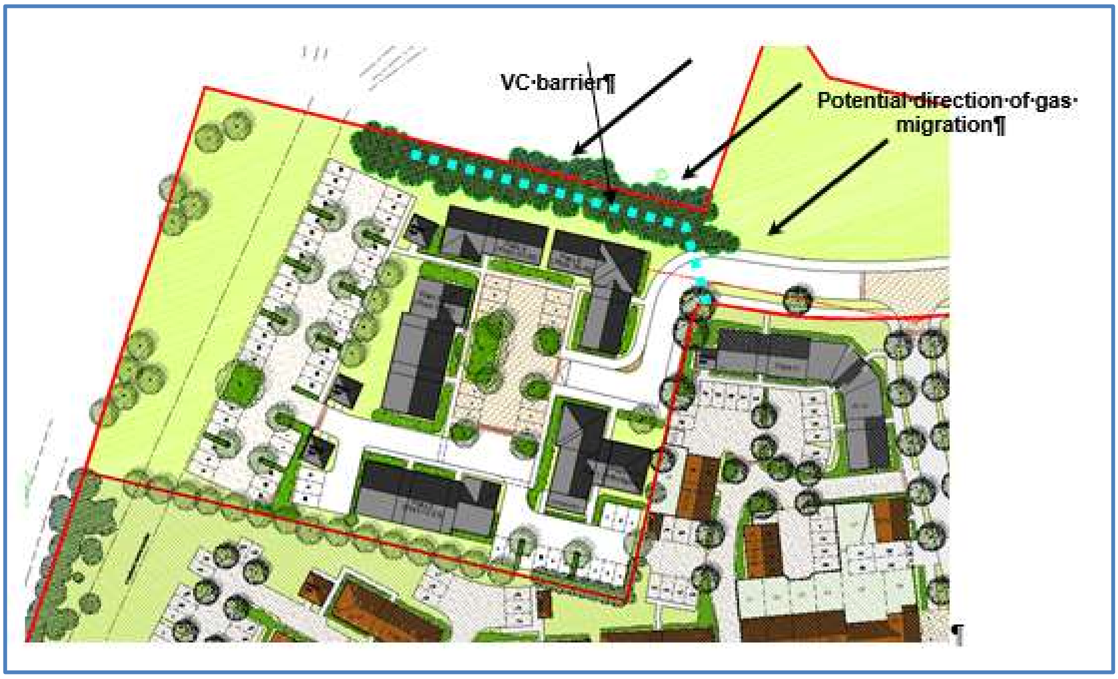


Figure 6 Approximate location of extension to barrier around former Hertfordshire Country Club

The Virtual Curtain gas barrier comprises a series of vent nodes in the ground driven to a depth of 6.5m on average (Figure 7). The vents are connected to a shallow ventilation duct that is connected to the black vent bollards seen along the southern edge of Chequersfield (Figure 8). The drawing in Appendix A indicates that the main section (referred to as Type B) comprised high capacity vent nodes 354mm by 150mm in plan at 1.062m centres (708mm gap between them). An extension (location not clear and referred to as Type A) was installed with standard vent nodes 410mm by 50mm at 2.5m centres.

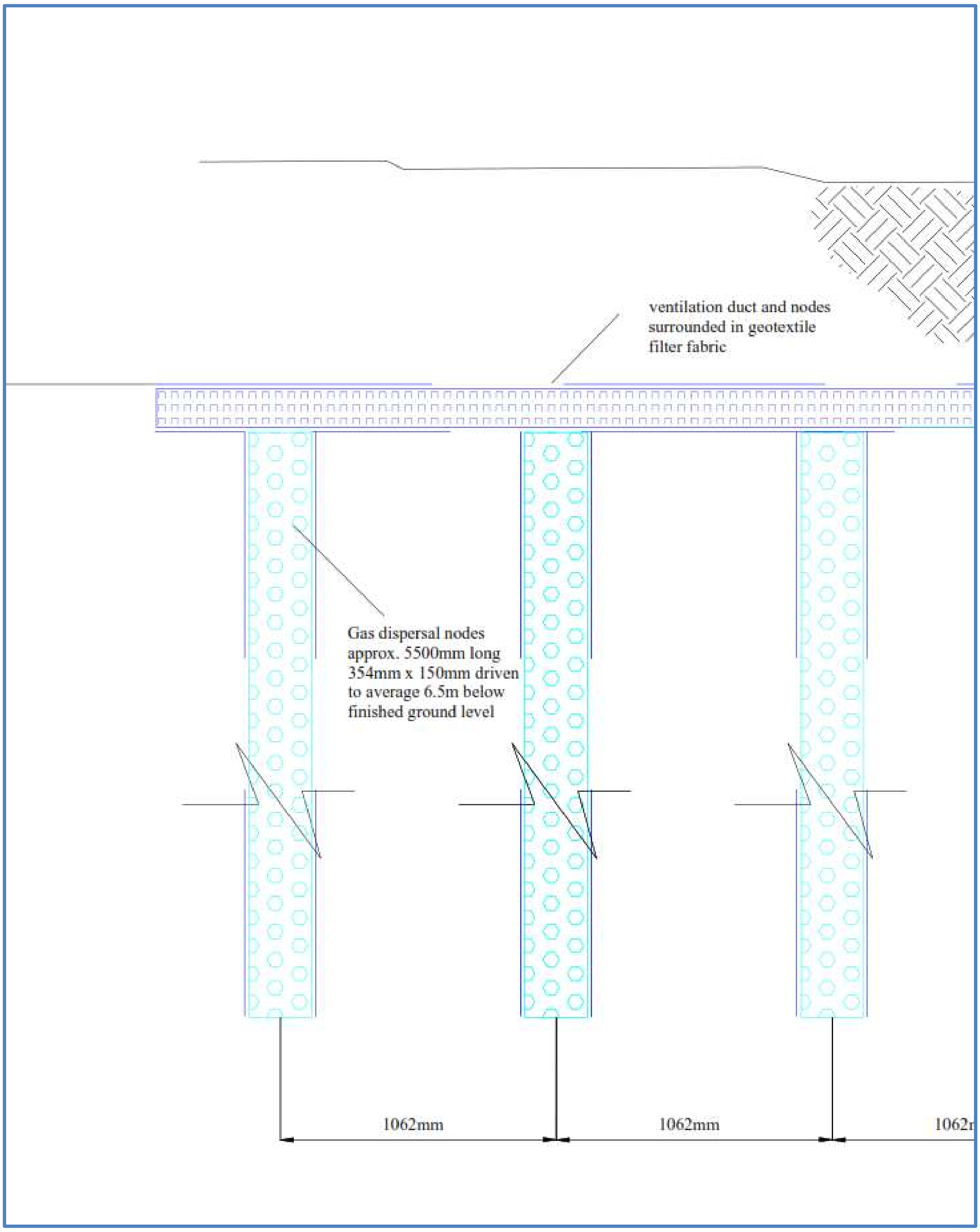


Figure 7 Design drawing section of Virtual Curtain

Figure 8 Google Streetview, Chequersfield showing one of vent bollards

4.3 Sources of gas and ground conditions identified previously

Previous site investigations of landfill and development area to the south

The Virtual Curtain design reports (Appendix A) indicates that the there were three potential gas sources at the Chequersfield site. These were:

The old landfill to the north. Comprises a black ash rich refuse material. In some areas only partly decomposed with papers dated 1957 to 1961 observed. It is now known that newspapers are printed on paper that comprise predominantly lignin. Lignin does not degrade significantly in anaerobic conditions and therefore the presence of newspapers is not an indicator that decomposition has not occurred. The fact that gas concentrations and flows were high in 1999 indicates it was occurring.

The landfill was reported to be up 5.5m deep which is consistent with the depth of the upper sand and gravel in this area. The design reports indicate it was filled between 1956 and 1976 with domestic and industrial refuse. It was vented passively using perimeter vent wells. In 1999 at the time of the STATS investigation there were reports of a strong odour of decomposition noted throughout. This is consistent with gas decomposition occurring which is typical of an uncapped landfill such as this where rainwater can percolate through the fill and provide moisture to allow gas generation to occur.

The total organic carbon (TOC) was reported to be between 8% to 38%, but the higher values may represent the ashy material which will have a high TOC but it is not degradable.

At the time of the design (2003) it was considered that the age and the evidence of non-degraded material meant that the generation potential was moderate to high (especially if moisture conditions changed in future). However, it is now known such older sites are low risk in terms of gas generation and this has been confirmed by gas generation modelling later in this report. In addition it is 17 years since that assessment and a significant reduction in gas generation will have occurred over that time. As such the landfill will bow have a very low generation potential.

Made Ground below the housing development site (existing to the south of this site). There is Made Ground below the existing development site which increases in thickness from the southern to the northern part of the site. The descriptions of this material are distinct from the landfill and it is clearly not ash rich refuse. It generally comprises reworked natural soils (clay and sand and gravel) with inclusions of demolition debris. In some areas it contains concrete obstruction and in others it comprises chalk fill. There is some localised hydrocarbon contamination.

The organic content appears to be very low and thus the generation potential is very low. The hydrocarbons also provide a very low generation source of methane and carbon dioxide as they biodegrade.

Chalk. A source of carbon dioxide. Very low generation potential. Present below the site and the adjacent landfill site.

Glacial Sand and Gravel. It is now known that concentrations of carbon dioxide above 5% are common in Glacial Sand and Gravel (and also in River Terrace Deposits). The elevated concentrations (which can reach up to 21% carbon dioxide) are caused by biological respiration of organic material in the natural soils and do not pose a risk of significant gas emissions from the ground surface.

Potential migration pathways from the landfill to the development that were identified were as follows:

Ground level (approx 79.5m to 81m AOD) to 6.0m - Made Ground and Upper Sand and Gravel present below the site. This material has been quarried and replaced with landfill on the adjacent site with no barrier installed. Predominantly gravelly silty sands and sandy fine to coarse gravel

Below 69.8m to 76.1m AOD (some 2.5m to 6.2m thick) - Lower Sand and Gravel. Typically comprises silty or very silty fine to coarse sand. Given the depth of the stratum compared to the base of the landfill (it is below the base of the landfill) and the presence of the Lacustrine Clay between the landfill and this layer it is considered that this lower layer is not a credible pathway. Methane detected in it is most likely due to hydrocarbon degradation.

Natural barriers to gas migration were identified as follows

Lacustrine clays - From base of landfill. The clays should prevent significant vertical migration of gas downwards and then laterally (which is unlikely in any event because generation rates are too low to provide sufficient pressure or provide a sufficient reserve of gas to cause downwards migration).

Groundwater – within Upper Sand and Gravel/Base of Made Ground at 75.6m AOD to 76.7m AOD.

Within the Lower Sand and Gravel at 70.7m to 70.1m AOD

The groundwater will provide a lower confining layer to prevent gas migration.

Note the landfill is placed against the Upper Sand and Gravel with no barrier to prevent lateral migration. It is considered that migration through this layer is the only credible pathway and that risk of migration in the lower layer is negligible.

Soiltechnics investigation

The site investigation by Soiltechnics within this development site encountered a similar series of soils to the previous investigations across the southern site. In particular there is Made Ground present below the site but it is not landfill waste material. The descriptions of the Made Ground encountered during the Soiltechnics investigation are summarised in Table 1.

Table 1 Summary of Made Ground below the development

Block	Relevant boreholes	Depth of Made Ground	Description	Indicators of waste or hydrocarbons
Block A	DTS101, DTS102, DTS105, BH102	2m to 3.6m	Dense dark brown sand and sandy gravelly clay, with flint, brick, charcoal, plastic fabric, concrete and chalk	Pungent odour noted throughout in DTS101
Block B	TP101 to TP105	The trial pits all terminated at shallow depth of around 1m or less and are of no use in this gas risk assessment. However, Vertase FLI defined the boundary of the landfill site and it is well away from Block B to the east. There is no evidence from other exploratory holes that anything other than general Made Ground is likely to be present below this area of the site. General Made Ground has been found across this site, the development site to the south and in the former Herts Country Club to the west.		

Previous descriptions of the landfill waste describe it as an ash rich refuse material. The descriptions of the Made Ground in Table 1 are clearly distinct from this and show that the Made Ground is reworked natural soil with inclusions of anthropogenic material such as brick, plastic, charcoal, etc. On this site it most likely represents overspill of the final soil cover that was placed over the landfill material. There is no evidence of widespread or serious hydrocarbon contamination and no evidence of highly degradable landfill waste within the Made Ground.

There is evidence that the general Made Ground does contain localised hydrocarbon contamination but it is not widespread. Soil testing by Soiltechnics in this site, although it has serious limitations (as identified by LQM) does not indicate any significant vapour intrusion risk to the development.

4.4 Gas monitoring data

The design of the Virtual Curtain was based on gas monitoring data from within the landfill site. Numerous visits were completed by STATS from 1990 to 1999 and onwards on a regular basis in wells throughout the landfill site. There was quarterly reporting of the results. The monitoring covered a range of atmospheric pressures from 995mb to 1018mb and although it cannot be confirmed, given the regular monitoring it is likely to have covered periods of falling pressure.

It is not possible to undertake a rational data quality assessment of the gas monitoring data because key pieces of information are missing (well construction details and water levels). Therefore, the data has a high degree of uncertainty attached to it but it does allow an overall understanding of the likely gas risk.

Within the landfill

The gas monitoring by STATS indicated that maximum methane concentrations within the landfill were up to 98.5% with carbon dioxide concentrations up to 12%. However, the results were variable and, on many occasions, methane was not detected. Borehole flow rates in the landfill site were up to 11.5l/h although in several holes they were much lower than this (between 2l/h and 3l/h). It was reported that at the northern end of the site the pressure within the boreholes could be felt by hand but this is well away from the development site. The design for Virtual Curtain assumed a flow rate of 12l/h at the landfill site boundary as a worst case.

Outside the landfill

Outside the landfill site methane was generally not detected with occasional and localised maximum values of 24%. Carbon dioxide was present outside the landfill up to 7.3% and in the absence of methane in most wells the bulk of carbon dioxide in the development site is now thought to be caused by biological respiration in the Glacial materials and Made Ground. Flow rates outside the body of the landfill site were up to 1.9l/h.

Further assessment of the data in relation to the current site

A summary of the data taken from the Virtual Curtain design report is provided in Figure 8. This covers the data supplied that was from April 1995 to August 1999 (consistent data sets were not provided for the full period from 1990).

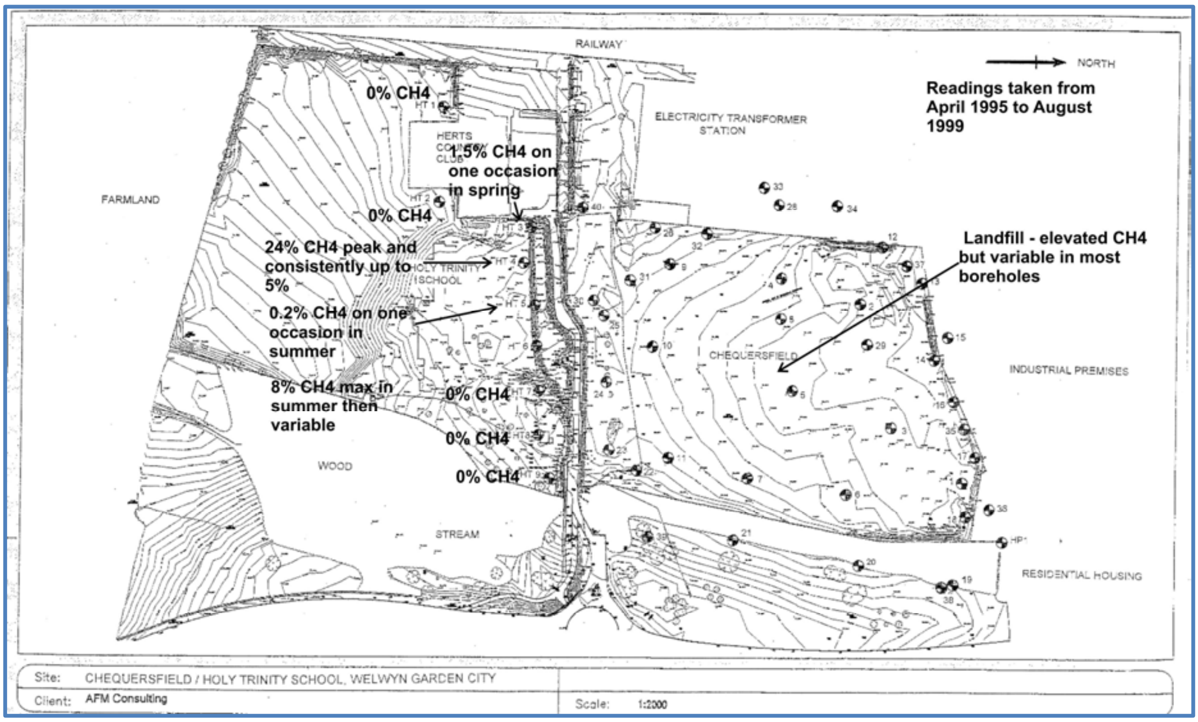


Figure 8 Summary of historic gas monitoring data in the landfill

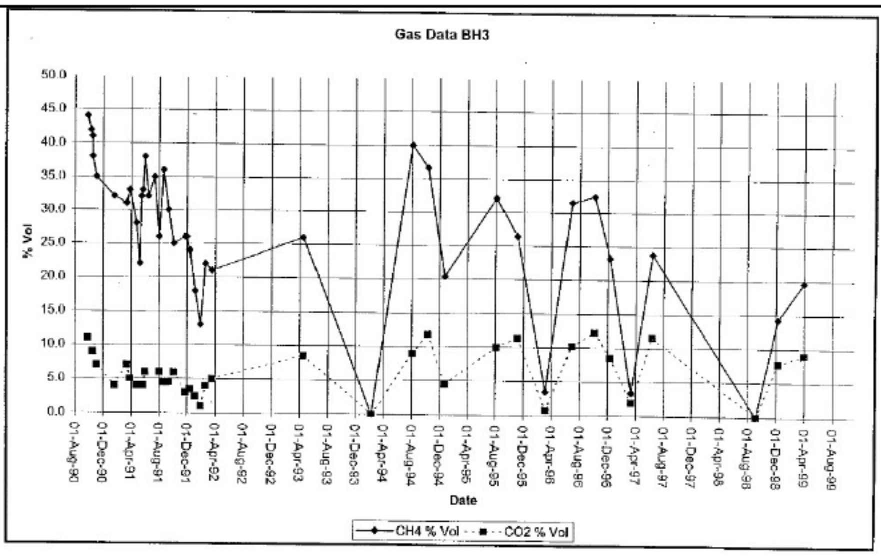
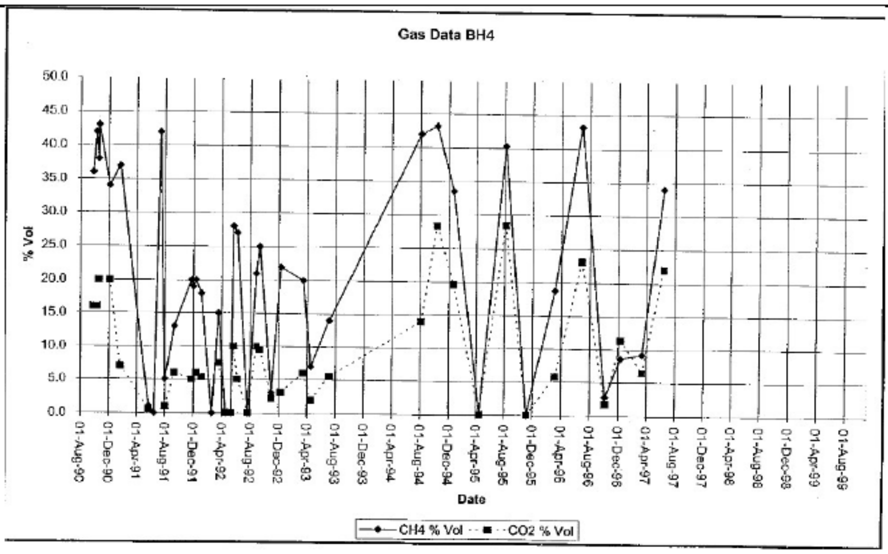
The gas monitoring data is provided in Appendix D. The summary shows that there was some potential migration from the landfill site towards the south. The methane concentrations in the landfill were elevated, but variable. The implication of this is discussed below. Outside the landfill site there was methane detected sporadically and locally. There was no evidence of widespread gas migration.

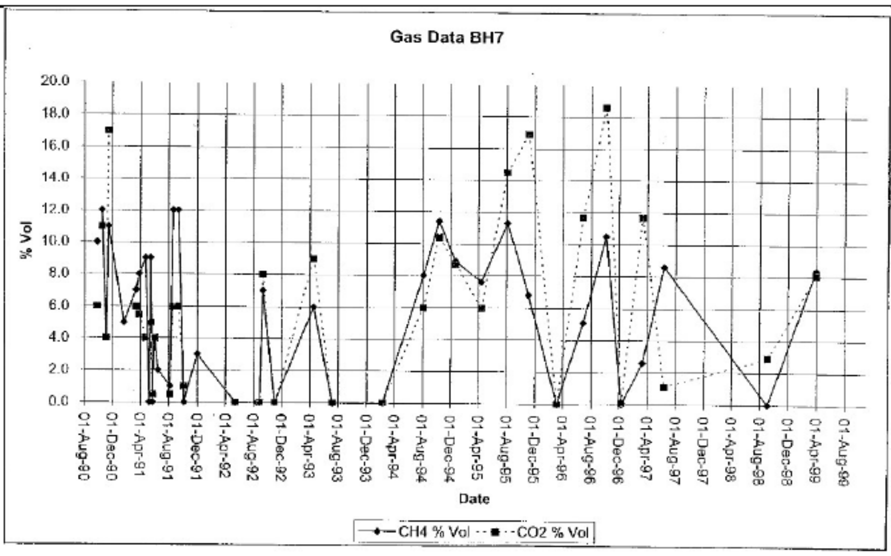
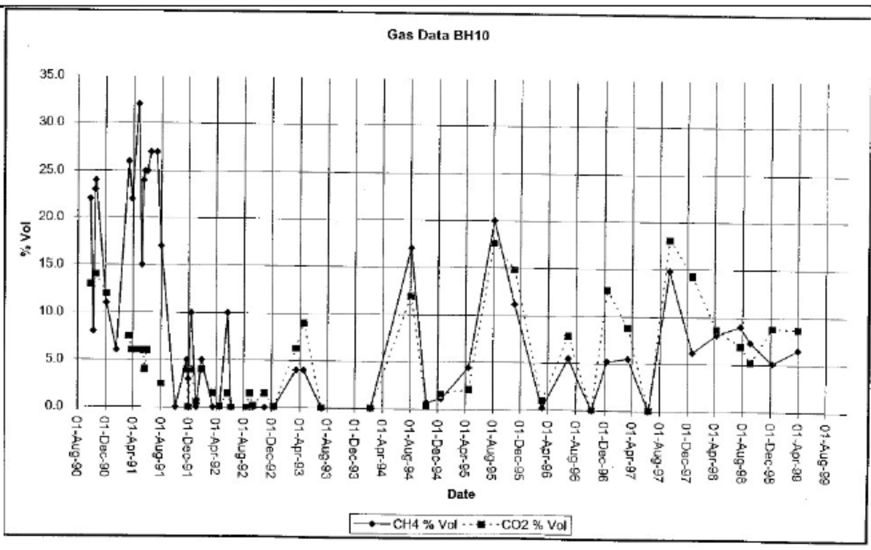
The gas monitoring wells that were located in the landfill waste were as follows:

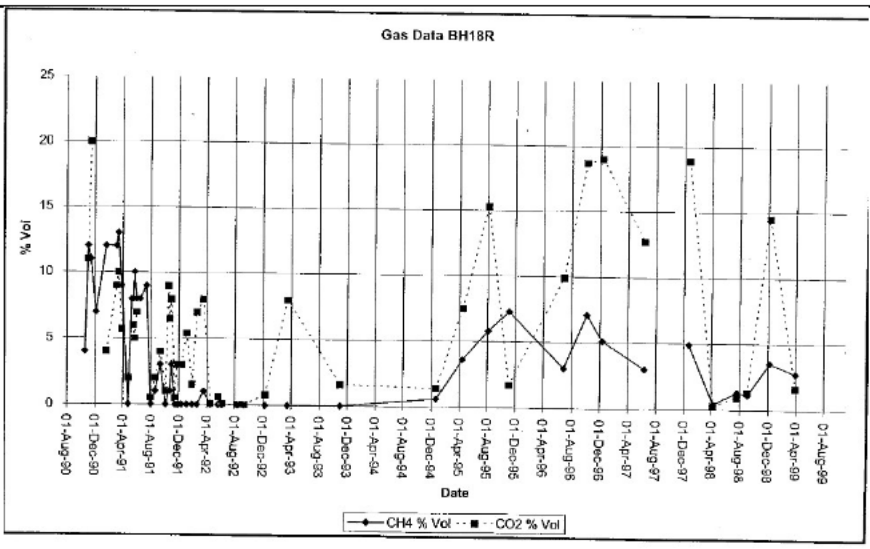
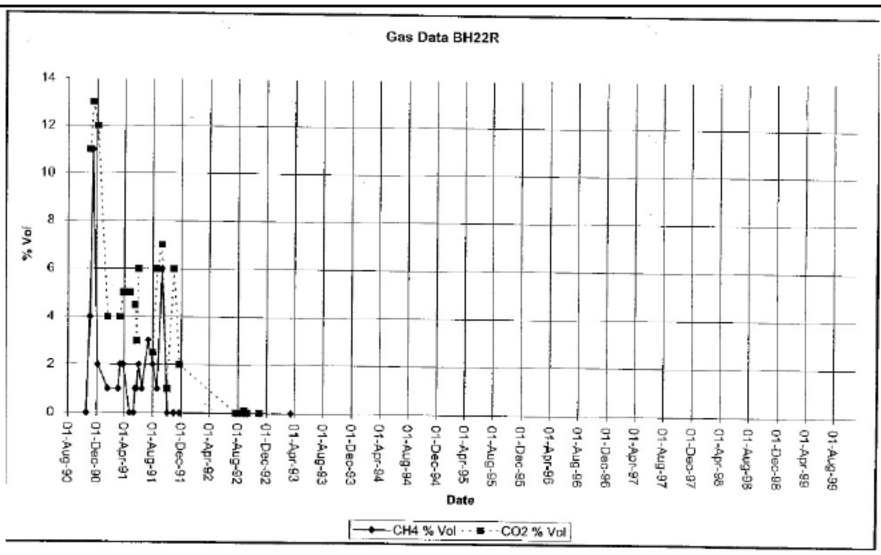
BH's 1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 18, 22, 28 These were all reported as lost in 2003.

Graphs of the methane and carbon dioxide concentration data from these wells (where available) are presented in table 2 below.

Table 2 Graphs of gas methane concentrations in monitoring wells 1990 to 1995 - landfill

Borehole	Graph	Comment
BH3		Elevated methane sporadically up to about 45% but reducing trend from 1990 to 1999. Obvious air intrusion. Carbon dioxide concentrations are low at about 12% maximum. The ratio of methane to carbon dioxide indicates peak generation has been passed
BH4		Elevated methane sporadically up to about 45%. Obvious air intrusion. Carbon dioxide concentrations are low at about 28% maximum. The ratio of methane to carbon dioxide indicates peak generation has been passed

Borehole	Graph	Comment
BH7		Carbon dioxide concentration is higher than methane in many cases. Maximum about 18% carbon dioxide and 12% methane. Gas concentrations are variable and indicate air intrusion. Ratio and gas concentrations indicate residual generation.
BH10		Maximum about 32% methane and 18% carbon dioxide. Gas concentrations are variable and indicate air intrusion. Ratio and gas concentrations indicate residual generation. reducing trend overall from 1990 to 1999.

Borehole	Graph	Comment
BH18		Maximum about 13% methane and 20% carbon dioxide. Carbon dioxide is highest. Gas concentrations are variable and indicate air intrusion. Reducing trend in methane and increasing carbon dioxide overall from 1990 to 1999, suggests low generation and oxidation
BH22		Maximum about 11% methane and 13% carbon dioxide. Carbon dioxide is highest, suggesting oxidation and low generation. Gas concentrations are variable and indicate air intrusion.

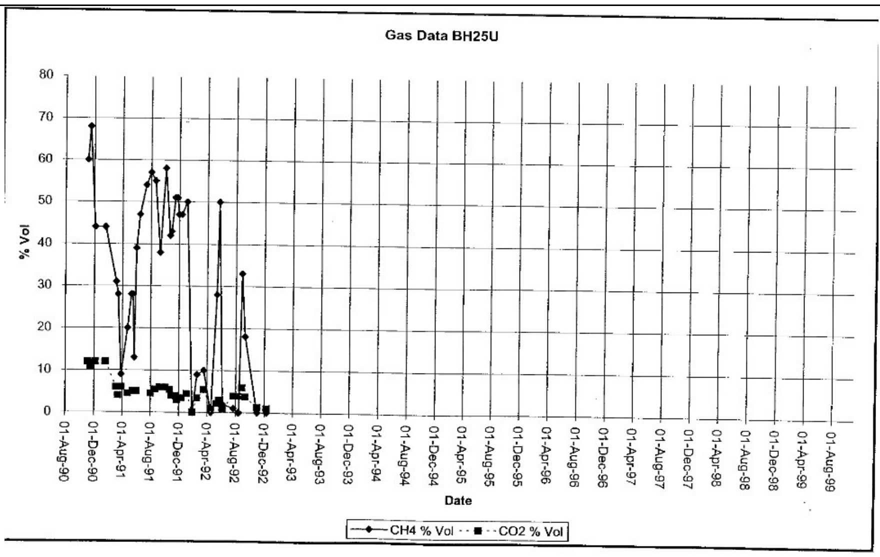
Overall the gas monitoring results inside the landfill indicate that gas generation rates in the 1990s were already declining and were past peak rates. This is consistent with the age of the landfill. Once landfill sites reach this condition there is no sustained pressure within them and the risk of landfill gas migration off site is reduced.

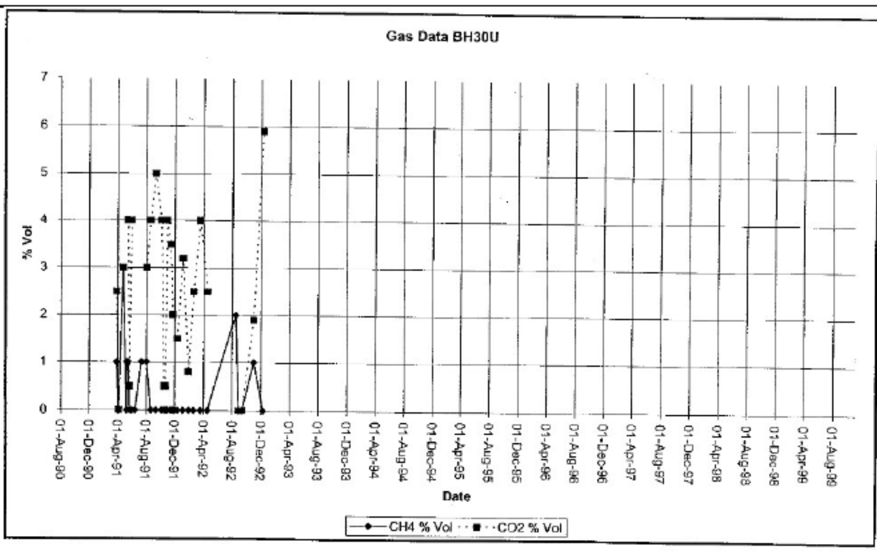
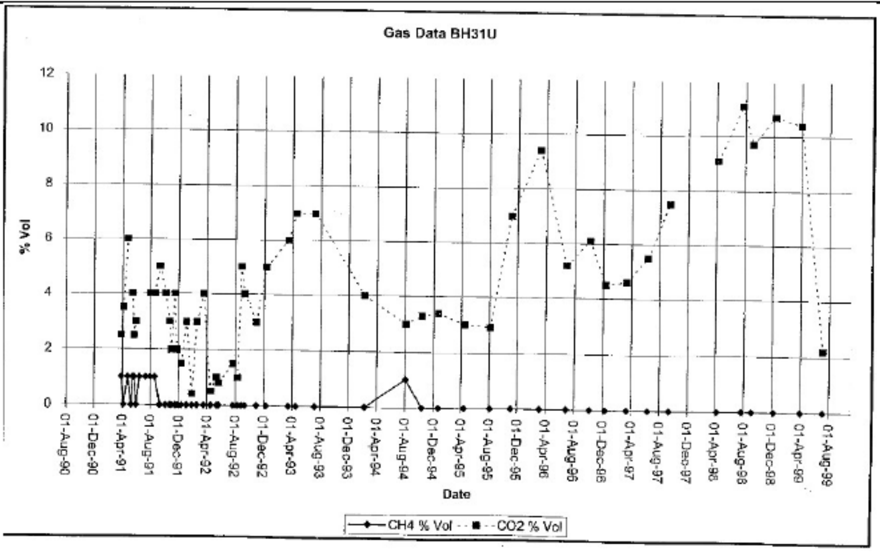
The following historic gas monitoring wells were located in the area of this development site but were outside the landfill material in the Made Ground that has been identified (or also the underlying sand and gravel):

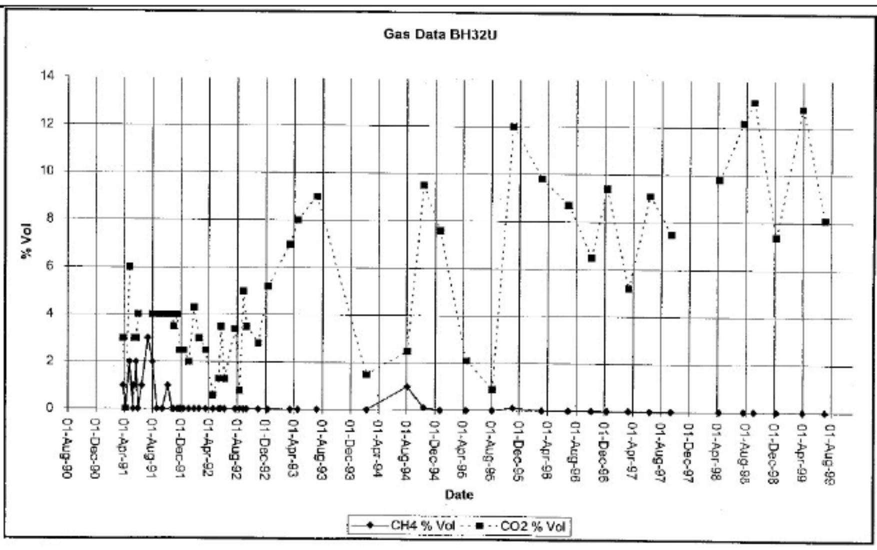
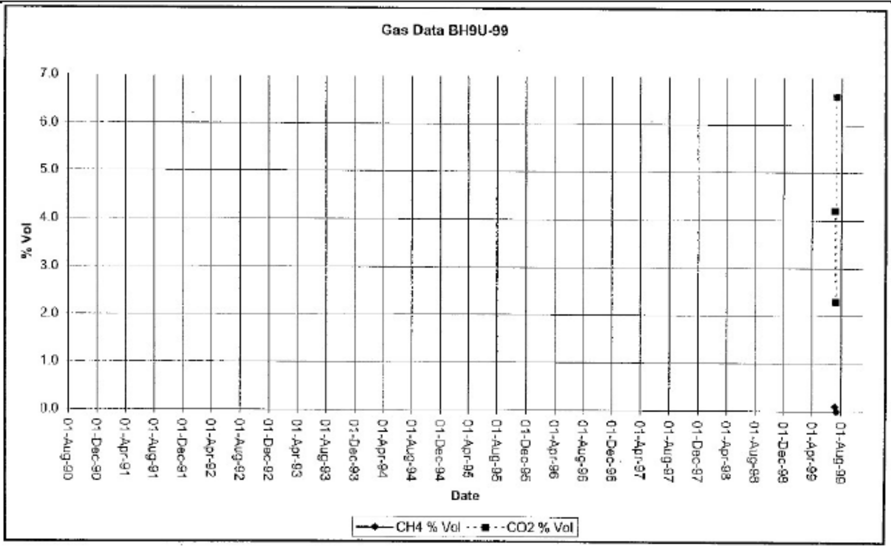
BH's 9, 25, 26, 30, 31, 32, 40, 56, 9-99, and 57. The latter 4 highlighted in red were monitored by Vertase in 2012.

Graphs of the methane and carbon dioxide concentration data from these wells (where available) are presented in table 3 below.

Table 3 Graphs of gas methane concentrations in monitoring wells 1990 to 1995 – outside landfill

Borehole	Graph	Comment
BH25		High methane concentration up to about 70% and low carbon dioxide concentrations about 11% suggest the source of this gas is hydrocarbon degradation rather than decomposition of organic waste. Variable results suggest no underlying overall gas migration from landfill site.

Borehole	Graph	Comment
BH30		Maximum about 3% methane and 6% carbon dioxide. Carbon dioxide is highest, suggesting oxidation and low generation. Gas concentrations are variable and indicate air intrusion. Most likely source is Made Ground
BH31		Maximum about 1% methane during first few readings and then generally not recorded and 11% carbon dioxide. Carbon dioxide is highest and absence of methane suggests biological respiration is cause of elevated carbon dioxide.

Borehole	Graph	Comment
BH32		Maximum about 3% methane during first few readings and then generally not recorded and 13% carbon dioxide. Carbon dioxide is highest and absence of methane suggests biological respiration is cause of elevated carbon dioxide.
BH9-99		Limited results in 1999. Up to about 7% carbon dioxide and methane not detected. Carbon dioxide is highest and absence of methane suggests biological respiration is cause of elevated carbon dioxide.

In summary the gas monitoring data is indicative that outside the landfill there is limited landfill gas migration. It is likely that carbon dioxide is present as a result of biological respiration in the Made Ground or natural soils and the highest methane concentrations (above 80%) combined with low carbon dioxide are indicative of hydrocarbon degradation as the source. Neither poses a significant risk of large scale gas emissions from the ground and would not be sufficient to cause lateral gas migration in an unconfined pathway.

4.5 Vertase and Soiltechnics gas monitoring

Vertase

Gas monitoring within the residential development, has been undertaken by Vertase FLI since the installation of the Virtual Curtain gas barrier. There are a series of results available from 2008 to 2012 (13 visits at a range of atmospheric pressure conditions) and more recently in 2019. The location of the post installation monitoring points is provided in Figure 9.

Figure 9 Location of long term monitoring wells (Vertase FLI)

In 2005 monitoring was also undertaken (prior to the installation of the Virtual Curtain) in 16 wells on up to 7 occasions over a 9 month period (from 10/2/05 - *before the curtain was installed* - to 3/11/05). The monitoring covered a wide range of atmospheric pressure variations. EPG no longer has the records for this data but it is summarised in a letter to Vertase from EPG dated 9th February 2013 (Appendix E). During this monitoring methane was not detected above the analytical limit of the gas monitor (0.1% v/v), except on two occasions in October and November 2005 when concentrations of

2.6% and 1.6% v/v were recorded in one well (BH10-04) in the northern part of the site. These elevated readings were obtained at low atmospheric pressure compared to the other readings (988mb and 1013mb respectively).

At the time it was thought that these elevated concentrations represented the dispersion and venting of gas within the site that had been present within the soils prior to the virtual curtain being installed. The low pressure conditions allowed the gases to disperse, as any driving pressure or diffusion gradient from the landfill was removed. However, BH10-04 in which methane was detected was further away from the landfill than others that did not record any methane and thus it is likely that it was caused by low level methane generation in the Made Ground. Current understanding of ground gas suggests that the carbon dioxide results indicate background concentrations from the Made Ground or natural soils rather than landfill gas migration.

The carbon dioxide concentrations are summarised in Figure 10.

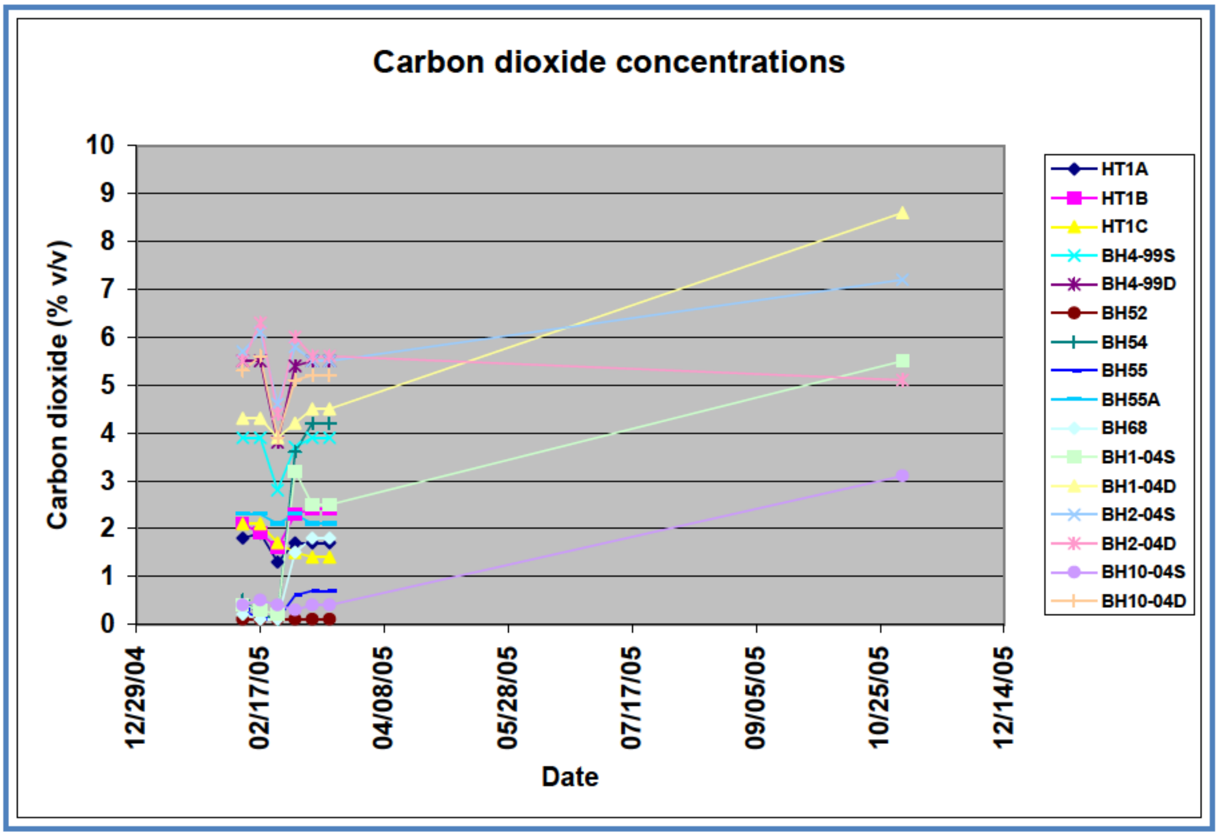


Figure 10 Carbon dioxide concentrations – 2005 post installation of Virtual Curtain

Comparable concentrations of carbon dioxide have been recorded in the monitoring undertaken from 2005 to 2012 and in 2019. Whilst carbon dioxide has been detected methane has not been detected in over 15 years in any area of the site, including the areas where migration was identified prior to development.

Carbon dioxide concentrations are elevated across the whole site and are representative of background concentrations and the underlying ground conditions. The evidence of this is that carbon dioxide levels have not changed over the whole site since before the installation of the Virtual Curtain whereas methane concentrations have reduced. If the gases were generated from the same source it would be expected that a similar reduction in levels would occur. Furthermore, carbon dioxide is not a good risk or compliance indicator in relation to landfill gas migration – see CLAIRE (2012), *Research Bulletin RB17* and C and P Environmental (2011), *Perimeter soil gas emissions criteria and associated management*. Although carbon dioxide can be present due to oxidation of methane this is most unlikely when methane has not been recorded at all in the wells over the past 11 years or so.

A ternary plot of the data from 2008 to 2019 has been prepared and is shown in Figure 11. This shows that none of the data from monitoring at various times over 11 years is indicative of large scale landfill gas generation or migration and is indicative of biological respiration in either the Made Ground or the natural soils below the site.

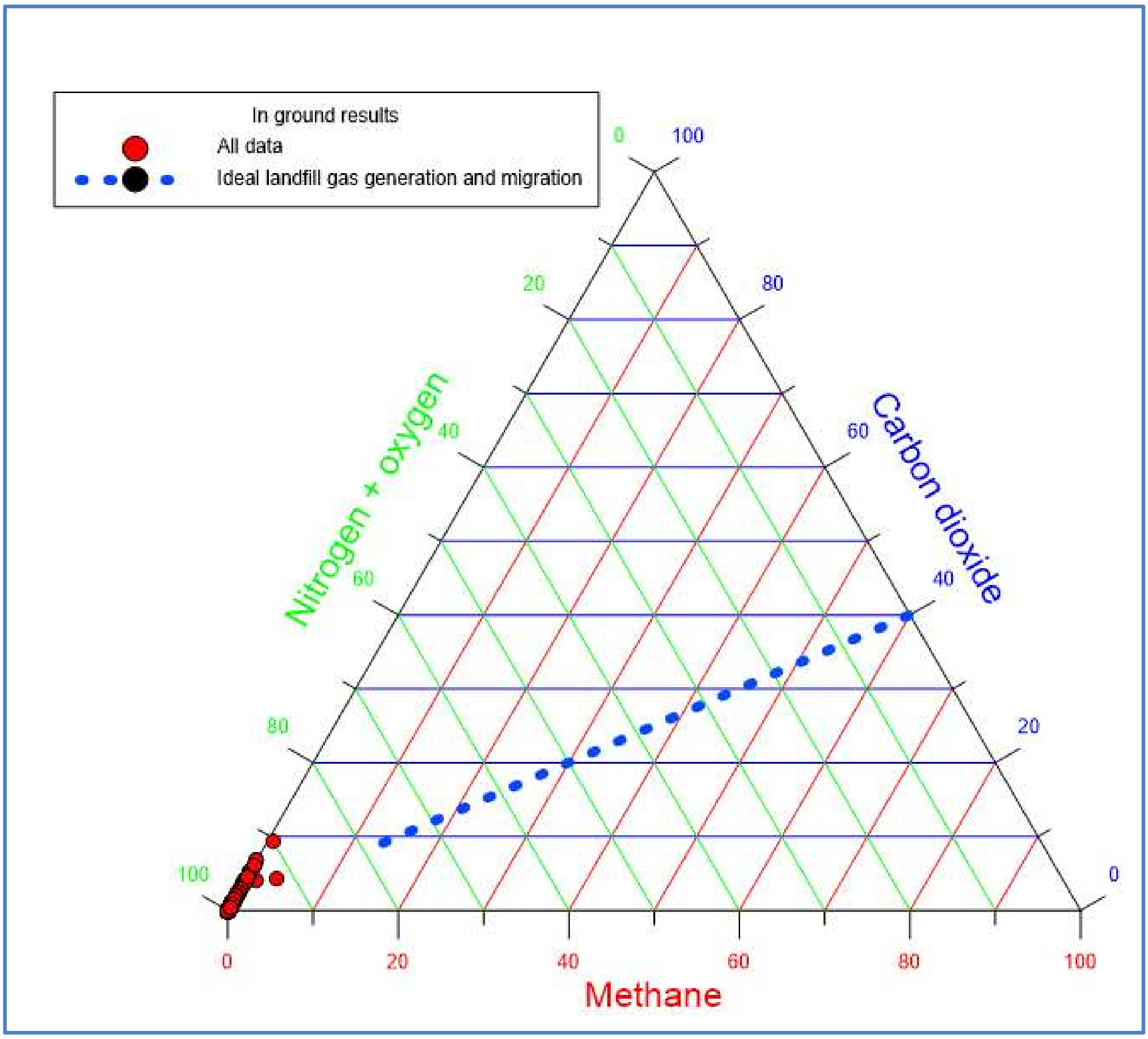


Figure 11 Ternary plot of the 2008 to 2019 data

The monitoring has also recorded predominantly very low or negative flow rates. Graphs showing the flow rates in the north of the site and the south of the site suggests the flow rates are more variable and have more negative values close to the barrier (Figure 12 and 13). The wells to the south are outside the zone of influence of the barrier and the very low flow rates again show that the elevated carbon dioxide represents background and is not caused by landfill gas migration.

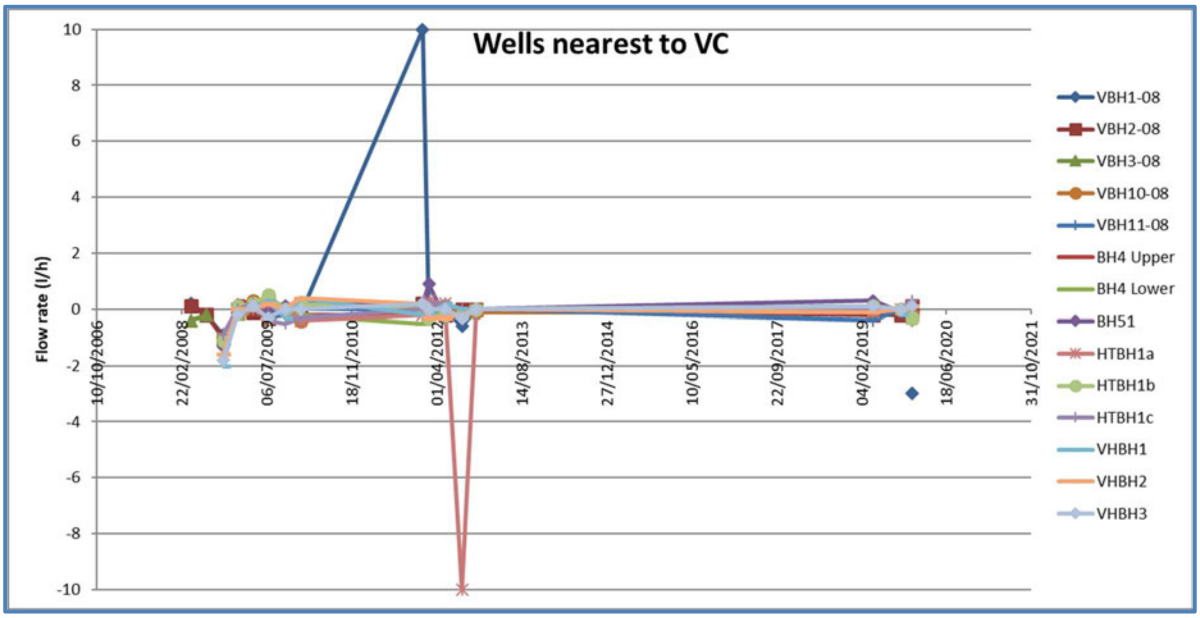


Figure 12 Flow rates close to Virtual Curtain (northern part of site)

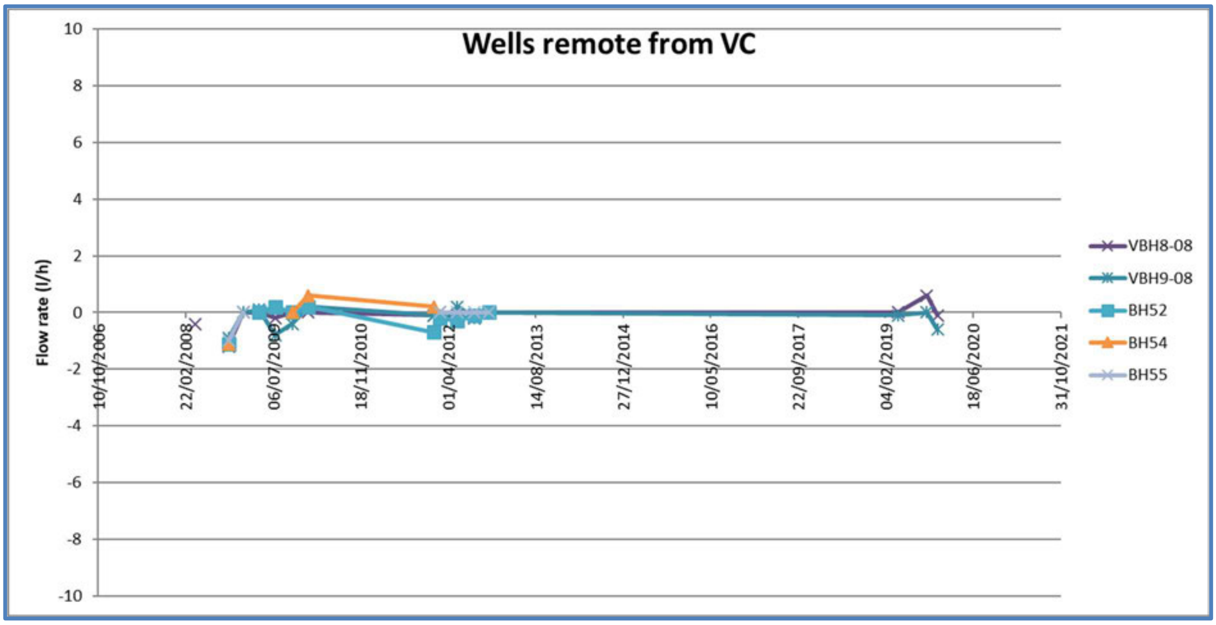


Figure 13 Flow rates remote from Virtual Curtain (southern part of site)

It is likely that given the age of the landfill at time the Virtual Curtain was installed that if gas migration was occurring it was caused by diffusion rather than advective flow. After a further 15 or so years since installation gas generation in the landfill will have declined significantly and this is supported by gas generation modelling in Section 6 of this report. Regardless of whether the elevated methane previously found in the north of the previous development was caused by gas migration from the landfill, leachate migration or hydrocarbon contamination, it is clear that subsequent to the installation of the Virtual Curtain it has not been detected (Figure 14) and the flow rate data suggests that the barrier is having an influence on flow rates measured in boreholes located within about 35m of it. This is consistent with the fact that the barrier is installed in the Glacial Sand and Gravel deposits.

Figure 14 Plan showing area of previous migration and areas with greatest magnitude of negative flow rates

Soiltechnics monitoring

As identified by LQM the gas monitoring by Soiltechnics is limited and on its own is not sufficient to allow a robust classification of this site. However, it does add to the overall evidence base regarding gas risk to the site.

Methane was not detected except on one visit at concentrations of 0.1% and 0.2% which are not considered significant as they are at or very close to the limit of detection and within the resolution of the instrument used (GA5000). Carbon dioxide is elevated up to 9.3% steady state and flow rates are negligible (from -0.6l/h to 0.1l/h) which shows that there is no overall advection pressure to drive gas from the ground.

The data has been plotted on a ternary plot in Figure 15, which shows the gas is caused by biological respiration and not landfill gas migration. This and the flow rate data is consistent with the presence of Made Ground below the site that is similar to the Made Ground below the site to the south. The gas on this site has the same signature as the gas on the previous site from 11 years of post-construction monitoring.

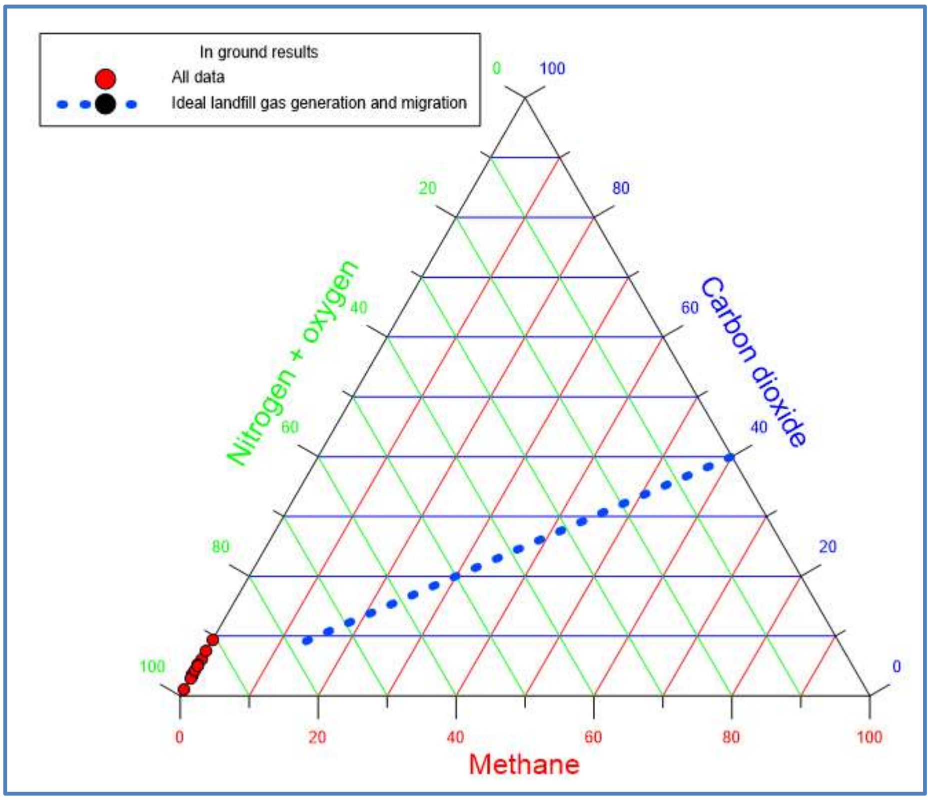


Figure 15 Ternary plot of Soiltechnics gas monitoring data

5. THE DEVELOPMENT

5.1 Site layout

Details of the site layout are provided in Appendix F and are reproduced in Figure 16.

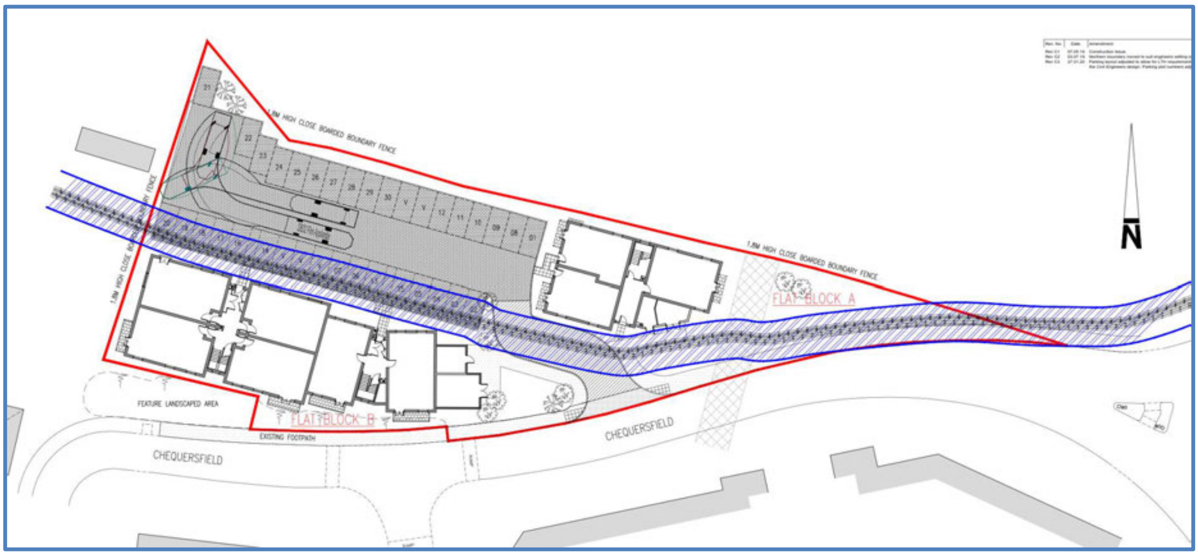


Figure 16 Development layout

An overlay of the development plana and the landfill boundary proved by Vertase in 2003 has been made (Figure 17). This shows that neither block is located on the landfill site whose boundary was defined by Vertase in 2003 (See Section 4).

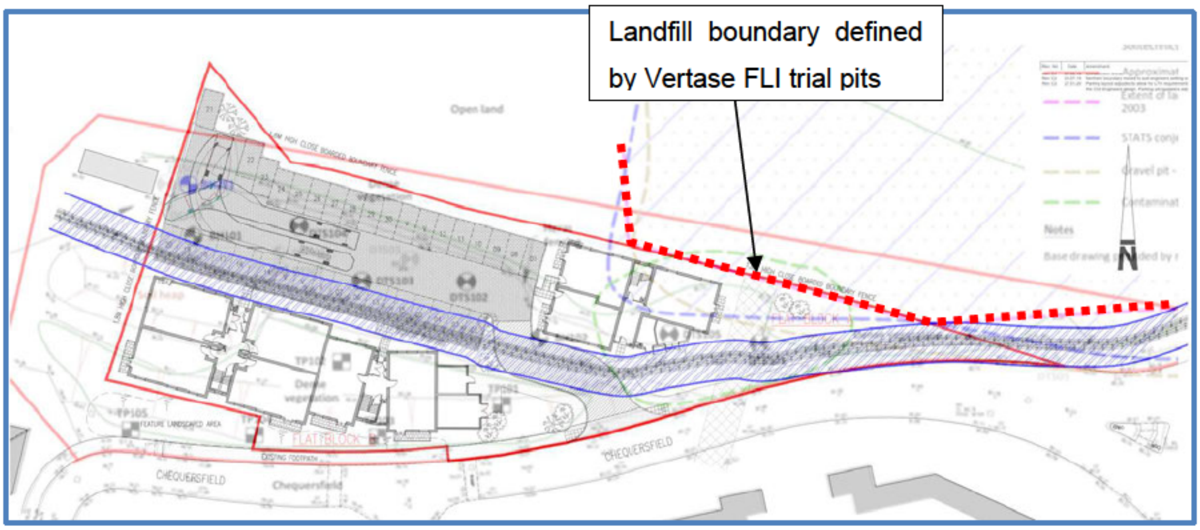


Figure 17 Development layout in relation to landfill boundary

5.2 Floor and foundation construction

Drawings with the details of the floor slab and venting are provided in Appendix F. The buildings have a ventilated underfloor void that is a minimum of 150mm deep below a suspended polystyrene block and beam floor with a reinforced structural concrete topping above. A gas membrane has been installed above the suspended floor. Extracts from the drawings are shown in Figures 18 and 19 and show that the void is ventilated with air bricks via cranked ventilators. Through ventilation is provided in the sub-floor walls.

The structural concrete topping part of the Jetfloor system will typically be 70mm thick with a minimum strength class RC28/35 reinforced with either polypropylene fibres, steel fibres or steel reinforcement mesh on insulating sheet material of minimum compressive strength 130N/mm². This overall construction above the block and beam floor provides some added resistance to gas flow into the buildings and even though it is not completely gas tight, it will give some attenuation. This is because gas cannot flow directly up a short distance from the ground as it would with a 100mm slab cast directly on the ground. The pathway for gas flow from the underside of the floor construction to the occupied space is longer and more tortuous which will slow down the rate of gas flow into the building.

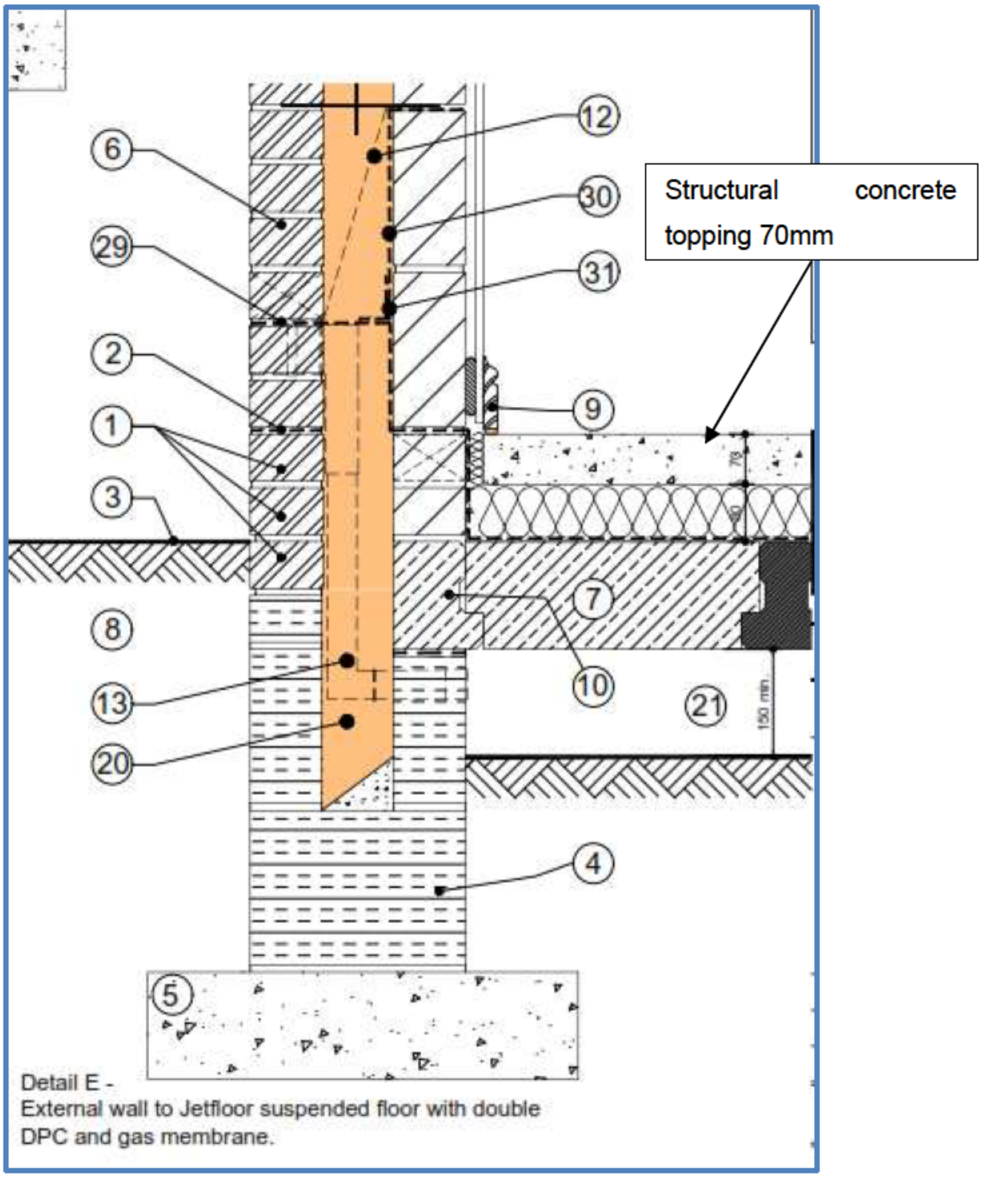


Figure 18 Cross section of floor construction

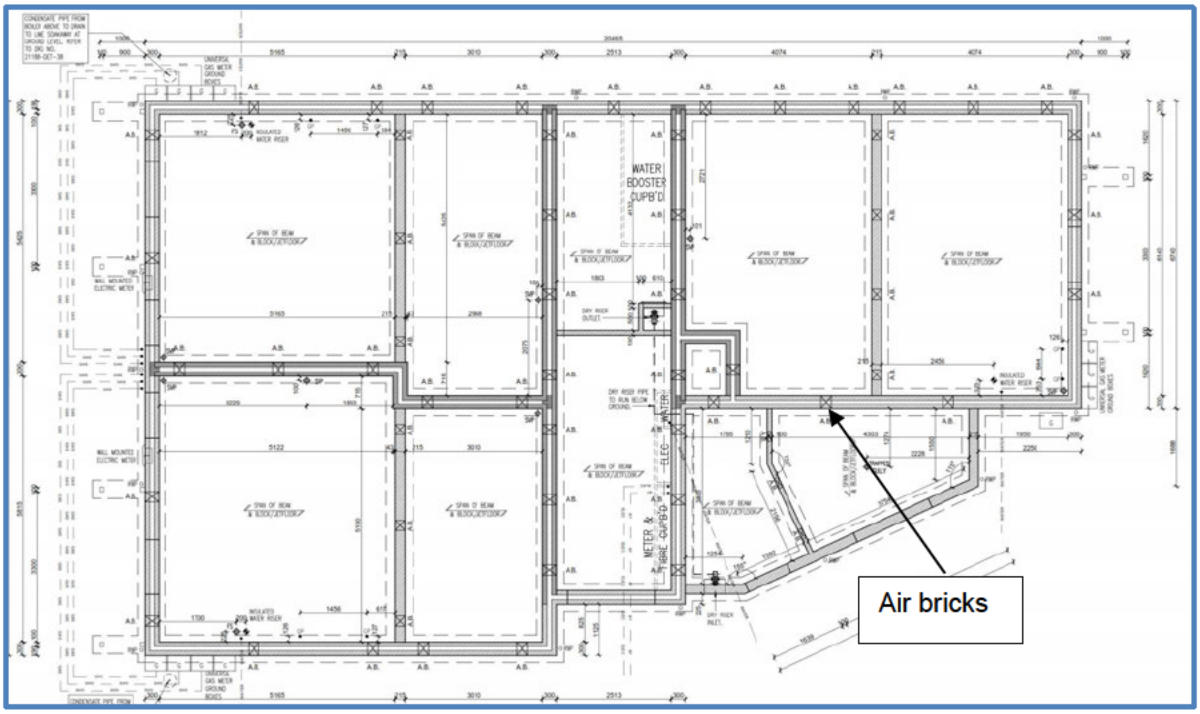


Figure 19 Block A venting details to underfloor void (Block B is similar)

5.3 Gas mitigation measures

The gas mitigation for the development as detailed in the floor construction above comprises the following:

1. Block and polystyrene beam suspended floor slab with insulation and structural concrete topping above;

2. 150mm ventilated void; and

3. Gas resistant membrane over the top of the floor slab (JUTA GP1).

The gas membrane installation has been verified by MEC Environmental. The verification report is supplied in Appendix G and shows the membrane has been installed to an acceptable standard. The full footprint (ie cavity and main floor area) was verified visually and by air lancing seams and joints.

For gas membranes placed on top of floor slabs and covered over by insulation there are no significant in service stresses such as point loads, tearing or tensile forces and the aluminium foil laminate membrane is acceptable in this application and will be sufficiently gas tight, durable, resistance to construction and in services stresses. This means the design follows the guidance provided in BS8485 regarding the specification of membranes.

JUTA GP1 has not been tested to determine the volatile organic compounds (VOC) vapour permeability and aluminium foil laminate membranes are not normally suitable as VOC membranes. This is because where high concentrations of VOCs may be present, they can cause delamination of the layers of membrane. The aluminium also has pinholes in it from manufacture (which increase over its lifetime) and thus it is not completely impermeable to vapour migration so would require permeation testing on aged samples to confirm the rates. On this site, although the data relating to VOCs is not comprehensive, as identified by LQM, there no evidence that there are widespread high concentrations of VOCs in the ground, especially at shallow depth. The presence of the underfloor void will dilute any VOCs and therefor the JUTA GP1 will provide acceptable mitigation against any localised hotspots in the ground and will be sufficiently durable as it is not below the slab and is not close to any VOC contamination in the ground.

Calculations to estimate the ventilation required if the site was classified as Characteristic Situation CS3 (ie 3.5l/h flow and 100% methane) are provided in Appendix G. These show that the venting required to maintain the equilibrium concentration of gas in the underfloor void at less than 1% is 2614mm^2/m of wall.

As part of the verification MEC recorded the number of air bricks provided to each block (but not the location or spacing). EPG has measured the perimeter of the blocks from the layout drawings supplied by Taylor Wimpey to obtain the approximate spacing as follows:

- Block A, 22 no airbricks provided, perimeter approximately 60m, spacing nominally 2.7m. Air bricks provided have a vent area of 6,000mm^2 so the vent area provided is 2222mm^2/m of wall nominally. This is slightly less than the 2614mm^2/m of wall required for CS3, but does exceed the NHBC minimum of 1500m^2/metre. However, The CS3 requirement is based on venting only on two sides of the building and venting has been provided on all four sides. This will increase the performance and therefore is considered more than adequate for the site. The venting will be sufficient to deal with the gas emissions identified from the gas generation modelling in Section 6.
- Block B, 38 no airbricks provided, perimeter approximately 114m, spacing nominally 3m. Air bricks provided have a vent area of 6,000mm^2 so the vent area provided is 2000mm^2/m of wall nominally. This is again slightly less than the design venting for CS3 but for the same reasons as Block A is considered acceptable.

5.4 Preferential pathways

The shallow services that feed the actual development all enter from Chequersfield to the south and do not pass over the landfill. Therefore, they will not provide a preferential pathway for landfill gas migration out of the landfill. They all pass through the ventilated void and are then sealed to the gas membrane so again they do not form a preferential pathway into the building.

There are High Voltage electric cables that run through the development to the nearby sub-station. The service plans indicate (Figure 20) that these may pass over landfill into development and could provide a potential preferential pathway for landfill gas migration to enter the development. In this case it does not pose a significant risk such that it would overcome the gas protection measures that have been provided to the buildings. This is because:

1. The distance from where the cable trench is close to the landfill or crosses it to the nearest Block (Block A) is 25m

2. The trench is a maximum of 1.5m deep (Figure 21) and if there was sufficient pressure to drive gas along it would likely be emitted at the surface before it reached the houses because the pressure gradient to eh surface would be greater than the horizontal one; and

3. The cables do not serve the development so there are no connections into the houses to direct gas towards them.

This type of cable also tend to be bedded in fine sand or even the as dug soil and not a single size free draining material such as pea gravel used in drainage trenches. This is not likely to have a significantly higher permeability than the surrounding ground such that it would promote a preferential pathway over a long distance. It may dry out because of the heat from the cables, but this would not have any significant effect in terms of the preferential pathway.

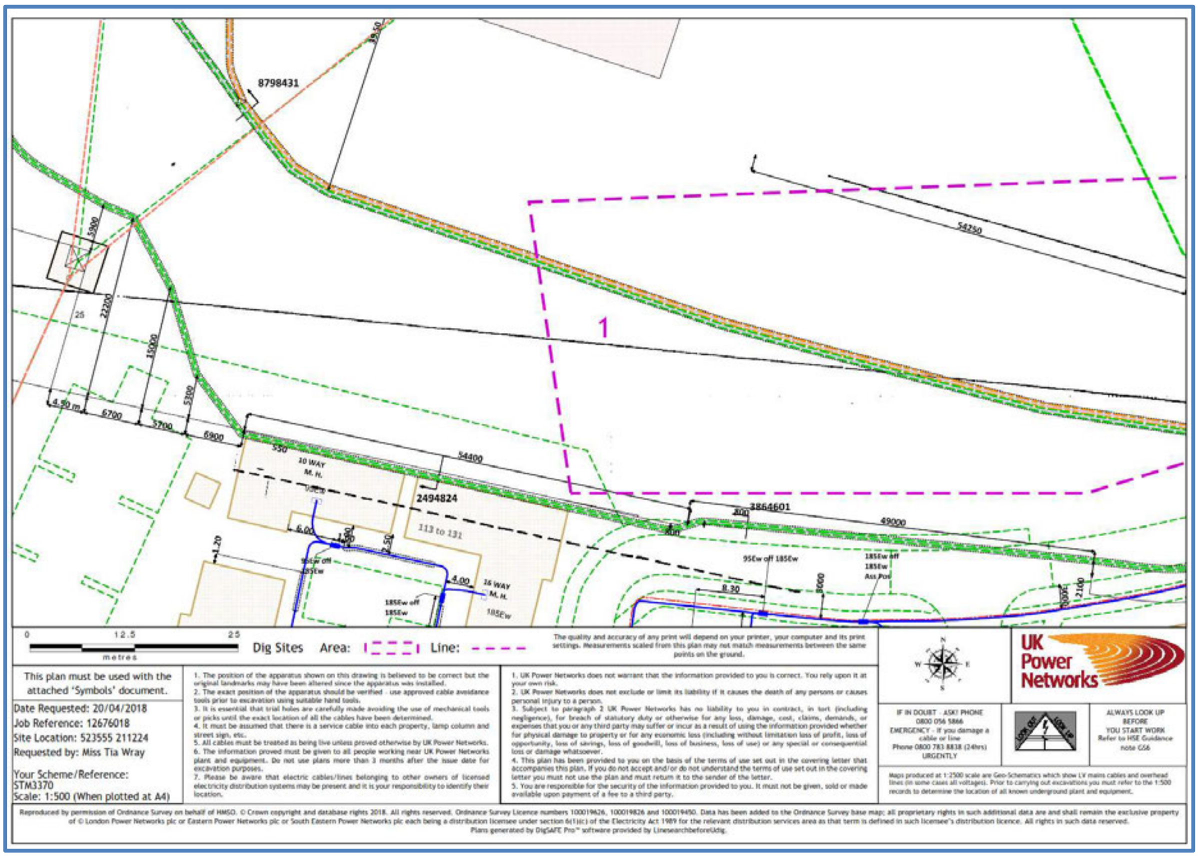


Figure 20 Location of HV cables

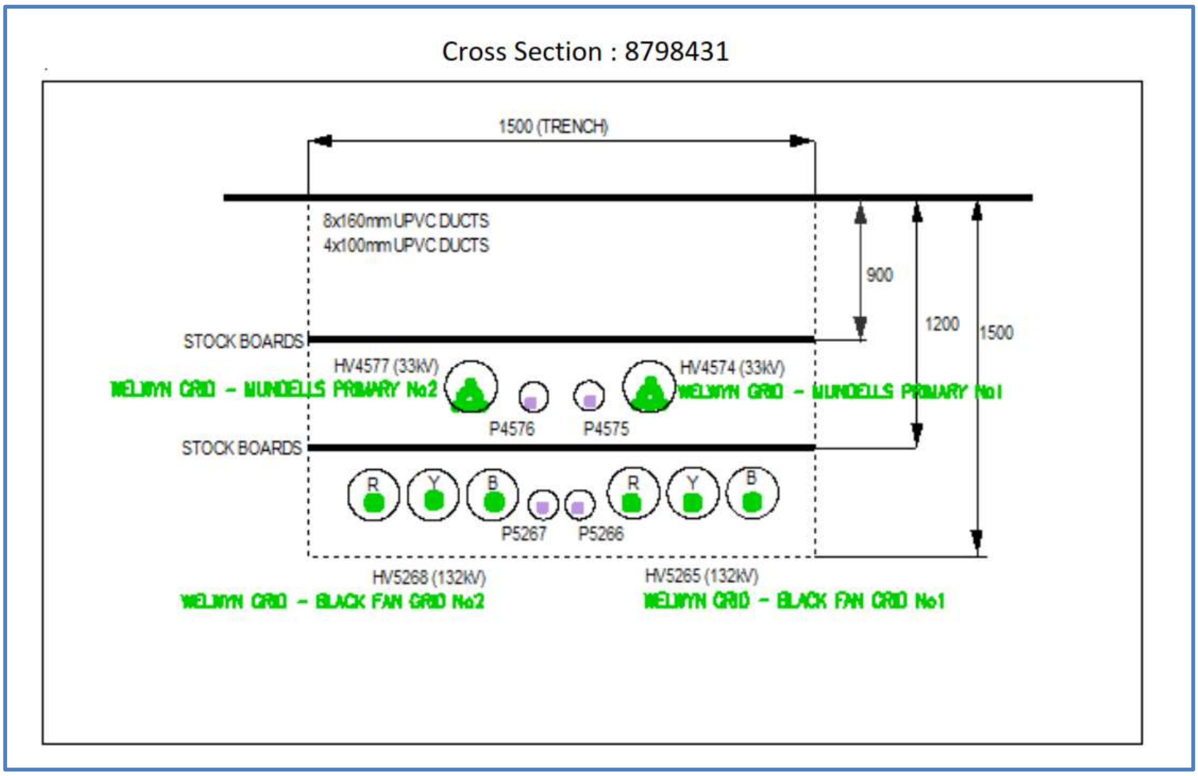


Figure 21 Section through HV cable trench

6. CONCEPTUAL SITE MODEL

Based on the preceding discussions, a pictorial Conceptual Site Model for ground or landfill gas has been derived for the site. This is shown in Figure 22.

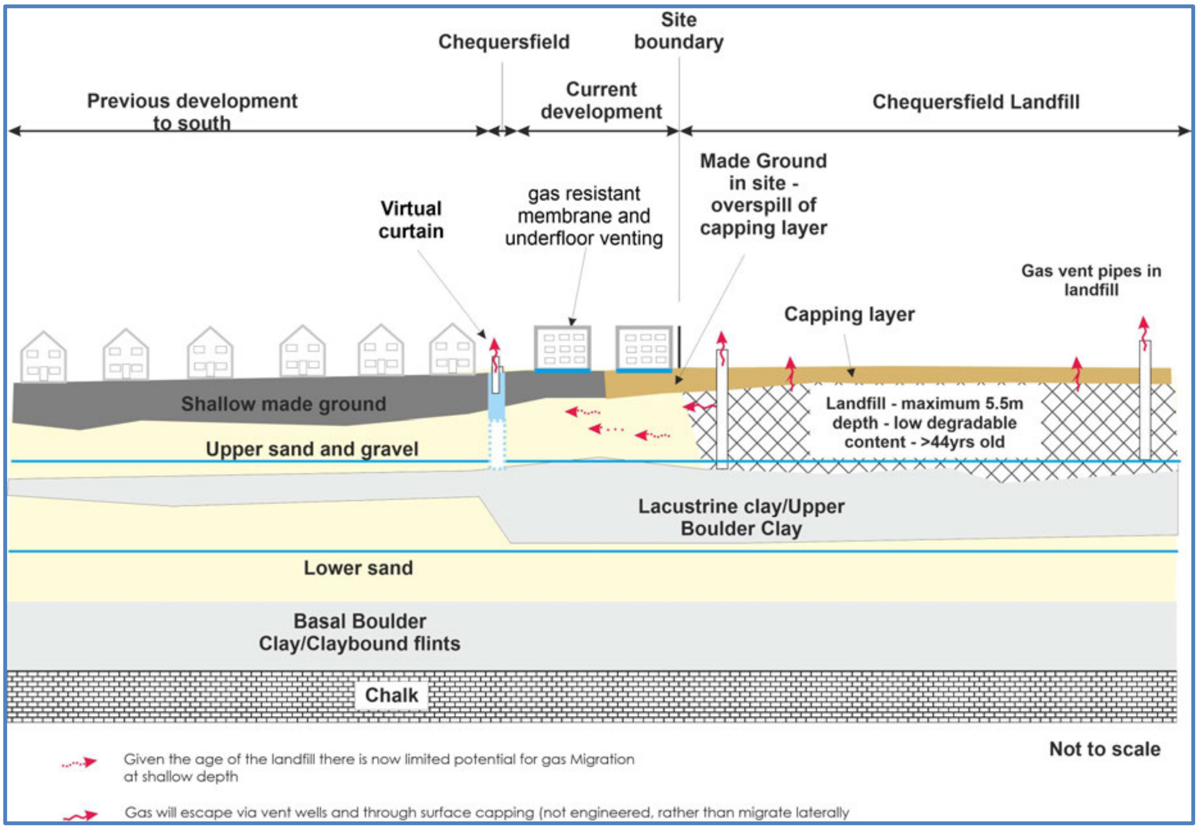


Figure 22 Conceptual Site Model for ground gas

6.1 Gas generation modelling

Gas generation modelling has been undertaken using the ACUMEN (assessing, capturing and utilising methane from expired and non-operational landfills) gas estimation tool, as presented in Figure 23 below. The modelling is based on the following assumptions:

- It covers an area of 33,000m^2 approximately;
- It is up to 5.5m deep (maximum used in analysis);

- Waste density assumed to be 1t/m^3 (it was probably much less than this when placed as little compaction applied to waste at that time and it would be well below modern standards of compaction). This gives tonnage of waste of 181,500t; and

- Closure was in 1976 (Note that the Acumen model assumes negligible gas generation after 50 years and the site has been closed for at least 44 years years).

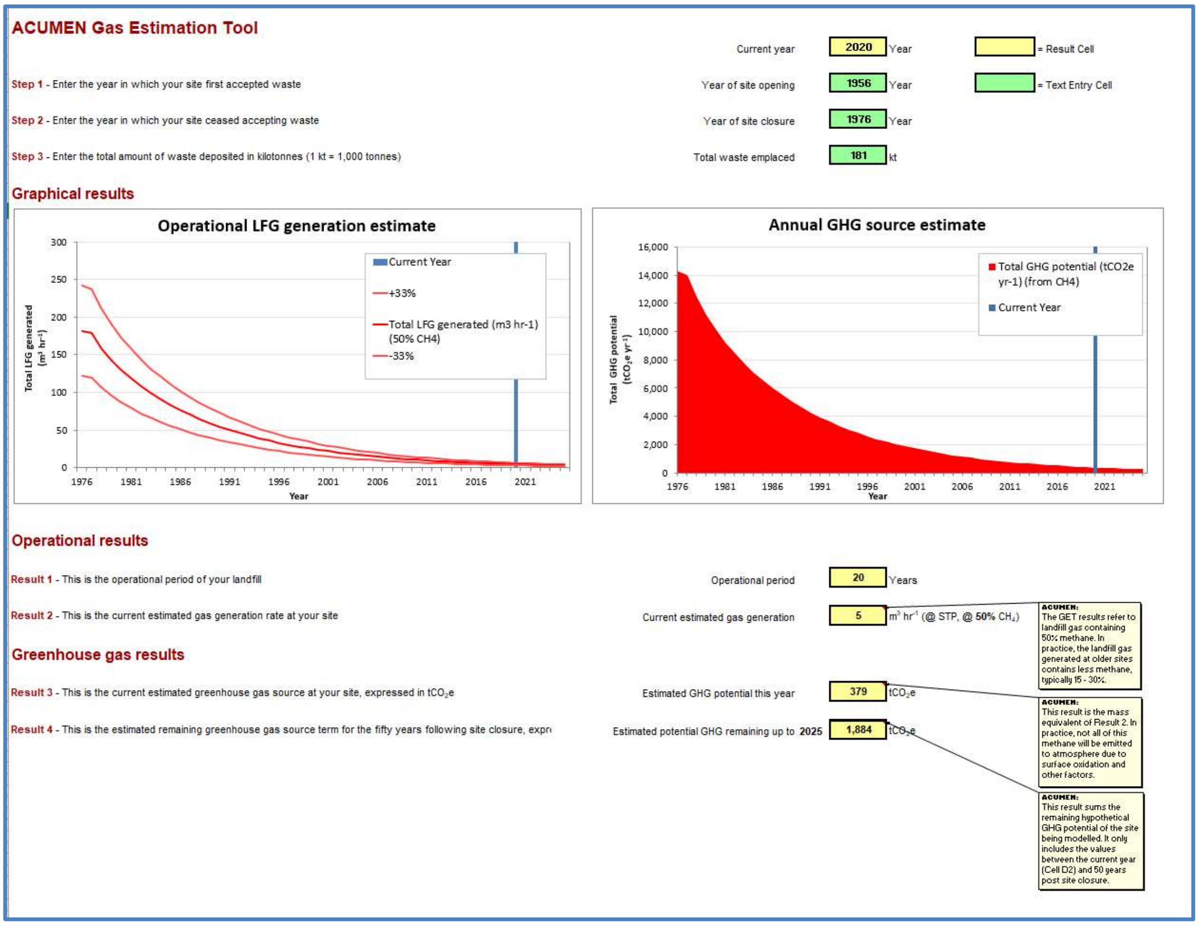


Figure 23 Gas generation modelling using ACUMEN

The results indicate that the site is at residual generation rates and could be generating around 5m^3/h landfill gas @50% methane. This gives 2,500l/h methane over and area of 33,000m^2. Thus the surface emission rate would be 0.075l/h/m^2 which if all emitted at surface would be equivalent to a borehole flow rate of 0.75l/h using Pecksen. This just exceeds the limiting borehole hazardous gas flow rate for Characteristic Situation CS2 in accordance with BS8485 and consistent with the monitoring data from the site investigation reports.

In 2004 when the Virtual Curtain was installed, gas generation was approaching residual rates and the generation rate would have been around 17m^3/h, or 8,500l/h methane over an area of 33,000m^2. If it was all emitted from the surface it would give a surface emission rate of 0.26l/h/m^2 which is equivalent to a borehole flow rate of 2.6l/h (ie CS3 in accordance with BS8485).

In 1999 (when STATS completed the gas monitoring on which the Virtual Curtain design was based) it was significantly greater as the site had only been closed for about 24 years. The estimated generation at that time was 26m^3/h which would be equivalent to a borehole flow rate of 3.9l/h using Pecksen (ie just exceeding the CS3 limit in accordance with BS8485 and consistent with the monitoring data from the site investigation reports by STATS at that time).

The maximum flows recorded by STATS were in excess of this (12l/h, although many results were around 2l/h to 3l/h) and are representative of either differing rates of generation in different parts of the landfill or flooding of monitoring wells (without the base data is not possible to conform which is most likely). In any event variations in generation becomes less significant as the overall rate of degradation reduces with longer periods of time and the source term (ie the degradable content) is used up so that gas generation reduces. The fact that there is good evidence that gas generation has occurred over a period of years indicates that future increases in gas generation (eg due to increased wetting) will not change the risk posed by gas emissions significantly because the source has been used up and only residual levels of generation will now be occurring, irrespective of what will not be slight variations after 50 years or more of degradation.

Thus, the modelling shows that within the landfill site itself the gas regime is now likely to be representative of CS2. Outside the landfill this will be lower, although there are data uncertainties such that it would be reasonable to assume CS3 conditions for the purposes of gas protection design for the buildings.

7. IMPACT ON GAS VENTING BARRIER

Previous gas monitoring after installation of the barrier indicates it has a zone of influence potentially about 35m either side of it (See Section 4).

It is often stated that constructing over a site with impermeable materials will force to gas to migrate sideways and increase the risk to nearby buildings. However, the only known cases where this has been shown to occur is where recently filled domestic landfill sites have been capped over and there is a highly permeable pathway (usually fractured rock) present. The capping has covered the entire gas source and has been sufficient to prevent or significantly reduce surface emissions out of the landfills.

On this site the gas in the ground is not being actively generated in significant quantities anymore and outside the landfill the evidence shows that the carbon dioxide that is present is caused by natural processes that cannot cause high emission from the ground (See Section 4). Therefore, an intermittent covering of impermeable materials in a housing development will not cause increased emissions that would adversely affect the buildings (especially as they have been provided with gas protection measures, see Section 5).

The development is on the opposite side of Chequersfield to the gas barrier some 10m or more away from it and therefore there is nothing in the development that could have adversely affected its performance (eg wind shielding of the vents, which were designed on the basis of it being in a built up area).

8. GAS MITIGATION RISK ASSESSMENT AND DESIGN

8.1 Risk assessment

Based on the preceding discussions, gas generation data and the gas monitoring it is considered that the gas generation in the landfill waste is now at residual levels. It is unlikely to cause significant migration towards this site. In the worst case the evidence shows that the site could be considered as Characteristic Situation CS2 if it was located directly onto the landfill material. However because of data uncertainty the gas protection design is based on the site being Characteristic Situation CS3.

8.2 Design

Considering the CSM for the site as well as data quality it is reasonable to assume Characteristic Situation CS3 in accordance with BS8485: 2015 + A1: 2019. A generic screening gas protection design on this basis is provided below.

Table 3 BS8485: 2015 + A1: 2019 – generic screening gas protection design assessment

Parameter	Over or very close to former landfill
CS Designation – Table 2, BS8485	CS3
Building Type – Table 3, BS8485	Type A Private because of the small flats it is possible that alterations to the rooms could occur without the knowledge of the leaseholder/management company)
Minimum Gas Protection Score (Points) – Table 4 BS8485	4.5 points required