Quantitative Risk Assessment (QRA) Report

for

Priory Wood Landfill, Tonbridge, Kent, TN11 0NA

Report

Ecologia™
experts on the ground

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Tonbridge, Kent, TN11 0NA

Prepared for: Tonbridge & Malling Borough Council
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Reference: EES 19.091.1

Date: 3rd November 2020

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Report

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Title: **Quantitative Risk Assessment (QRA) Report**
Priory Wood Landfill, Tonbridge, Kent, TN11 0NA

Ecologia Reference: EES 19.091.1

Client:	Tonbridge & Malling Borough Council	**Client Reference:**	Priory Wood Landfill

Management Systems Control

Ecologia operates under an integrated management system certified to ISO 9001:2015, ISO 14001:2015 and BS OHSAS 18001:2007.

Version No.	Status	Prepared by:	Checked by:	Authorised by:	Date
1	FINAL	L. Allen BSc	LA. Cammack BSc	LA. Cammack BSc	03/11/2020

EXECUTIVE SUMMARY

Site Location & Description	The Site is located at Priory Wood Landfill, Tonbridge, Kent, TN11 0NA. The Site comprises a public open space park with mainly grass across the centre and routes are cleared to facilitate walking paths. The Site can be accessed from Deakin Leas in the south west or from Vauxhall Gardens in the north east. The site is at an elevation of approximately 70-65 m above ordnance datum; however, the surface is undulating. Woodland is present around the perimeter of the Site. A steep cutting is present in the east falling to an adjacent active railway line. A locked compound comprising a gas extraction system is present in the south west of the Site, with 5No. ventilation stacks across the western side. Off-site to the west are residential properties of Deakin Leas, to the south is a slope leading to the A21 Tonbridge By-Pass, the east is a railway line and to the north is Tonbridge Grammar School.
Objective	This QRA report is intended to assess the risk from ground gas associated with the landfill and identify the need for any additional investigation or risk mitigation works that may be required.
Environmental Setting	The Site geology comprises superficial strata of Wadhurst Clay in the west and Ashdown Formation in the east. The Tonbridge Sand Formation is also present to the south and east. BGS geological mapping of the area (BGS, 1997) indicates the presence of a fault at depth between the Wadhurst Clay and the Ashdown Beds trending east to west and south west within the Site. The mapping indicates that the Wadhurst Clay is at an incline north of 10-15 degrees. The Wadhurst Clay Formation is an unproductive stratum. The Ashdown and Tonbridge Sand Formations are designated as Secondary A aquifers. The Site is not within a groundwater source protection zone. Surface water drains are present on the northern and western boundaries of the Site. A pond is present in the south west of the Site. The nearest surface water feature off-site is a pond approximately 107 m south of the Site. Ancient and semi-natural woodland is present on the eastern and western boundaries of the Site. The Site is also within an area of adopted greenbelt. The High Weald (an area of outstanding natural beauty) is located approximately 40 m south of the Site.
Historical Setting	The Site was undeveloped on the earliest mapping of 1867-1891 and was therefore likely quarried prior to the earliest available maps. The Site was historically an open cast quarry to obtain iron ore from the Wadhurst Clay Formation and was known as the Priory Wood Pits. The eastern area of the Site was quarried for Sandstone and was known as the Priory Wood Quarry. Other quarrying activities, known as lambshank pits as well as brickworks, were historically present in the vicinity of the Site. Permission for landfilling at the Site was granted in 1956 and was extended to include tipping of household waste in 1969. It is understood tipping ceased by 1980 when the site is no longer shown as a refuse tip on historical maps. Planning permission was granted for use of the land as a public open space with informal recreational use was granted in 1988.

Conclusions & Recommendations	The following conclusions are made: • The landfill area is still generating high concentrations of methane and carbon dioxide gas, which are being adequately ventilated by the gas extraction system and/or naturally via vertical emission from soils. • Risks to on-site receptors comprising recreational users are considered **low** on the basis that exposure would be of limited duration. • Risks to off-site residential receptors are **moderate to low** based on elevated carbon dioxide concentrations identified in boreholes near to the property. • Risks to off-site school receptors are **moderate to low** on the basis that gas concentrations in the landfill are measured up to 44% methane within nearby waste material. No gas monitoring has been undertaken between the waste material and the school boundary to confirm risks. • There is uncertainty with respect to whether monitoring included a period of 'worst case' pressure fall. Also uncertainty as to whether a continuous water body is present in shallow soils and if this extends to residential properties and whether the faults in the underlying bedrock could act as a preferential pathway for ground gases, should the gas extraction system cease operation. The following recommendations are made: • Installation of additional monitoring wells between the waste area and school land in the north and monitoring for ground gases. • Hydraulic permeability testing of natural strata, and measurement of surface emissions across the landfill area. • Replacement of monitoring well at BH1 and routine monitoring of water levels. • Continuous ground gas monitoring in selected boreholes to confirm the potential for gas accumulation and migration with changes in atmospheric pressure. • Sampling of gases within the landfill and near to residential properties for carbon isotope testing to confirm the potential source of elevated carbon dioxide.

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PLANS

APPENDICES

1. INTRODUCTION

1.1. Background

Ecologia was instructed by Tonbridge and Malling Borough Council (the 'Client') to carry out ground gas monitoring over a 12 month programme and complete a Quantitative Risk Assessment (QRA) Report for Priory Wood Landfill, Tonbridge, Kent, TN11 0NA.

As part of the works, Ecologia (part of the RSK Group) commissioned RSK Environment Limited (RSK) to undertake the ground gas risk assessment. The key findings of the report are summarised in Section 2 and Section 3, with the full report included in Appendix I.

1.2. Objectives

The objective of QRA report is as follows:

- To review the findings of previous site investigation and ground gas monitoring data collected at the Site;
- To undertake an assessment of risk from ground gas associated with the landfill to off-site receptors (i.e. residential properties and school); and,
- To identify the need for any additional investigation or risk mitigation works that may be required.

1.3. Previous Assessments

This report should be read in conjunction with the following previous assessments completed for the Site:

- Leap Environmental Ltd, 'DRAFT Phase 1 Desk Study and Site Reconnaissance Report' (Ref: LP1702). Dated 5th October 2018;
- Ecologia Environmental Solutions Ltd, 'Preliminary Land Contamination Assessment' (Ref: EES 19.091.1). Dated 20th September 2019;
- Ecologia Environmental Solutions Ltd, 'Quarterly Ground Gas Monitoring Report' (Ref: EES 19.091.1). Dated 29th November 2019;
- Ecologia Environmental Solutions Ltd, 'Quarterly Ground Gas Monitoring Report (Q2)' (Ref: EES 19.091.1). Dated 31st March 2020;
- Ecologia Environmental Solutions Ltd, 'Quarterly Ground Gas Monitoring Report (Q3)' (Ref: EES 19.091.1). Dated 1st June 2020; and,
- Ecologia Environmental Solutions Ltd, 'Quarterly Ground Gas Monitoring Report (Q4)' (Ref: EES 19.091.1). Dated 8th September 2020.

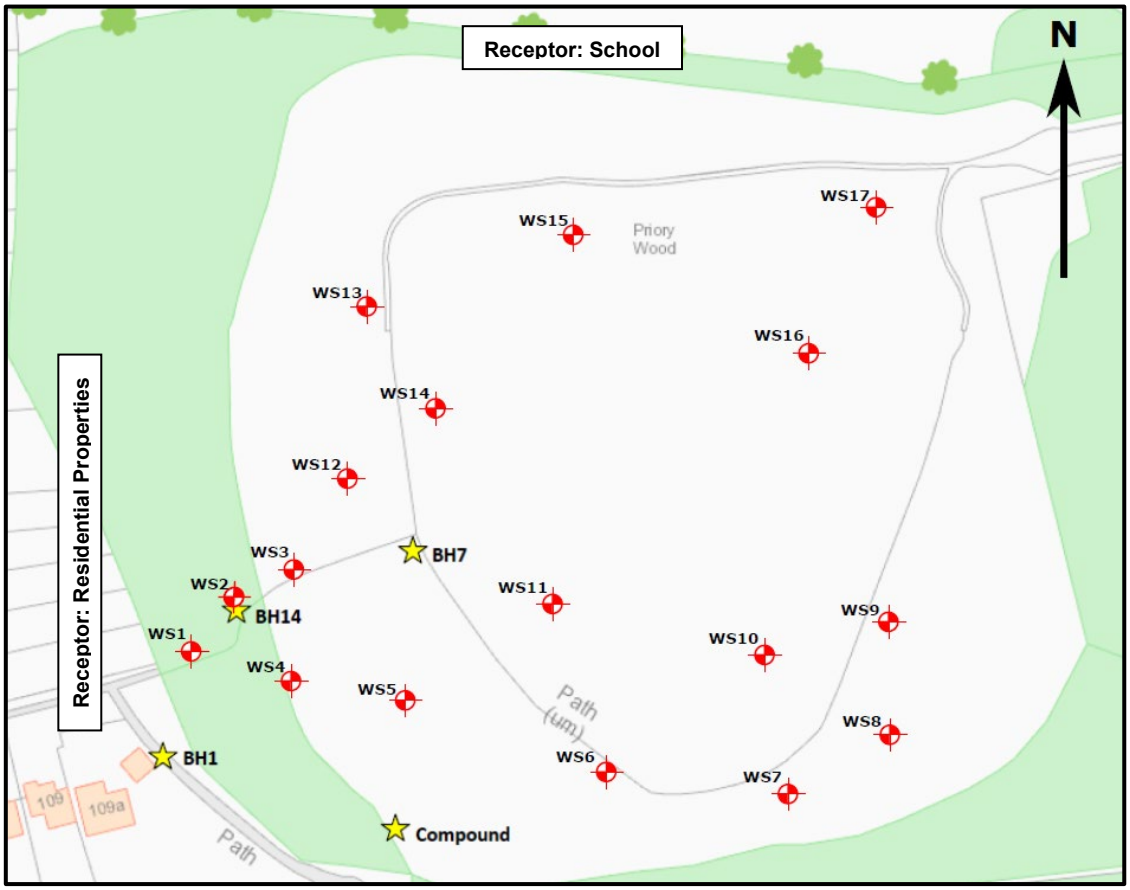
A range of other third-party information comprising geological maps, maps of existing and historical ground gas extraction boreholes, drawings of existing gas mitigation measures and planning records were also reviewed.

2. GROUND GAS RISK ASSESSMENT

2.1. Background

Ecologia has completed twenty-six rounds of ground gas monitoring on a fortnightly basis between 29th August 2019 and 26th August 2020. Atmospheric pressure recorded during the monitoring period was low (<1000mb) on 7 of the 26 monitoring rounds, with the lowest atmospheric pressure of 986 mb, recorded on 7th November 2019.

The borehole locations monitored by Ecologia 'WS1 – WS17' are depicted on Plan 1 below. We understand that Tonbridge and Malling Borough Council (TMBC) also regularly monitor from boreholes 'BH1, BH7 and BH14'.



Plan 1. Ground Gas Monitoring Well Locations

2.2. Gas Management System

It is understood that circa 1993 TMBC installed a gas extraction system comprising of a cut-off trench along the western boundary of the landfill. The trench is understood to be 10 m deep and include 5No. vented granular wells. These comprise a slotted 150 mm HDPE pipe with drainage curtain, leading to a single 3 m high ventilation vent pipe rising above ground and secured with a concrete base. The pipe is protected by geomembrane and overlain by turf and topsoil. The ventilation pipe is shown to have a port at 1 m height for the collection of gas samples.

The ventilation system incorporates an electrical gas booster to improve gas extraction rates. It is understood that this system operates each working day between 8am and 6pm.

2.3. Ground Gas Monitoring Results

A summary of findings at each borehole monitored by Ecologia are presented in Table 2.1 below, including the maximum gas concentrations and maximum steady-state flow rates.

Table 2.1. Summary of calculated Hazardous Gas Flow Rates (Ecologia Data)

Zone	Location	Peak Methane (% v/v)	Peak Carbon Dioxide (% v/v)	Maximum Steady-State Flow Rate (l/hr)	Methane GSV (l/hr)	Carbon Dioxide (l/hr)	Characteristic Situation
Outside	WS1	0.7	2.7	<0.1	<0.01	<0.01	CS1
Outside	WS2	2.1	4.9	0.1	0.002	0.004	CS1
Outside	WS3	7.1	7.5	<0.1	<0.01	<0.01	CS1
Inside	WS4	68.4	39.9	0.1	0.068	0.037	CS1
Inside	WS5	76.3	39.9	0.1	**0.076**	0.031	**CS2**
Inside	WS6	45.1	39.9	0.1	0.045	0.027	CS1
Inside	WS7	47.1	35.2	<0.1	<0.01	<0.01	CS1
Inside	WS8	30.4	24.0	0.1	0.030	0.021	CS1
Inside	WS9	76.3	35.0	0.1	**0.076**	0.031	**CS2**
Inside	WS10	45.4	25.1	<0.1	<0.01	<0.01	CS1
Inside	WS11	57.7	26.2	<0.1	<0.01	<0.01	CS1
Inside	WS12	13	20.0	0.1	0.013	0.008	CS1
Inside	WS13	67.9	30.2	0.2	**0.136**	0.053	**CS2**
Inside	WS14	14.7	23.9	<0.1	<0.01	<0.01	CS1
Inside	WS15	23.0	24.5	0.1	0.023	0.024	CS1
Inside	WS16	10.0	20.2	<0.1	<0.01	<0.01	CS1
Inside	WS17	44.3	21.6	<0.1	<0.01	<0.01	CS1

Based on the data collected by Ecologia, boreholes within the landfill represent CS2 conditions due to hazardous gas flow rates greater than 0.07 l/hr (low hazard potential).

The calculated hazardous gas flow rates for boreholes outside the landfill represent CS1 conditions (very low hazard potential).

It is important to note that the calculated hazardous gas flow rates are much lower than those reported by Leap between 2009 and 2018, which may have been recorded during times when the gas extraction system was inoperable. Due to this, a 'worst case' calculation has been undertaken to determine hazardous gas flow rates with more precautionary flow rates. The results are presented in Table 2.2 overleaf.

Table 2.2. Summary of 'worst case' Hazardous Gas Flow Rates

Zone	Location	Peak Methane (% v/v)	Peak Carbon Dioxide (% v/v)	Maximum Steady-State Flow Rate (l/hr)	Methane GSV (l/hr)	Carbon Dioxide (l/hr)	Characteristic Situation
Outside	WS1	0.7	2.7	12.9	0.09	0.34	CS2
Outside	WS2	2.1	4.9	12.9	0.27	0.63	CS2
Outside	WS3	7.1	7.5	12.9	0.92	0.96	CS3
Inside	WS12	13.0	20.0	12.9	1.67	2.58	CS3
Inside	Various	76.3	39.9	8.1	6.18	3.23	CS4

The use of 'worst case' gas flow rates as reported by Leap would indicate a CS4 (moderate to high hazard potential) within the landfill area and CS2 outside of the landfill area (low hazard potential).

3. CONCLUSIONS AND RECOMMENDATIONS

3.1. Conclusions

The following conclusions are made following the ground gas risk assessment:

- The landfill area is still generating high concentrations of methane and carbon dioxide gas. The recorded flow rates and differential pressure in monitoring wells by Ecologia was low and indicated that gases were being adequately ventilated by the active gas extraction system and/or naturally via vertical emission from soils.
- Risks to on-site receptors comprising workers are **low** on the basis that mitigation can be provided through appropriate workplace exposure controls in accordance with the Health and Safety at Work Act.
- Risks to on-site receptors comprising recreational users of the Site as a public open space are considered **low** on the basis that exposure would be of low duration and gas emissions are low and readily diluted in the atmosphere.
- Risks to off-site receptors comprising residential properties at Deakin Leas are **moderate to low** based on elevated carbon dioxide concentrations identified in boreholes near to the property. It is considered that there remains uncertainty as to whether this data reflects gas migration from the landfill or natural sources.
- Risks to off-site school receptors are **moderate to low** on the basis that gas concentrations in the landfill are measured up to 44% methane within nearby waste material and that gas monitoring has not been undertaken between the waste material and the school boundary. Risks to existing school buildings are considered likely to be low based on limited monitoring completed during planning, however, the potential for gas migration into the school land has not been directly assessed.
- There is uncertainty with respect to whether monitoring included a period of 'worst case' pressure fall, the potential for continuous water body in shallow soils at the Site and if this extends to residential properties, whether gas migration occurs between the waste area and the school boundary, and whether the known faults in underlying bedrock could act as a preferential pathway for ground gases, should the gas extraction system cease operation.

3.2. Recommendations

In order to further refine the risk assessment, the following actions are recommended:

- Installation of additional monitoring wells between the waste area and school land in the north, including hydraulic permeability testing of natural strata, and measurement of surface emissions across the landfill area.
- Replacement of the monitoring well at BH1 and routine monitoring of water levels to confirm the potential for gas migration at this location and the source of elevated carbon dioxide.
- Continuous ground gas monitoring in selected boreholes inside and outside of the landfill area to confirm the potential for gas accumulation and migration with changes in atmospheric pressure.
- Sampling of gases within the landfill and near to residential properties for carbon isotope testing to confirm the potential source of elevated carbon dioxide.

APPENDIX I

GROUND GAS RISK ASSESSMENT

Tonbridge & Malling Borough Council

Priory Wood Landfill, Tonbridge, Kent, TN11 0NA

Ground Gas Risk Assessment

1921480-R01 (01)

OCTOBER 2020

RSK GENERAL NOTES

Project No.: 1921480 R01 (01)

Title: Ground Gas Risk Assessment

Client: Tonbridge & Malling Borough Council

Date: 29 October 2020

Office: RSK Environment Limited, 18 Frogmore Road, Hemel Hempstead, Herts, HP3 9RT, Contact: Andrew Fellows, Tel: 07503 065876

Status: Rev 01

Author(s):	Andrew Fellows *CEnv, CSci, ASoBRA*	Principal Geo-Environmental Consultant
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Quality Reviewer	Ellie Sanders	Administrator

Revision control sheet

Revision reference	Date	Reason for revision
Rev 00	23/10/20	First issue
Rev 01	29/10/20	Second issue following Ecologia comments

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FIGURES

APPENDICES

1 INTRODUCTION

1.1 Commissioning

RSK Environment Limited (RSK) was commissioned by Ecologia Environmental Solutions Ltd, on behalf of Tonbridge and Malling Borough Council (TMBC) ('the client'), to undertake a ground gas risk assessment for the Priory Wood Landfill, Tonbridge, Kent, TN11 0NA (herein referred to as 'the site').

The project was carried out to an agreed brief as set out in RSK proposal Ref: 1921480 T01 dated 28 August 2020.

The risk assessment has been undertaken following completion of a preliminary land contamination assessment by Ecologia, which included site investigation works, and the completion of follow-on ground gas monitoring on 26 occasions from 28 August 2019 to 26 August 2020.

This report is subject to the RSK service constraints given in **Appendix A** and limitations that may be described through this document.

1.2 Objectives

The objective of the work is:

- to review the findings of previous site investigation and ground gas monitoring data collected at the site;
- to undertake an assessment of risk from ground gas associated with the landfill to off-site receptors; and
- to identify the need for any additional investigation or risk mitigation works that may be required.

1.3 Scope of works

The scope of this assessment has been developed in accordance with relevant British Standards and authoritative technical guidance as referenced through the report.

The assessment of the contamination status of the site has been undertaken in general accordance with Land Contamination: Risk Management (LCRM, 2020), and in general accordance with BS 10175: 2011 + A2 2017 (BSI, 2017).

The assessment of risk from ground gas has been undertaken in accordance with relevant guidance as referenced throughout this report.

The scope of works will comprise an assessment of the site, its development and environs, to include:

- A brief review of investigation data obtained for the site by Ecologia and relevant information as provided by TMBC;
- Development of a ground gas conceptual site model;
- Ground gas risk assessment based on the available data; and
- Recommendations for further investigation or mitigation, if required.

1.4 Existing reports

The following reports were made available for review:

- Ecologia Environmental Solutions Ltd. Preliminary Land Contamination Assessment. Tonbridge & Malling Borough Councl. Ref: 19.091.1. September 2019.
- Leap Environmental Ltd. DRAFT Phase 1 Desk Study and Site Reconnaissance Report. Tonbridge & Malling Borough Council. Ref: LP1702. October 2018.

A range of other third-party information comprising geological maps, maps of existing and historical ground gas extraction boreholes, drawings of existing gas mitigation measures, planning records, and the findings of correspondence between Ecologia and TMBC were also provided to RSK.

1.5 Limitations

The study aims principally to identify and assess the potential risks and liabilities associated with ground gas generation within the landfill to current off-site receptors. This report has been designed generally to meet the objectives of a ground gas risk assessment as set out in BS8485 (2015) and associated guidance.

The report and associated assessment are based largely on third party data provided by others. RSK assume this information to be reliable and correct, and no additional checks have been made to confirm its authenticity. RSK accept no liability for any errors or omissions in the data provided.

This report should be considered in the light of any changes in legislation, statutory requirement or industry practices that have occurred after the date of issue.

The opinions expressed in this report, and the comments and recommendations given, are based on the information provided by Ecologia and TMBC. No intrusive investigations have been undertaken by RSK to confirm the actual ground conditions and hence the environmental status of the site.

2 SITE INFORMATION

2.1 Site location

The following information comprises a brief summary of desk-based and site investigation information as contained in the reports referenced in Section 1.4. A summary of relevant site information is provided in **Table 1**.

Table 1 Site Information

Category	Information
Site name	Priory Wood Landfill
Site address and postcode	Deakins Leas, TN9 2JT
National Grid reference	TQ 59170 44980
Approximate Site Area	5.21 Hectares
Site Description	The site comprises a public open space park and consistent of overgrown vegetation and grass across the center and routes cleared to facilitate walking paths. The site is accessed from Deakin Leas in the south west. The site is at an elevation of approximately 70-65 m above ordnance datum, however, the site surface is undulating. Woodland is present in the east, west, and north boundaries of the site. A steep cutting is present in the east falling to an adjacent active railway line. A locked compound comprising a gas extraction system is present in the south west of the site. In the west of the site are 5 ventilation stacks.
Site Surroundings	To the west are residential properties of Deakin Leas, to the south is a slope leading to the A21 Tonbridge By-Pass, the east is a railway line and to the north is Tonbridge Grammar School.
Geology	The site geology comprises superficial strata of Wadhurst Clay (weathered stiff plastic Clay at surface with dark grey shales, mudstones, sandstone, limestone and clay ironstone at depth) in the west and Ashdown Formation (interbedded siltstone and sandstone with subordinate mudstone and shale horizons) in the east. The Tonbridge Sand Formation comprising interbedded mudstones, clays, silts and thinly bedded sandstones is to the south and east. A weathered horizon typically comprises red and mottled grey and orange silts. BGS geological mapping of the area (BGS, 1997) indicates the presence of a faults at depth between the Wadhurst Clay and the Ashdown Beds trending east to west and south west within the site. The mapping indicates that the Wadhurst Clay is at an incline north of 10-15 degrees.
Hydrogeology	The Wadhurst Clay Formation is an unproductive stratum. The Ashdown and Tonbridge Sand Formations are designated as Secondary A aquifers. The site is not within a groundwater source protection zone.
Hydrology	Surface water drains are present on the northern and western boundaries of the site. A pond is present in the south west of the site. The nearest surface water feature off-site is a pond approximately 107 m south of the site.
Sensitive Land Uses	Ancient and semi-natural woodland is present on the eastern and western boundaries of the site. The site is also within an area of adopted greenbelt. The High Weald (an area of outstanding natural beauty) is located approximately 40 m south of the site.
Site History	The site was undeveloped on the earliest mapping of 1867-1891 and was therefore likely quarried prior to the earliest available maps. The site was historically an open cast quarry to obtain iron ore from the Wadhurst Clay Formation and was known as the Priory Wood Pits. The eastern area of the site was quarried for Sandstone and was known as the Priory Wood Quarry. Other quarrying activities, known as lambshank pits as well as brickworks, were historically present in the vicinity of the site. Permission for landfilling at the site was granted in 1956 and was extended to include tipping of household waste in 1969. It is understood tipping ceased by 1980 when the site is no longer shown as a refuse tip on

Category	Information
	historical maps. Planning permission was granted for use of the land as a public open space with informal recreational use was granted in 1988.
Landfill Records	Landfill records provided by TMBC indicate that tipping of waste commenced circa 1958 and the last records are from 1975. Waste deposited was recorded to include condemned food including meat products including 'offensive matter' related to a case of 'T.B' (assumed tuberculosis). Site ledgers record numerous complaints of rodent infestation, flies and odour. Leachate runoff associated with the site was appeared to be controlled as part of an apparent dilute and disperse process.

3 GROUND GAS CONCEPTUAL SITE MODEL

The site has been subject to previous investigation and monitoring by Ecologia as detailed in their Preliminary Land Contamination Risk Assessment Report (EES 19.091.1, September 2019). The following chapter provides a summary of the investigation findings with respect to risks from ground gas in the context of the conceptual site model.

Diagrammatic conceptual cross sections of the site based on recent investigation by Ecologia and as provided are in **Appendix B**. With respect to the wider Conceptual Site Model, reference should be made to the Ecologia report (2019).

3.1 Ground Gas Sources

The Ecologia preliminary risk assessment identified potential sources of ground gas as follows:

- Historic refuse tip: Landfill gases including carbon dioxide, methane, and volatile organic compounds (VOCs).

The Leap Desktop Study identified a potential off-site source of ground gas associated with an infilled pond located immediately south-west of the site. The potential for on-site migration of landfill gas was identified associated with this source, however, risk from landfill gas were only identified to off-site residents and therefore this source has not been carried forward for further assessment. No other off-site sources were identified by Ecologia or Leap.

Details pertaining to the historical refuse tip as a source of ground gas, as identified in desk-based information, is detailed below.

3.1.1 Priory Wood Landfill

The Ecologia report notes that the site historically comprised a brick quarry prior to 1872 and later become a refuse tip up to 1972. It is understood that materials placed into the tip were unmonitored and are therefore of the potential for placement of putrescible material of unknown nature. In accordance with Figure 6 of BS 8576:2013, the age of the landfill and potential for municipal waste to be present, indicates the generation source potential of the landfill to be high to very high.

A summary of historical site Investigation reports prepared by Leap Environmental (ref: LE/QEMS/Doc 07-5-01-Rev3, 2018) indicates ground conditions at the site as follows:

- The landfill area comprised orange/yellow brown and grey firm to stiff silty Clay (of 0.8-1.1 m thickness) over predominately domestic waste material, which included polythene bags, iron, wood, newspapers, metal, plastic bottles, glass paint tins, clinker, ceramic, rubber fabric, wire, paper, shows, food waste, and concrete. The waste was recorded of between 7.4 m and 10.4 m in thickness and was underlain by 1.35-1.85 m of clay fill. Mudstone was locally encountered from 7 m depth.
- Outside of the waste area, the ground conditions comprised Made Ground comprising light brown clay with occasional tip rubbish (up to 1.5 m) over Wadhurst Clay (blue grey clay/orange brown clay with ironstone) of 1.7 m in thickness, over Ashdown Beds (brown silty clay).
- Perched water was encountered within the landfill at 1.9 m bgl within the waste area.

Later investigations by WEEKS in 1992 indicated that the waste area extended to within shrubland in the west. A single trial pit located to determine the position of a mapped fault in the underlying bedrock did not identify the fault.

Numerous boreholes were later installed by Kent County Council (KCC) and included re-numbering of existing monitoring boreholes to comprise BH1 to BH14. The majority of these were in the west of the site, within the waste, and outside the known waste boundary. Borehole BH1 appears to be located within the boundary of a residential property.

Perched water was identified on site during historical investigations within shallow Made Ground (circa 1.7-1.9mbgl) and standing water levels, likely comprising groundwater, were recorded at approximately 9 mbgl.

3.1.2 Gas Management System

It is understood that circa 1993 TMBC installed a gas extraction system comprising of a cut-off trench as shown on the proposed plan as provided by TMBC.

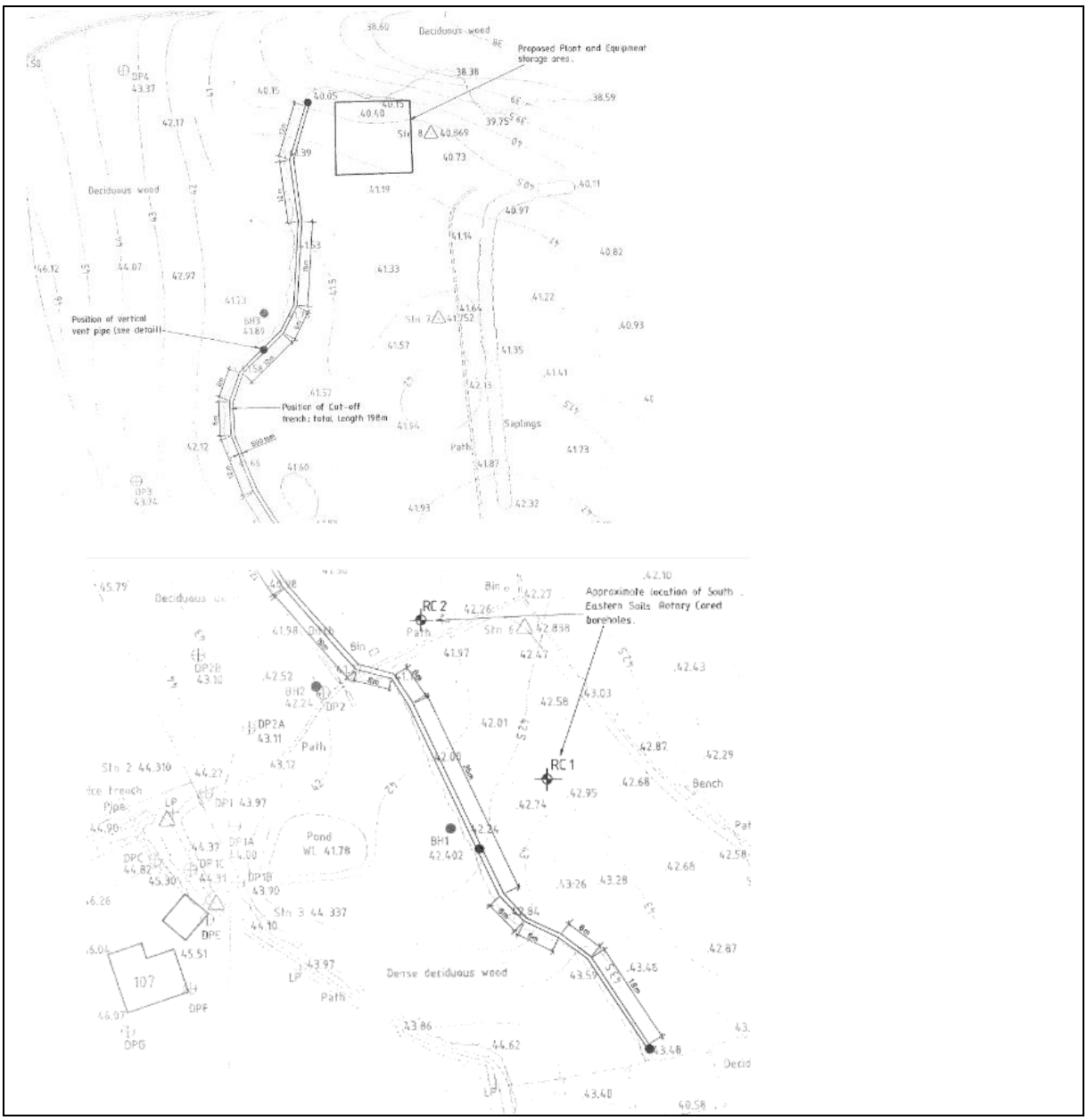

Plate 1: Extract of Ventilation Trench Location (from TMBC)

Information recorded by Leap Environmental (Ref: LE/QEMS/Doc 07-5-01-Rev3, 2018) indicates that the gas cut-off trench was designed by WEEKS and was approximately 200 m long and 2.5 m deep. It is understood from the Leap report that the landfill gas control system was reviewed and that gas concentrations remained elevated. This was considered likely due to landfill gas generation deeper than 2.5 mbgl and subsequent migration in underlying fissures. It was recommended that a further gas ventilation borehole would be located at the edge of the waste (along the line of the assumed fissure) and pumped for two weeks.

A gas pumping trial had been undertaken in October 1993 and demonstrated a reduction in gas concentrations at up to 60 m from the pump but no decrease at 70 m from the pump.

It was further recommended that a 10 m deep cut-off trench was installed to include 5 vented granular wells. It is understood this was implemented in August 1994 by A2 Coring Services.

The design of the ventilation system based on partial drawings provided by TMBC is shown in Plate 2.

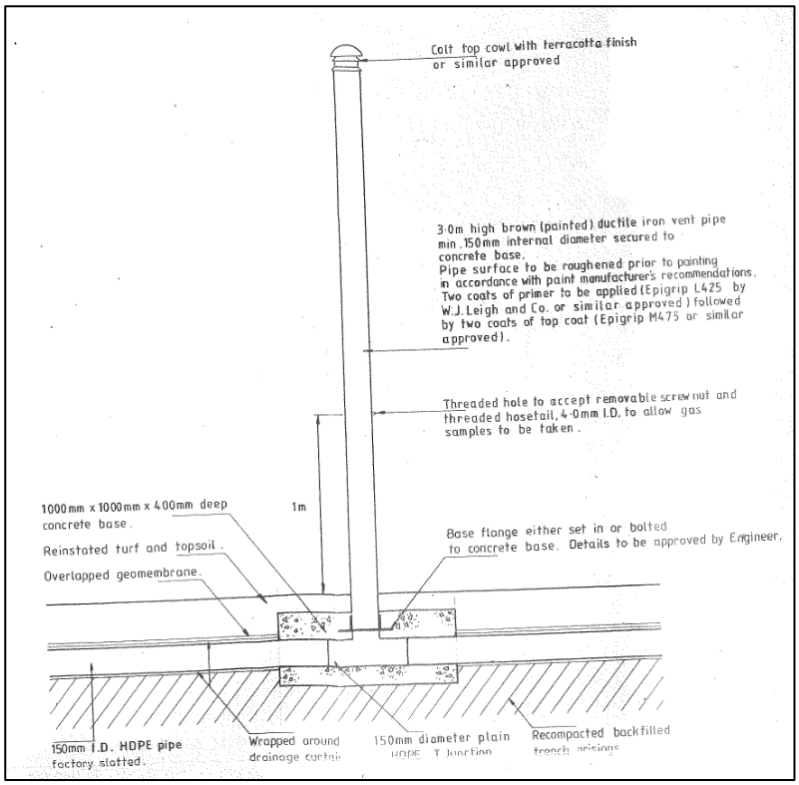

Plate 2: Extract of Ventilation System Design (from TMBC)

This comprises a slotted 150 mm HDPE pipe with drainage curtain, leading to a single 3 m high ventilation vent pipe rising above ground and secured with a concrete base. The pipe is protected by geomembrane and overlain by turf and topsoil. The ventilation pipe is shown to have a port at 1 m height for the collection of gas samples.

The landfill gas migration control system ventstack operational manual, prepared by Soiltec, indicates that the ventilation system incorporates an electrical gas booster to improve gas extraction rates. It is understood that this system operates each working day between 8am and 6pm.

3.1.3 Historical Landfill Gas Monitoring

Leap Environmental reviewed available historical ground gas monitoring data for the site from the period of 1991 through to 1996. The majority of historical ground gas monitoring wells installed at the site were centred in the waste and where outside of the waste were towards residential housing in the west.

Four boreholes (BH1-BH4) installed outside of the waste between the venting trench and residential properties on Deakin Leas were routinely monitored during operation of the pumped system. As reported by Leap, initial methane concentrations in boreholes of 20-80% v/v recorded in April 1996 decreased by June to 0% in BH1, BH2 and BH3. Concentrations in BH4, closest to the ventilation trench, remained circa 30-40% v/v.

3.1.4 Historical Ground Gas Risk Assessment

Leap Environmental also reviewed ground gas monitoring data collected by TMBC dated from 2009 to 25 June 2018 (the latest monitoring having been undertaken by Leap). The dataset included boreholes BH1, BH7 and BH14. The remaining boreholes on site were indicated to have been lost or damaged.

A summary of maximum steady ground gas concentrations and flow rates as summarised by Leap Environmental are presented in **Table 2**. Leap Environmental do not summarise the atmospheric pressure at which monitoring was undertaken.

Table 2 Summary of Ground Gas Monitoring (BH1, BH7, BH14 and Pump) (from Leap, 2018)

Borehole	Pump On	Pump off	Pump On	Pump Off
	Maximum concentration within landfill		Maximum recorded concentration outside of landfill	
Carbon Dioxide	6.0	27.3	19.1	20.1
Methane	6.1	58.9	0.4	0.1

Flow rates were reported by Leap to be up to 12.9 l/hr in BH1 (located outside of the landfill) and up to 8.1 l/hr in 2013 in BH7 (located within the landfill material).

Based on the data summarised in **Table 2**, Leap calculated Gas Screening Values (GSV) and associated Characteristic Situation (CS) ratings in line with British Standards BS8485:2015. Leap determined the following characteristic situation:

- Within the landfill with pump on: CS3
- Within the landfill with pump off: CS4
- Outside the landfill with pump on: CS3
- Outside the landfill with pump off: CS3.

It should be noted that the characterisation of gas outside of the landfill was based on elevated carbon dioxide concentrations identified in BH1. The assessment identified that there were potentially unacceptable risks (categorised as high) to the off-site residents from ground gases associated with the landfill.

3.1.5 Contaminants of Concern

Based on the prior studies by Leap Environmental, contaminants of concern pertinent to ground gas are as follows:

- Methane; and
- Carbon Dioxide.

The potential for volatile organic compounds (VOCs) associated with putrescible landfill waste was identified by Leap Environmental. It is beyond the scope of this report to assess potential risks from VOCs, however, where this linkage is considered relevant, further recommendations have been made.

3.2 Receptors

Potential on-site receptors to hazardous ground gas as identified by Ecologia included:

- Public Open Space Users.

Off-site receptors for ground gas have also been identified as follows:

- Users of Residential land use to the west; and
- School Users to the north.

Buildings can be considered as a receptor but are typically of a lower sensitivity. Based on risk assessment protective of building occupants (i.e. human health), it is likely that protection would also be conferred to buildings and therefore these have not been subject to assessment.

Site workers have not been considered as receptors on the basis that future works on site would be subject to appropriate controls put in place in accordance with the Health and Safety at Work Act (1990).

Historical site visits by Leap and Ecologia do not identify observations of vegetation die back or the presence of vegetation or ecology as a sensitive receptor and therefore site vegetation has also been excluded as a receptor.

3.3 Pathways

Potential pathways for ground gas within the landfill to the aforementioned receptors are as follows:

- Inhalation of hazardous ground gas resulting in asphyxiation (on-site and off-site receptors); and
- Accumulation of hazardous ground gases beneath buildings followed by explosion (off-site receptors).

For a pollutant linkage to be complete to off site receptors, gases must migrate from the source within the landfill towards these receptors and be of concentration and flow to pose a hazard.

The potential for a migration pathway is dependent on several factors and could be subject to preferential pathways. Credible preferential pathways potentially connecting the source and receptor through vertical and lateral migration are:

- Geology including presence of fissures and fractures;
- building foundations (i.e. piled foundations and vibro-stone columns);
- construction joints and cracks within building structure, specifically the floor slab; and
- utility routes and service penetrations into buildings.

Based on the limited presence of shallow groundwater on site migration via gases dissolved in groundwater is not considered to be complete and is thus excluded from further assessment.

3.4 Preliminary risk assessment

The risk classification to identify Potential Contaminant Linkages (PCLs) has been undertaken based on the combination of hazard consequence and probability using a risk matrix from CIRIA C552 (Rudland et al., 2001).

The preliminary risk assessment incorporates those previously identified by Ecologia and Leap Environmental, as well as risks to school users to the north. A summary of potential risks for identified ground gas PCLs is presented in **Table 3**.

Table 3 Preliminary Risk Assessment Summary

Potential source	Potential receptor	Possible pathway	Likelihood	Severity	Potential risk
Landfill Ground Gas (Methane, Carbon Dioxide)	Human health (site users – workers and public)	Inhalation of outdoor gases/vapours	Low likelihood	Severe	**Moderate**
	Human Health - adjacent residential users	Ingress of ground gas into buildings causing asphyxiation	Likely	Severe	**High**
		Accumulation ground gas into buildings causing explosion	Likely	Severe	**High**
	Human health – school users	Ingress of ground gas into buildings causing asphyxiation	Low likelihood	Severe	**Moderate**
		Accumulation ground gas into buildings causing explosion	Low likelihood	Severe	**Moderate**

3.5 Conceptual Uncertainty

As identified in the previous gas risk assessment prepared by Leap, there were uncertainties pertaining to the underlying data as follows:

- The number and spacing of existing monitoring wells at the site were considered inadequate with reference to current good practice guidance, and therefore further monitoring well installations were required to characterise the current ground gas regime.
- The assessment of gas historical data by Leap did not include comparison of gas concentrations with other site conditions, such as atmospheric pressure to determine the likely source of gas concentrations. Furthermore, flow was noted to have been monitored from BH1, BH7 and at the pump, however, it appears only values from BH1 were presented. Flow rates from gas generation within the landfill are not clear, nor is it clear whether flow rates correlated with high gas concentrations.

- The effectiveness of the existing gas extraction system appears to be effective at reducing gas concentrations within the landfill, based on the comparison of gas concentrations recorded by TMBC and presented by Leap. However, should the gas extraction system become inoperable or fail, the migration of gas within the landfill could change and risks to off-site receptors increase.

4 GROUND INVESTIGATION AND MONITORING

4.1 Site Investigation by Ecologia (2019)

On the instruction of TBMC, Ecologia undertook a site investigation of the Priory Wood Site comprising 17 window sample boreholes (WS1-WS17) to depths of between 2 and 3 m below ground level (mbgl). Each borehole was installed as a ground gas monitoring well. A total of 22 samples were taken and analysed at a UKAS accredited laboratory for asbestos, and chemical analysis including metals, total petroleum hydrocarbons (TPH), BTEX (benzene, toluene, ethylbenzene, xylenes), polycyclic aromatic hydrocarbons (PAH) and fraction organic carbon (FOC).

The locations of exploratory boreholes and pre-existing monitoring wells on site is presented in Plate 3.

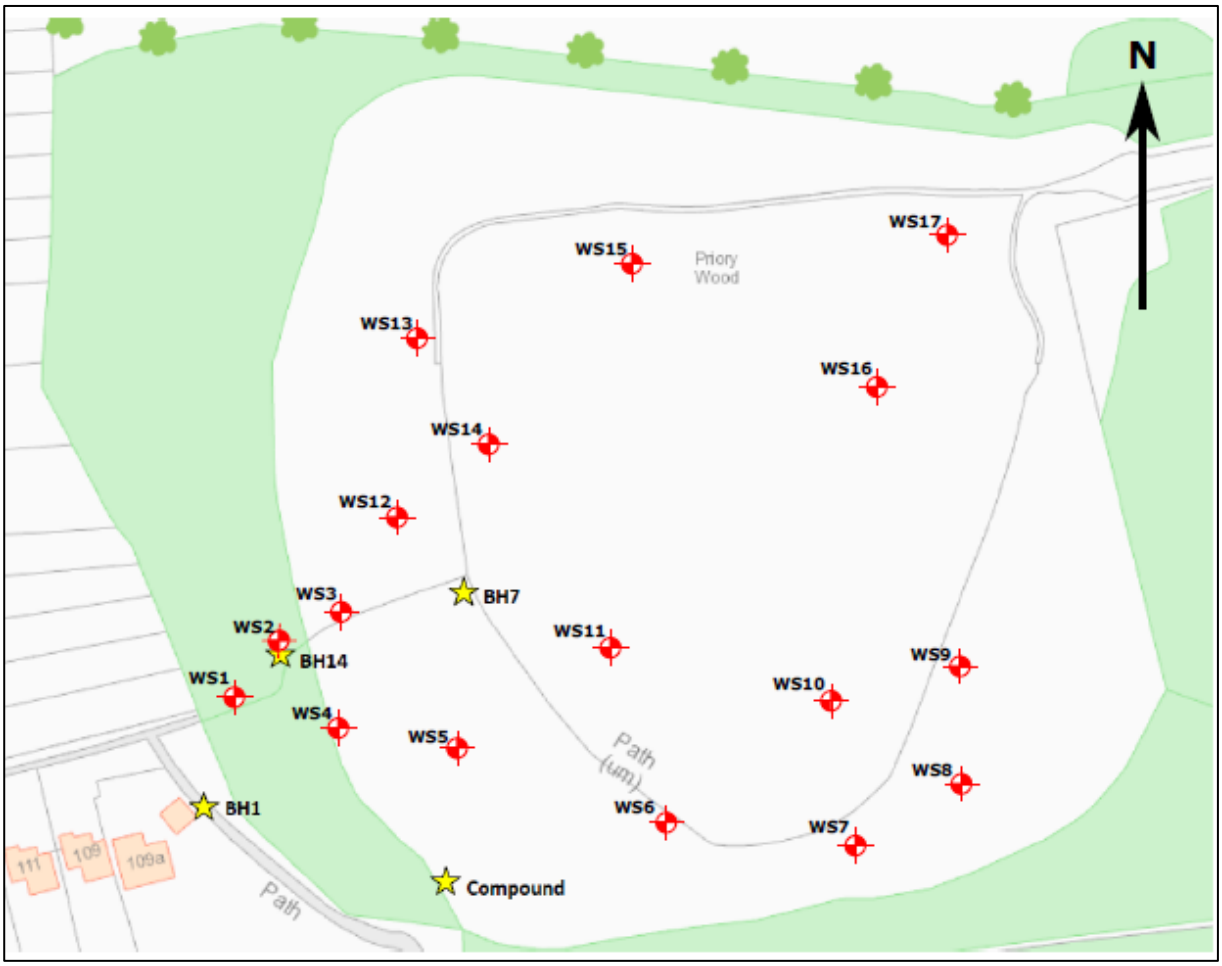

Plate 3: Ecologia Exploratory Hole Location Plan

Full details of the investigation findings are presented in the Ecologia Report (EES 19.091.1), however, a brief summary of the findings is provided below:

- Made Ground was encountered in all exploratory boreholes. Outside of the waste area ground conditions typically comprised very soft to soft sandy gravelly clay to a depth of 0.8 mbgl followed by stiff grey mottled orange/brown very closely laminated clay to a depth of 3 mbgl;

- Waste material was not identified in WS2 located in the west of the site, and visual observations of waste material in WS1 (furthest west) were limited to flint and wood between 2.18 and 2.3 m;
- Domestic refuse waste was encountered in WS4 to WS11, and WS13 to WS17 at surface in some locations to the full depth of investigation (3 m). The waste was identified to be thickest in the east and centre parts of the site as these locations did not identified the base.
- In the borehole to the north (WS17) was identified to comprise 0.25 m of very soft brown slightly gravelly fine to coarse sandy clay, with presence of plastic, brick, wood, glass and concrete from 0.25 m. A wooden obstruction was identified between 0.4 m and 0.6 m. Firm grey mottled brown sandy gravelly clay including gravel sized fragments of flint, brick and wood and rare plastic and chalk was identified from 0.6 m to 1.8 m. Gravel of angular concrete, brick and glass and a moderate odour of hydrocarbons was identified from 1.8 m to the full exploratory hole depth (3.0 m).
- In WS15, soils were described as soft gravelly clay throughout with presence of metal, wood, plastic, flint, glass and brick were identified from surface. At 2.0 to 3.0 m was identified paper and black organic streaking. A large piece of wood was identified between 2.8-2.85 m and ash between 2.9-3.0 m (the full depth of exploratory investigation).
- Perched water was encountered in WS4 (2.35 mbgl), WS8 (2.0 mbgl) and WS14 (2.2 mbgl).
- Chemical analysis of soil samples taken across the site indicated fraction organic carbon to range from 0.0049 (in natural material at 2.2 m in WS2) to 0.042 (in waste material in WS17).

4.2 Ground Gas Monitoring by Ecologia (2019-2020)

Ecologia completed ground gas monitoring at the site on 26 occasions between 29 August 2019 and 26 August 2020. Monitoring across the site on a fortnightly basis for 12 months is consistent in line with a good practice guidance for sites of high to very high generation source potential.

Atmospheric pressure recorded during the monitoring period was low (<1000mb) on 7 of the 26 monitoring rounds, with the lowest atmospheric pressure of 986 mb, recorded on 7 November 2019. It is understood that the gas extraction system remained operational throughout the monitoring undertaken by Ecologia.

Monitoring was completed in installed window samples WS1 to WS17. The full dataset can be found in **Appendix C**. A summary of the ground gas monitoring data is presented in **Table 4**.

Table 4 Summary of Ecologia Ground Gas Monitoring Data

Landfill Location	Location	Peak Methane (% v/v)	Peak Carbon Dioxide (% v/v)	Minimum Steady State Oxygen (%)	Maximum Steady-State Flow Rate (l/hr)	Relative Borehole Pressure Range (mb)
Outside	WS1	0.7	2.7	1.6	<0.1	-1.5 – 0.5
Outside	WS2	2.1	4.9	12.7	0.1	-0.2 – 0.1
Outside	WS3	7.1	7.5	6.5	<0.1	-0.7 – 0.8
Inside	WS4	68.4	39.9	0.1	0.1	-0.1 – 0.7
Inside	WS5	76.3	39.9	<0.1	0.1	-0.2 – 1.0

Landfill Location	Location	Peak Methane (% v/v)	Peak Carbon Dioxide (% v/v)	Minimum Steady State Oxygen (%)	Maximum Steady-State Flow Rate (l/hr)	Relative Borehole Pressure Range (mb)
Inside	WS6	45.1	39.9	<0.1	0.1	-2.8 – 0.8
Inside	WS7	47.1	35.2	0.1	<0.1	-0.1 – 0.5
Inside	WS8	30.4	24.0	<0.1	0.1	-0.2 – 1.0
Inside	WS9	76.3	35.0	<0.1	0.1	-0.2 – 0.2
Inside	WS10	45.4	25.1	0.1	<0.1	-0.2 – 0.2
Inside	WS11	57.7	26.2	<0.1	<0.1	-0.2 – 0.6
Inside	WS12	13.0	20.0	8.0	0.1	-2.3 – 0.9
Inside	WS13	67.9	30.2	<0.1	0.2	-0.1 – 0.5
Inside	WS14	14.7	23.9	<0.1	<0.1	-0.4 – 1.8
Inside	WS15	23.0	24.5	<0.1	0.1	-0.1 – 0.2
Inside	WS16	10.0	20.2	0.4	<0.1	-0.1 – 0.7
Inside	WS17	44.3	21.6	<0.1	<0.1	-0.2 – 0.5

The gas concentrations identified within the interior of the landfill indicate gas concentrations indicative of active gas generation (typically 60% methane, 40% carbon dioxide). Flow rates were consistently recorded to be low (maximum 0.2 l/hr) and relative borehole pressures (0.2-1.8 mbar) are typical of a gas generation. The recorded gas generation and lack of flow is likely due to the existing gas ventilation and extraction measures, but also due to the lack of a landfill cap. The lack of a confining layer would act to encourage vertical emission and limit horizontal migration of ground gas.

Boreholes located outside of the waste mass indicate that landfill gas concentrations decrease with distance from the known waste deposition area. The location furthest away from known waste sources (WS1) had significantly lower concentrations of methane and carbon dioxide than identified within the waste material.

Steady state concentrations of carbon dioxide in wells outside of the waste area (WS1, WS2, WS3) were typically 2.7-7.5% v/v with the highest concentrations recorded in WS3 and lowest in WS1.

On occasion monitoring of gases recorded depleted oxygen, with the low of 1.6% v/v recorded on 29 January, 26 February, 12 March, 26 March, and 09 July 2020. However, all other monitoring visits for WS1 recorded concentrations of oxygen in the normal range (i.e. 14-20% v/v). The depleted oxygen in WS1 is lower than as found in other boreholes installed outside of the waste area (6.5-12.7% v/v). It is possible that during this period, soils were waterlogged (as identified elsewhere) and therefore the borehole could not be replenished with ground gas or localised anoxic conditions increased nitrogen in the monitoring well.

4.3 Monitoring by Tonbridge & Malling Borough Council (2019-2020)

Ground gas monitoring of data collected by TMBC on boreholes BH1, BH7 and from the gas extraction compound is undertaken and has been provided for 2019 and 2020. Data from a total of 11 monitoring

visits was provided comprising 9 in 2019 and 2 in 2020. It should be noted that BH1 was not routinely monitored due to this location being in an area of standing water during wet meteorological conditions.

Atmospheric pressure recorded during monitoring visits varied from 992 mbar to 1020 mbar. A summary of the collated information is provided in **Table 5**. The full dataset is provided in **Appendix C**.

Table 5 Summary of TMBC Ground Gas Monitoring Data (2019-2020)

Landfill Location	Location	Peak Methane (% v/v)	Peak Carbon Dioxide (% v/v)	Minimum Steady State Oxygen (%)	Maximum Steady-State Flow Rate (l/hr)*	Relative Pressure Range (mb)
Outside	BH1	0.1	8.5	10.2	0.2 (-1.5)	0 - 0.05
Inside	BH7	1.4	2.4	18.7	0.0 (-2.5)	0 - 0.07
Outside	Compound	1.8	2.7	18.4	-2.7	0.02 - 0.1

Note:

* Highest negative flows are presented in brackets.

The ground gas monitoring data provided by TMBC indicates that methane concentrations adjacent to the property were recorded up to 0.1% v/v and carbon dioxide of up to 8.5% v/v. Flow rates were typically low and up to 0.2 l/hr, however, negative flow of up to -1.5 l/hr was also identified. It should be noted that not all monitoring events were recorded due to the well being observed to be flooded.

The recorded installation of BH1 (then DPD) in May 1992 indicates plain pipework was installed to 1 m depth whereby perforated piezometer tubing was installed to 3.1 m depth. The strata encountered comprised sandy clay from 0.5 m depth. Groundwater levels were not recorded and other than where flooded are not subsequently recorded. It is considered possible that high groundwater levels at BH1 impede gas flow into the borehole and result in depleted oxygen levels.

The concentrations of landfill gas within BH7, located in the east of the waste area and on the landfill side of the ventilation trench indicates gas concentrations that are an order of magnitude lower than those identified by Ecologia in nearby monitoring wells (e.g. WS11, WS14 and WS5). Historical logs of BH7 (KCC< 1994) indicate that material in this location comprised 0.2 m topsoil over 4.5 m of grey brown clay, over 'black ash some clay small amount of plastic' and was described as 'wet'. Natural strata comprising the Tonbridge Sands was encountered at 9.7 m below ground level. The installation of this borehole appears to comprise 1 m plain section followed by slotted pipework to 10 m. Water levels at this location do not appear to be monitored by TMBC and it is therefore plausible that the screened section of the borehole does not adequately target the waste deposits and that groundwater levels are acting to restrict gas emission at this location.

Landfill gas concentrations in the compound (understood to be measured from the landfill gas extraction pump) are similar to those observed in BH7. However, the compound is not in an area of known landfill waste.

4.4 Monitoring by Soils Limited at Tonbridge Grammar School

A Phase 2 Ground Investigation was undertaken by Soils Limited in 2014 on behalf of Tonbridge Grammar School. This was associated with proposals to develop a new sixth form centre located on the southern boundary of the school grounds and to the north of the Priory Wood site.

Soils Ltd investigation scope included four windowless sampled boreholes to depths of 4.1 mbgl and installation of monitoring standpipes were included in WS3 and WS4 located in the south east and north east of the proposed development area.

Borehole logs indicated the geology in these locations to comprise Made Ground comprising yellowish brown slightly gravelly very sandy silt or silty clay (of 0.35-0.6 m thickness) over Wadhurst Clay Formation comprising firm light orange grey yellow mottled silty clay (of 0.85 to 1.5 m thickness) over bedrock of fine to medium dark grey green weakly cemented ferruginous stained siltstone, which extended to the base of the borehole.

Groundwater and ground gas installations comprised screened sections across the Wadhurst Clay Formation and Siltstone. Groundwater levels were recorded at depths between 1.95 mbgl and 2.37 mbgl.

Ground gas monitoring was undertaken on three occasions and was reported to include falling barometric trends, however, the atmospheric pressure at time of monitoring was not recorded. Gas concentrations were identified to comprise a maximum of 3.2% carbon dioxide and no detection of methane. There were no positive flow rates reported and a single negative flow of -0.1 l/hr.

The school development was characterised by Soils Ltd with reference to BS 8485:2007 as a Characteristic Situation 1 or ‘very low’ hazard potential.

5 GROUND GAS RISK ASSESSMENT

5.1 Risk Assessment Methodology

The recent monitoring by Ecologia and TMBC provide an updated monitoring dataset, upon which ground gas risk assessment can be undertaken. The assessment has been undertaken to assess the following potential contaminant linkages:

- Ground gas and vapour migration from landfill to impact current site users (workers and the public) via outdoor inhalation;
- Ground gas migration from landfill to impact off-site residential receptors via ingress of ground gas and asphyxiation and accumulation of ground gas and subsequent explosion; and
- Ground gas migration from landfill to impact off-site school users via ingress of ground gas and asphyxiation and accumulation of ground gas and subsequent explosion.

The risks to habitable buildings from ground gases have been assessed in accordance with BS8485:2015+A1:2019 (BS8485), which provides guidance on ground gas (methane and carbon dioxide) characterisation and hazard assessment, as well as providing a framework for the prescription of protection measures within new buildings.

The process involves characterising the gas hazard from combining the qualitative assessment of risk (using the CSM) with ground investigation data so that a 'characteristic situation' (CS) can be derived for the site or zones within the site. Characteristic situations range from CS1 to CS6, the higher the CS, the higher the hazard potential. Gas protection measures within new buildings can be prescribed using a point scoring system, taking into consideration the CS and the proposed building type.

To determine the site CS, borehole hazardous gas flow rates (Qhg) are calculated per borehole for methane and carbon dioxide as follows:

Peak gas concentration (%) / 100 x Steady state flow rate (l/hr) = Hazardous Gas Flow Rate (l/hr)

In determining the applicability of Qhg, consideration is given to the reliability of the measured gas concentrations and flow rates, whether there is adequate data for assessment, and whether the findings are as expected in line with the conceptual site model.

More detailed quantitative risk assessment, for example to estimate the potential for gas migration to a defined building through specific strata and to estimate surface emission rates at the receptor. However, detailed quantitative risk assessment is outside the scope of this report. A detailed quantitative assessment would be supported by the collection of further specific site data (i.e. soil permeability, building dimensions and foundations etc.) in order that quantitative estimates reflect the site conditions.

5.2 Site Zoning

The site has been zoned into areas comprising the area of landfill within which waste is present and the area outside of the landfill. It is noted that monitoring wells are not present in natural strata to the north. It has been assumed that ground conditions as identified in other monitoring wells outside of the waste to the west are representative of conditions to the north.

5.3 Hazardous Gas Flow Rates (Ecologia Data)

The summary of hazardous gas flow rates from Ecologia dataset is provided in **Appendix D**. A summary of findings at each borehole, based on the maximum gas concentrations and maximum steady-state flow rates for each borehole monitored by Ecologia is presented in **Table 6**.

Table 6 Summary of calculated Hazardous Gas Flow Rates (Ecologia Dataset)

Zone	Location	Peak Methane (% v/v)	Peak Carbon Dioxide (% v/v)	Maximum Steady-State Flow Rate (l/hr)*	Methane GSV (l/hr)	Carbon Dioxide GSV (l/hr)	Characteristic Situation
Outside	WS1	0.7	2.7	<0.1	<0.01	<0.01	CS1
Outside	WS2	2.1	4.9	0.1	0.002	0.004	CS1
Outside	WS3	7.1	7.5	<0.1	<0.01	<0.01	CS1
Inside	WS4	68.4	39.9	0.1	0.068	0.037	CS1
Inside	WS5	76.3	39.9	0.1	**0.076**	0.031	**CS2**
Inside	WS6	45.1	39.9	0.1	0.045	0.027	CS1
Inside	WS7	47.1	35.2	<0.1	<0.01	<0.01	CS1
Inside	WS8	30.4	24.0	0.1	0.030	0.021	CS1
Inside	WS9	76.3	35.0	0.1	**0.076**	0.031	**CS2**
Inside	WS10	45.4	25.1	<0.1	<0.01	<0.01	CS1
Inside	WS11	57.7	26.2	<0.1	<0.01	<0.01	CS1
Inside	WS12	13.0	20.0	0.1	0.013	0.008	CS1
Inside	WS13	67.9	30.2	0.2	**0.136**	0.053	**CS2**
Inside	WS14	14.7	23.9	<0.1	<0.01	<0.01	CS1
Inside	WS15	23.0	24.5	0.1	0.023	0.024	CS1
Inside	WS16	10.0	20.2	<0.1	<0.01	<0.01	CS1
Inside	WS17	44.3	21.6	<0.1	<0.01	<0.01	CS1

Based on the data collected by Ecologia, it is noted that boreholes located within the landfill are indicated to represent CS2 conditions due to hazardous gas flow rates greater than 0.07 l/hr and thus a low hazard potential. The calculated hazardous gas flow rates outside the landfill are consistent with a CS1 category or very low hazard potential.

Based on the maximum gas concentrations identified in WS1 in the west, flow rates would need to reach 10 l/hr to be categorised as CS2. In the north, concentrations observed in WS17 would require flow rates of 0.15 l/hr to be categorised as CS2.

It is noted that the calculated hazardous gas flow rates are lower than those reported by Leap in 2018 due to steady state flow rates consistently reported as circa the instrument limit of detection. This may be due to the continued operation of the gas extraction system, and therefore may not be sufficiently precautionary should the gas extraction system be inoperable.

Flow rates were recorded by TMBC from 2019-2020 of up to 2.7 l/hr (if recorded negative flows are indicative of potential positive flow rate). Leap identified from a review of data from 2009 to 2018 that flow rates of up to 12.9 l/hr were recorded outside the landfill and 8.1 l/hr inside the landfill. Therefore, a worst-case calculation has been undertaken to determine hazardous gas flow rates with more precautionary flow rates. The summary of calculated hazardous gas flow rates is presented in **Table 7**.

Table 7 Summary of 'worst case' Hazardous Gas Flow Rates

Zone	Location	Peak Methane (% v/v)	Peak Carbon Dioxide (% v/v)	Maximum Steady-State Flow Rate (l/hr)*	Methane GSV (l/hr)	Carbon Dioxide GSV (l/hr)	Characteristic Situation
Outside	WS1	0.7	2.7	12.9	0.09	0.34	CS2
Outside	WS2	2.1	4.9	12.9	0.27	0.63	CS2
Outside	WS3	7.1	7.5	12.9	0.92	0.96	CS3
Inside	Various	76.3	39.9	8.1	6.18	3.23	CS4
* Flow rate based on higher rates as measured from historical monitoring data and reported by Leap Environmental Ltd.							

Gas concentrations recorded by Ecologia are consistent with gas concentrations identified by TMBC historically and as reviewed by Leap in 2018. The use of 'worst case' gas flow rates as reported by Leap would indicate a CS4 (moderate to high hazard potential) within the waste area and CS2 outside of the waste area (low hazard potential).

Outside of the waste area, there is observed a reduction in ground gas concentrations with distance from the source. The location furthest from the source (WS1) indicates a Characteristic Situation 2 or 'low' risk of ground gas based on the 'worst case' recorded flow rate.

It is noted that the recorded carbon dioxide concentrations in locations outside the landfill range from 0.7-7.1% v/v in Ecologia dataset and were recorded by TMBC in BH1 up to 8.5 % v/v. The source of elevated carbon dioxide could be due to landfill gas migration or the effect of microbial respiration in soil or groundwater.

Data reported by Leap indicated that when the gas extraction system was switched off gas concentrations within the landfill increased. However, there was little change in gas concentrations recorded outside of the landfill when the pump was on or off. This could indicate evidence of limited connectivity between the landfill and surrounding geology, however, consideration would need to be given to whether this data included periods of low and falling pressure or whether there would be a lag period for gases to build up within the landfill and migrate laterally.

Based on interpretation of the above data, it is considered that risks to off-site school buildings are likely to be mitigated on the basis that school buildings are in excess of 150 m from the site, are located over low

permeability strata (Wadhurst Clay), and this has been confirmed, to a limited extent, by ground investigation during a prior extension of the school facilities.

Potential risk to residential receptors on Deakin Leas, is low to moderate, which is consistent with a CS2 designation based on Ecologia data of WS1 and elevated carbon dioxide in BH1. Ground gas migration is considered likely to be mitigated with distance from the landfill due to the presence of Wadhurst Clay, however, risks may increase should current gas extraction methods cease.

It should be noted that there are specific uncertainties with respect to the reliability of data taken from historical boreholes located adjacent to the residential property and lack of data collected outside of the waste material adjacent to the school site and therefore further works should be undertaken to better clarify these potential contaminant linkages.

5.4 Preferential Gas Pathways

It should be noted that gas migration occurs via the path of least resistance along pressure gradients (advection) and concentration gradients (diffusion) as well as in solution via groundwater flow. Therefore, gas migration could occur laterally through the underlying geological faults and then be emitted elsewhere. Gas could also migrate into properties via cracks in foundations or service ducts.

The geological records for the site indicate that a fault line is present between the underlying Ashdown Beds and Wadhurst Clay trending west to east towards the residential properties and north to south within the Ashdown Beds in the south east of the site towards the Tonbridge By-Pass. Sections presenting the assumed fault locations as inferred by Weeks (provided in **Appendix B**), indicate that the fault underlying off-site residential properties is at depth and is overlain by significant thickness of Wadhurst Clay. It is also noted from records reviewed by Leap, that historical investigations to identify the fault on site were unsuccessful.

It is possible that the fault could act as a conduit for ground gas, however, this s considered unlikely based on the following:

- The landfill is not capped and therefore gases can freely be emitted to surface;
- The borehole pressure records provide further evidence that hazardous gases are not accumulating within the landfill;
- Shallow perched water within the landfill is likely to limit movement of gases at depth;
- The continued operation of the gas extraction system ; and
- The suspected geological fault is indicated by Weeks to be by covered by a significant thickness of Wadhurst Clay at locations equivalent to the distance to residential properties, and therefore this limits the potential for gas emission/migration.

It is understood that the properties adjacent west of the site on Deakin Leas were constructed prior to the landfill and thus would be unlikely to have gas protection measures. Therefore, if present hazardous gases could ingress into properties across the building footprint as well as through service penetrations.

5.5 Risks to site users and workers

Risks to site workers associated with ground gas at the site, for example those undertaking excavations or working within the landfill compound area, would be subject to controls in accordance with the Health and Safety at Work Act (1974). Therefore, risks to workers have not been further assessed.

Risks to the public from outdoor exposure are likely to be limited to short time periods associated with recreational activities. Furthermore, no public buildings or large depressions on site in which gases could accumulate. Due to the likelihood for gas emissions to readily mix with ambient air, the overall exposure to hazardous gases for on-site users is likely to be low.

5.6 Residual Data Gaps and Uncertainty

Based on a review of the data provided by Ecologia and TMBC, there are inherent uncertainties regarding the site conceptualisation and monitoring data, detailed as follows:

- The Priory Wood Landfill continues to generate gas at methane and carbon dioxide ratios typical for degradation of proteins and lipids. The landfill waste is recorded to extend to approximately 10 m below ground level and is not typically located beneath an engineered cap. Monitoring wells installed by Ecologia did not fully permeate the waste stratum and may therefore not represent potential gas sources at depth.
- The gas extraction system is situated in western part of the landfill and continues to operate as monitored and maintained by TBMC. Should the gas extraction system cease or become inoperable, ground gas risks may increase due to a possible increase in gas pressure within the landfill.
- No recent monitoring locations are positioned between the waste deposition area and Tonbridge Grammar School to the north. Previous investigations by Soils Ltd did not identify significant concentrations of ground gas or flow, however the monitoring conducted was of limited duration and spatial extent and may not have identified 'worst case' conditions. The presence of Wadhurst Clay is confirmed in the vicinity of the school and therefore based on the information pertaining to Deakin Leas the risks could be considered low. However, the extent of gas protection measures in existing school buildings are unknown and therefore the potential for gas migration towards this receptor should be subject to specific confirmatory investigation.
- Perched water has been identified on site and is likely to be present in localised areas due to variability in underlying landfill deposits and presence of the Wadhurst Clay. The Tunbridge Wells Sand Formation and underlying Ashdown Formation are designated aquifers and is likely to contain groundwater at depth. The potential for dissolved phases gases to enter groundwater and migrate off-site is considered unlikely to be a significant gas migration pathway, but has not been confirmed through previous investigation.
- Monitoring of ground gas at BH1 indicates that this location is routinely flooded due to ingress of surface water run-off. The level of observed perched water or groundwater within the borehole is not on records received and it is therefore unclear whether the borehole is routinely flooded with groundwater or not. On this basis, the ground gas results from BH1 are not considered in isolation to be reliable for the assessment of ground gas risk to the adjacent residential property.

6 UPDATED CONCEPTUAL SITE MODEL

Based on the ground gas risk assessment, the preliminary risk assessment can be updated as summarised in **Table 8**.

Table 8 Preliminary Risk Assessment Summary

Potential source	Potential receptor	Possible pathway	Likelihood	Severity	Potential risk
Landfill Ground Gas (Methane, Carbon Dioxide)	Human health (site users – workers and public)	Inhalation of outdoor gases/vapours	Very Unlikely	Severe	Low
	Human Health – adjacent residential users	Ingress of ground gas into buildings causing asphyxiation	Unlikely	Severe	**Moderate / Low**
		Accumulation ground gas into buildings causing explosion	Very Unlikely	Severe	Low
	Human health – school users	Ingress of ground gas into buildings causing asphyxiation	Unlikely	Severe	**Moderate / Low**
		Accumulation ground gas into buildings causing explosion	Unlikely	Severe	**Moderate / Low**

Moderate to low risks have been identified for residential users associated with elevated carbon dioxide concentrations (up to 8.5% v/v) that may be associated with migration of landfill gas or from other natural sources. It is considered that further investigation of groundwater levels near to the property and monitoring from an associated source may provide evidence that this linkage could be reduced to low.

Moderate to low risks are also identified to school users on the basis that monitoring undertaken to date as part of planning proposals was of limited duration. The likelihood of low risks may be confirmed through the monitoring of ground gas at the northern site boundary in locations outside of the waste deposition area.

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7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Based on the review of previous historical investigations, risk assessments and recent ground gas monitoring by Ecologia and TMBC, RSK conclude the following:

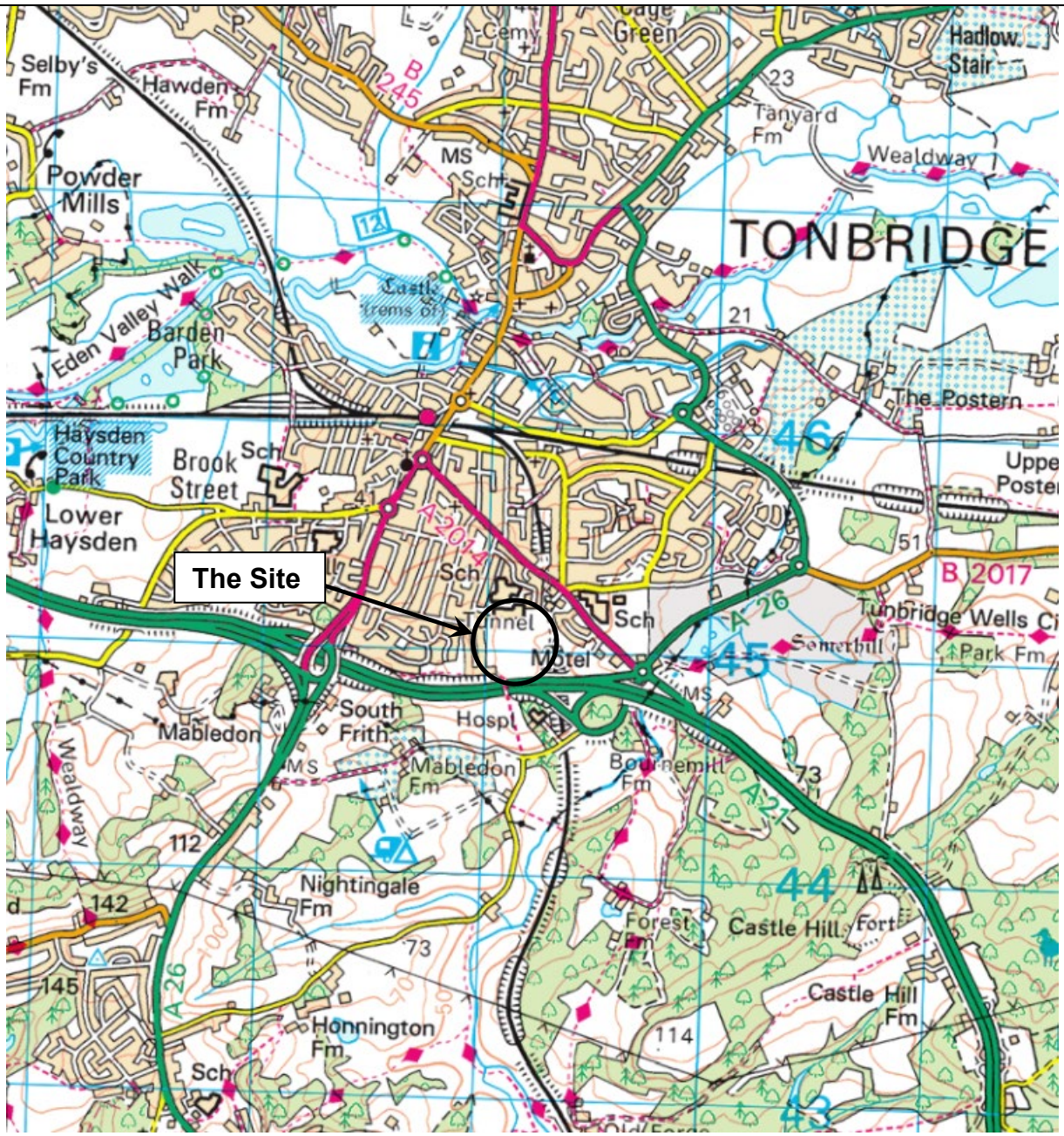
- The monitoring of hazardous ground gas within the landfill confirms that the waste deposition area is still generating high concentrations of methane and carbon dioxide gas, consistent with the age and recorded types of waste buried. The recorded flow rates and differential pressure in monitoring wells by Ecologia was low and indicated that gases were adequately ventilated by the active gas extraction system and/or naturally via vertical emission from soils.
- Risks to on-site receptors comprising workers are low on the basis that relevant mitigation can be provided through appropriate workplace exposure controls in accordance with the Health and Safety at Work Act. Risks to on-site receptors, considered to comprise recreational users of the site as a public open space are also considered low on the basis that exposure would be of low duration and gas emissions are low and readily diluted in the atmosphere.
- Risks to off-site receptors comprising residential properties at Deakin Leas are **moderate to low** based on elevated carbon dioxide concentrations identified in boreholes near to the property. It is considered that there remains uncertainty as to whether this data reflects gas migration from the landfill or natural sources.
- Risks to off-site school receptors are **moderate to low** on the basis that gas concentrations in the landfill are measured up to 44% methane within nearby waste material and that gas monitoring has not been undertaken between the waste material and the school boundary. Risks to existing school buildings are considered likely to be low based on limited monitoring completed during planning, however, the potential for gas migration into the school land has not been directly assessed.
- There is significant uncertainty with respect to whether monitoring included a period of 'worst case' pressure fall, the potential for continuous water body in shallow soils at the site and if this extends to residential properties, whether gas migration occurs between the waste area and the school boundary, and whether the known faults in underlying bedrock could act as a preferential pathway for ground gases, should the gas extraction system cease operation.

7.2 Recommendations

In order to further refine the risk assessment presented herein, RSK recommend the following:

- Confirmatory investigation to be undertaken to include monitoring wells between the waste area and school land, hydraulic permeability testing of natural strata, and measurement of surface emissions across the landfill area;
- Replacement of the monitoring well at BH1 and routine monitoring of water levels to confirm the potential for gas migration at this location and the source of elevated carbon dioxide; and
- High frequency monitoring in locations within and outside of the waste material to confirm the potential for gas accumulation and migration with changes in atmospheric conditions. If this is not conclusive, sampling of gases within the landfill and near to residential properties could include carbon isotope analysis to confirm the potential source of elevated carbon dioxide concentrations.

FIGURES



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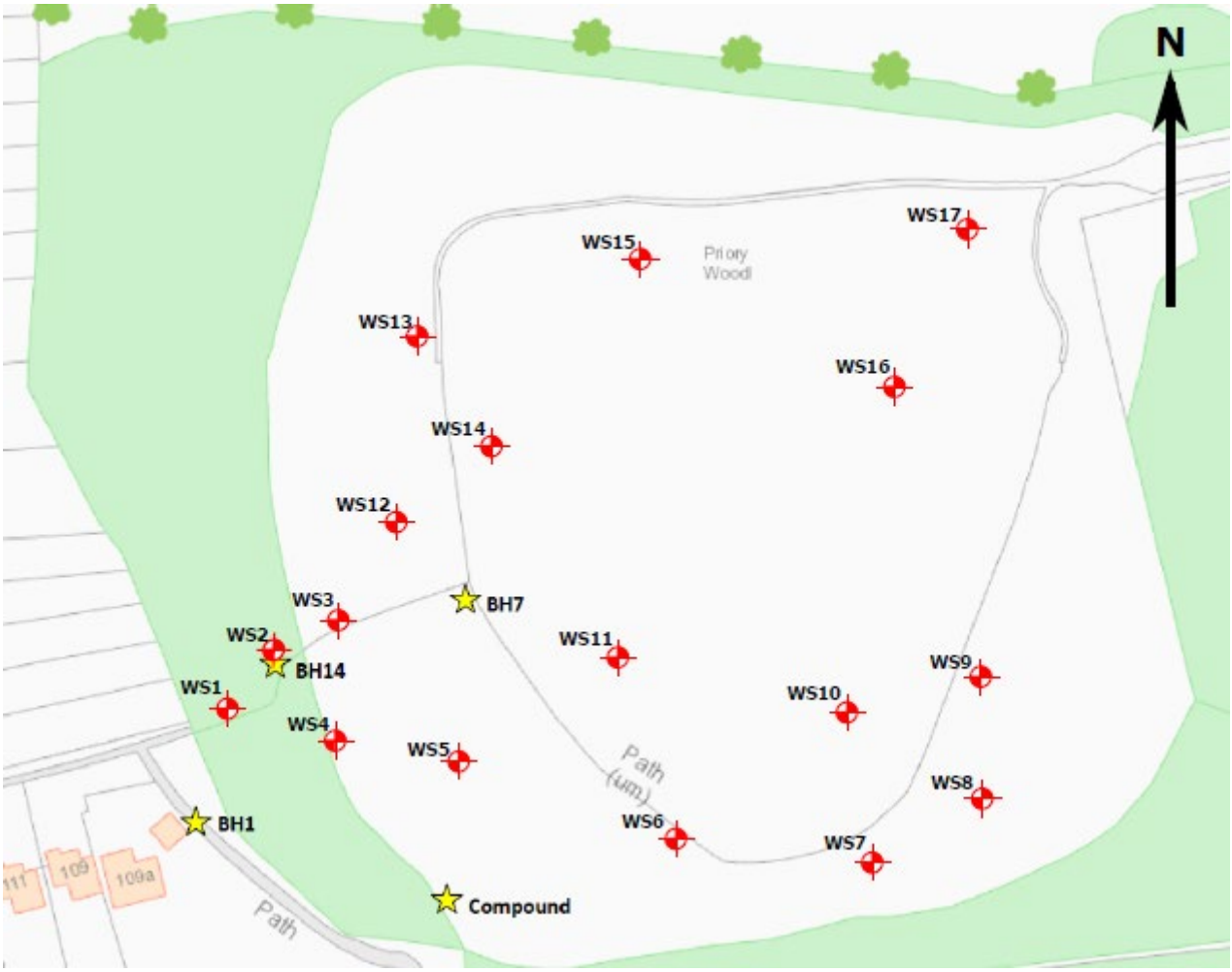
RSK	**SITE LOCATION PLAN**	**Client: Ecologia Environmental Solutions Ltd**	**Figure No: 1**
		Site: Priory Wood Landfill	**Job No: 1921480**
		Scale: NTS	**Source: OS**



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RSK	**SITE LAYOUT PLAN**	**Client: Ecologia Environmental Solutions Ltd**	**Figure No: 2**
		Site: Priory Wood Landfill	**Job No: 1921480**
		Scale: NTS	**Source: OS**