Kildare County Council

Remediation of Legacy Landfill Site at Digby Bridge, Sallins, Co. Kildare
Stage 1: Environmental Risk Assessment and Remediation Plan

Attachment D1- Tier 3: Refinement of CSM and Quantitative Risk Assessment

Volume 1: Landfill Gas

July 2020

CDM Smith

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Abbreviations

BH	Borehole
CSM	Conceptual Site Model
DOC	Degradable Organic Carbon
EPA	Environmental Protection Agency
FID	Flame Ionisation Detector
FOD	First Order Decay
IPCC	Intergovernmental Panel on Climate Change
LFG	Landfill Gas
m bgl	Metres below ground level
m OD	Metres above Ordnance Datum
MW	Monitoring well
SPR	Source Pathway Receptor
SVOC	Semi-Volatile Organic Compound
VOC	Volatile Organic Compound

Section 1 Introduction

1.1 Project Background

Digby Bridge legacy landfill site is located south east of Digby Bridge which crosses the Grand Canal, in the townland of Barrettstown, less than three kilometres from Sallins.

Landfilling first started at Digby Bridge in 20/06/1980 and finished approximately on 31/12/1982. A Tier 1 Risk Assessment of the site was completed in 2008 by Kildare County Council, in line with the Environmental Protection Agency (EPA) Code of Practice: Environmental Risk Assessment for Unregulated Waste Disposal Sites 2007 (CoP). A preliminary Conceptual Site Model (CSM) of the site was developed and the Source-Pathway-Receptor (SPR) linkages were evaluated. The Tier 1 categorized the site as being of 'High Risk (Class A)' due to the number of high risk SPR linkages. The site was entered on Kildare County Council's Waste Management Act Section 22 Register, a list of unregulated waste disposal sites.

Kildare County Council appointed CDM Smith Ireland Ltd (CDM Smith) in 2017 to prepare a Stage 1 Environmental Risk Assessment and Remediation Plan in accordance with the Environmental Protection Agency (EPA) Code of Practice and comprising of Tier 2 Site Investigation and Tier 3 Refinement of CSM and Quantitative Risk Assessment which was then used to inform the Remediation Plan. This will provide the basis for the Council's application for a Certificate of Authorisation to the EPA as required under S.I. No. 524 of 2008 Waste Management (Certification of Historic Unlicensed Waste Disposal and Recovery Activity), Regulations, 2008. It will also be required to inform Stage 2 of the Project: Remediation Works.

In accordance with the objectives of the project, as set out in the Project Brief, three reports will be prepared as part of the project deliverables.

- Tier 2: Site Investigations and Testing (Doc. Ref. 117838/40/DG/11);
- Tier 3: Refinement of Conceptual Site Model and Quantitative Risk Assessment
  - Volume 1 addressing Landfill Gas (this report); and
  - Volume 2 addressing Groundwater (Doc. Ref. 117838/40/DG/13).
- Remediation Plan (Doc. Ref. 117838/40/DG/14).

An additional report (Doc. Ref. 117838/40/DG/10) has been prepared which reviews background information relevant to the project, including the Tier 1 Risk Assessment of the site completed in 2008 by Kildare County Council. An Appropriate Assessment Screening Report (Doc. Ref. 117838/40/DG/16) was also prepared.

1.2 Summary of Tier 2 Investigation

The Tier 2 Report (Doc. Ref. 117838/40/DG/11) presents the results of the gas investigations in detail. To summarise, landfill gas monitoring was undertaken on 4 March and 25 June 2019, using gas analysers and a flame ionisation detector (FID). Monitoring was necessary to gain an understanding of static concentrations of LFG from installed wells and to investigate if emissions were emanating from the landfill surface. An offsite gas property survey was undertaken on 15 and 17 October 2018 at nearby properties and houses to establish if LFG was migrating offsite through the subsurface.

The gas monitoring conducted during the Tier 2 investigation identified high concentrations of landfill gas in the waste mass and concentrations of landfill gas above EPA 2003 trigger values in monitoring wells both inside and outside the waste body. There are also several houses and buildings adjacent to and within 250 metres of the site but the offsite gas property survey did not detect any landfill gas concentrations above EPA 2003 trigger values.

The Tier 2 investigation concluded that to complete the Tier 3 Refinement of CSM and Quantitative Risk Assessment, the true nature of the landfill gas within the waste body needed to be understood further. An additional investigation was therefore recommended using time-limited withdrawal of landfill gas while measuring temperature, flow and the concentration of CH_4, CO_2, CO and O_2 at different horizons in monitoring wells.

1.3 Format of this Report

This report presents the Tier 3 Assessment for Landfill Gas (LFG).

The contents and format of this report follow the reporting requirements set out in Section 5.6 of the EPA Code of Practice and the requirements of the Project Brief.

Requirements of Project Outcomes	Section of this Report
Determine bulk landfill gas composition	Section 4.3
Determine organic carbon discharge via the gas path	Section 4.3
Verification of first aerobic degradation in areas of the landfill	Section 4.3
Verification of landfill gas production and gas potential	Section 3.2
Determination of possible leaks in vertical gas wells	Section 4.3. 4.4
Assess potential risk from landfill gas impacting offsite receptors	Section 5.1, 5.3
Assess potential risk from landfill gas impacting onsite receptors	Section 5.2

Section 2 of this report presents an overview of LFG technical issues, including typical composition, LFG mitigation mechanisms (with more detailed descriptions contained in **Appendix A**) and legislative requirements for LFG in Ireland. Section 3 discusses the available data and the modelling techniques for determining Gas Potential (with more detail on the theory in **Appendix B**). Section 4 discusses the Gas Extraction Tests undertaken as an additional investigation to the Tier 2 investigation. Section 5 concludes with the LFG Risk Assessment and provides an updated Conceptual Site Model (CSM).

1.4 Limitations

Literature values have been used for the biodegradation rates for modelling the gas potential of the waste mass but actual degradation at the site may not reflect these values and values predicted for future gas production rates are estimates.

Section 2 Overview of Landfill Gas

2.1 Introduction

The factors controlling LFG migration are complex and dynamic, but the key factor is a rapid drop in atmospheric air pressure. This was responsible for the LFG explosions which resulted in fatalities and destroyed domestic properties at Loscoe, Derbyshire, England in 1986 and Skellingsted, Denmark in 1991. The absence of an explosion years or after decades following the closure of a landfill does not mean that a risk is not present. Risk is a function of probability and consequences, where by a rapid LFG migration event could be a low probability event but with catastrophic consequences. Any identified potential risk related to LFG warrants further investigation and understanding. The key factors in LFG gas migration will be explained in this section and in the context of potential LFG gas risk assessment for Digby Bridge.

2.2 Typical Composition

The typical composition of air in soil and atmosphere are broadly similar and are shown on Table 1. Landfill wastes, mining activities, and contamination by petroleum hydrocarbons can alter the composition of gasses in the pore spaces in soils. The elevated levels of carbon dioxide and methane in the subsurface at Digby Bridge are related to the landfill.

Table 1: Composition of Atmospheric Gases in Soil Pores and the Atmosphere

Gas	Soil Pores	Atmosphere
Nitrogen	79.2%	79.0%
Oxygen	20.6%	20.9%
Carbon Dioxide	0.25%	0.04%
Methane	0.00	0.00

Mature LFG is a mixture composed of predominantly methane and carbon dioxide, with small amounts of hydrogen. Nitrogen and oxygen derived from ambient can be drawn into the landfill, therefore varying amounts may exist. The sum of these gases is generally known as bulk gas, a summary of some typical concentrations can be seen in Table 2. Methane and carbon dioxide are the bulk gases of most concern when considering health and dangerous impacts from LFG. Some limit values for these and other associated landfill gases are shown in Table 3.

Table 2: Typical Values of Bulk Gases (Source: Environment Agency (2004) Guidance on the management of landfill gas)

Bulk LFG	Typical value (% v/v)	Observed maximum (% v/v)
Methane	63.8	88.0
Carbon Dioxide	33.6	89.3
Oxygen	0.16	20.9*
Nitrogen	2.4	87.0*
Hydrogen	0.05	21.1
Water vapour (typical % w/w, 25°C)	1.8	4.0

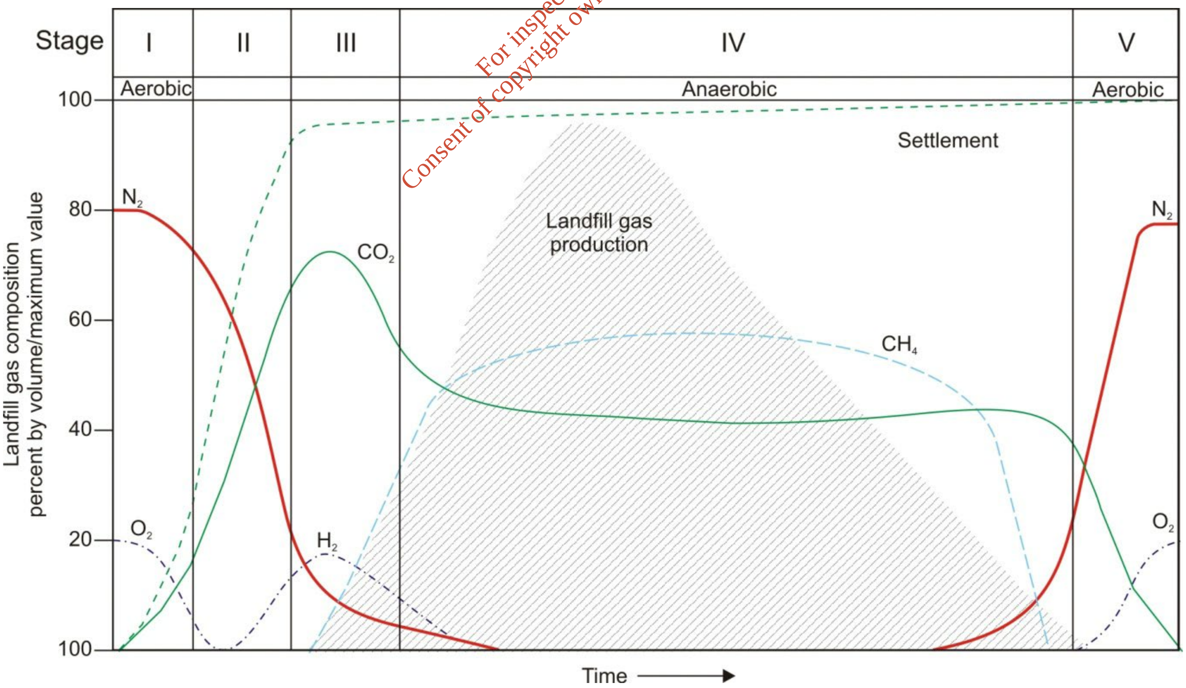
** Derived entirely from the atmosphere*

Table 3: LFG Exposure Limits and Thresholds

LFG	Occupational Exposure Limit Value (8-hour reference period) (% v/v)	Occupational Exposure Limit Value (15-minute reference period) (% v/v)	Source
Carbon dioxide	0.5	1.5	HSA
Carbon monoxide	0.002	0.01	HSA
Hydrogen sulphide	0.0005	0.001	HSA
LFG	**NIOSH 8-hours Threshold Limit Value (% v/v)**	**Potentially Explosive (LEL & UEL) (% v/v)**	**Asphyxiation**
Methane	0.1	5 to 15	50

LFG composition varies throughout the life of a landfill. Several stages are involved in waste decomposition process, during these stages different groups of bacteria break down complex organic substances. The changes in production and composition of LFG over time are shown in Figure 1. Bacteria consume any oxygen contained at the start of the degradation process and release mainly carbon dioxide, water and heat. After anaerobic conditions have been established in the waste body, methane production will start, this is typically 3 to 6 months after waste deposition. During peak LFG production the bulk gas typically consists of 50 to 60% v/v methane and 40 to 50% v/v carbon dioxide. Gas composition in the waste returns to atmospheric conditions as shown in Table 1, once all biodegradable substrate has been consumed and LFG production slows.

Figure 1: Changes in the Production and Composition of Landfill Gas Over Time



Source: EPA Management of Low Levels of Landfill Gas (2011)

The trace component composition of LFG has a large variability. It can constitute approximately 1% v/v and can historically contain 120 to 150 trace components. The range of trace compounds present is largely determined by the types of waste deposited. The degradation of this waste by aerobic or anaerobic processes will also affect the composition of landfill LFG trace components. A ranking system utilising toxicity and studied concentrations can be useful in identifying the most important trace components to consider as shown in Table 4. The individual chemical scores are a product of the toxicological importance and a factor derived from the average or median compound concentrations of LFG.

Table 4: Highest Ranking Trace Components in LFG Assessed on Toxicity and Concentration

	Chemical Name	Toxicological Importance	Average or median Concentration (μgm^{-3})	Toxicity Significance Score	Percentage of total score
1	1,1-dichloroethane	10	477435	4774352	28
2	Chloroethane	50	76821	3841050	22
3	Chloroethene	50	66324	3316235	19
4	hydrogen sulphide	8	134233	1073867	6
5	Chlorobenzene	3	245520	736561	4
6	Tetrachloroethene	5	113193	565968	3
7	1,1,1-trichloroethane	2	190856	381712	2
8	Chlorodifluoromethane	2	166169	332339	2
9	Benzene	50	4862	243125	1
10	Toluene	2	75698	151398	0.9
11	Trichloroethene	10	15040	150402	0.9
12	n-butane	2	70283	140568	0.8
13	1,2-dichloroethene	8	16495	131963	0.8
14	1,2-dichloroethane	5	19516	97583	0.6
15	Dichloromethane	5	19329	96645	0.6
16	n-hexane	4	20947	83791	0.5
17	cis-1,2-dichloroethene	2	33055	66111	0.4
18	carbon monoxide	1	62952	62952	0.4
19	Acetone	2	29203	58406	0.3
20	Tetrachloromethane	10	5262	52628	0.3
21	Dichlorodifluoromethane	4	12668	50674	0.3
22	trans-1,2-dichloroethene	4	10147	40590	0.2
23	Dichlorofluoromethane	2	19900	39802	0.2
24	Ethylbenzene	1	39165	39165	0.2
25	1,2-dichlorotetrafluoroethane	1	34382	34382	0.2

Source: Environment Agency (2002) Investigation of the Composition and Emissions of Trace Components in Landfill Gas

The EPA (2003) Landfill Monitoring Manual establishes trigger levels for which methane and carbon dioxide are not to exceed. This guidance recommends that monitoring can be discontinued when the following criteria are met:

- The maximum concentration of methane is less than 1% by volume (21% LEL) at all monitoring points over a 24-month period;
- The maximum concentration of carbon dioxide is less than 1.5% at all monitoring points over a 24-month period; and
- Measurements must be carried out on at least four separate occasions, including two occasions when atmospheric pressure was falling and was below 1,000 mbar.

The trigger levels for emissions of methane and carbon dioxide are 1% v/v and 1.5% v/v respectively in boreholes outside the waste body. The trigger levels also apply to measurements in any service duct or manhole on, at or immediately adjacent to the landfill.

2.3 LFG Migration

LFG can leave the waste mass laterally or vertically by the mechanisms of advection and diffusion. LFG migration through the subsurface is controlled by landfill engineering and management, soil physical properties gas permeability and gas diffusivity, microbial activity, water content of the soil and atmospheric pressure variations. Microbial activity is controlled by temperature, nutrient availability, and oxygen concentration.

Under the right circumstances, LFG can travel hundreds of meters through the subsurface from the landfill. The mechanisms and factors responsible for gas migration are discussed in more detail in **Appendix A**, and includes discussion of the following mechanisms:

- Mechanisms of Gas Migration;
- Horizontal / Lateral Migration;
- Atmospheric Pressure Changes;
- Landfill Construction and Management;
- Site Geology / Native Geology;
- Groundwater Table or Leachate Level Movement;
- Dissolved in groundwater;
- Microbial Transformations of Carbon Dioxide and Methane;
- Wind Induced Dispersion; and
- Modelling Lateral LFG Movement and Risk Assessment.

Some of the factors are dynamic / seasonal and the worst case is for a few factors to occur concurrently for lateral LFG migration to offsite receptors to take place.

2.4 Legislative Requirements for LFG Management

Section 4, Annex 1 of the 1999 EU Landfill Directive outlines the gas control requirements for all classes. The Landfill Directive was transposed into Irish law by the Waste Management Licensing Regulations 2000 and the Waste Management Act 1996 – 2011. These requirements include:

- Appropriate measures must be taken to control the accumulation and migration of landfill gas;
- Landfill gas must be collected from all landfills receiving biodegradable waste and the landfill gas must be treated and, to the extent possible, used; and
- Collection, treatment and use of landfill gas under sub-paragraph (2) must be carried on in a manner, which minimises damage to or deterioration of the environment and risk to human health; and

Landfill gas which cannot be used to produce energy must be flared.

Section 3 Determination of Gas Potential

3.1 Evaluation of Records and Findings

3.1.1 Total Storage Volume

Kildare County Council was able to provide some initial information regarding the landfilling activities at the site. Landfilling started at the site on 20/06/1980, and it is estimated that operation continued until 31/12/1982 at the latest. The site was used for the disposal of mainly municipal waste but also commercial waste.

Findings from the geophysical survey indicate that the main waste body lies across central, southern and western parts of the site. Using the geophysical waste body footprint of 4.7 Ha, the volume of waste is estimated as 366,600 m^3. Using a typical density of 1.4 tonnes/m^3 for municipal waste the tonnage is estimated at 513,240 tonnes.

3.1.2 Quantity of Waste Type

Few records exist on the type of waste deposited in the landfill. Although some records of domestic, commercial and industrial waste disposal are retained by Kildare County Council there is nothing quantifiable. Therefore, the quantities used for modelling gas potential will be based on the observations made during intrusive investigation – trial pitting and drilling. Table 5 below shows the relative tonnages related to each waste type based on these observations.

Table 5: Waste Type Tonnages

Material Type	Weighting %	Waste Type	Tonnage
Plastic	24.5	Municipal*	125,631
Organic	20.0	Municipal	102,410
Timber	13.7	Commercial and Industrial	70,258
Ash	12.1	Municipal*	61,922
Metal	6.8	Commercial and Industrial	35,129
Glass	4.6	Commercial and Industrial	23,816
Wire	4.2	Commercial and Industrial	21,435
Paper	4.1	Municipal*	20,839
Rope	2.6	Commercial and Industrial	13,099
Cable rollers	1.9	Commercial and Industrial	9,526
Concrete	1.2	Commercial and Industrial	5,954
Insulation	0.9	Commercial and Industrial	4,763
Fabric	0.8	Commercial and Industrial	4,168
Tyres	0.8	Commercial and Industrial	4,168
Video film	0.8	Municipal	4,168
Cotton	0.7	Municipal	3,572
Brick	0.5	Commercial and Industrial	2,382

* *could be Commercial and Industrial but more likely Municipal*

3.2 Gas Generation Models

3.2.1 Classical Method – Model A

Using the data evaluated in Section 3.1 and considering the lack of gas collection infrastructure, a simplified landfill gas forecast has been presented in this section. In principal, the results of the gas forecast calculations are subject to uncertainties, since the parameters included in the models are sometimes not quantifiable to a high degree of certainty. The studies which form a basis for long term LFG potential are described in **Appendix B.1**.

In a conservative approach, the calculations were based only on the organic content of the backfill volume (household waste, household-type commercial and industrial waste and garden waste) and the expected gas volume was calculated based on half-lives of 7 ½, 10 and 12 ½ years, from IPCC Guidelines.

The following assumptions were made to estimate the area in which gas production at the Digby Bridge legacy landfill will occur:

- The quantities of the waste deposited between 1980 and 1982 are taken as a basis. This results in a total volume of 366,600 m^3 or 513,240 Mg including inert materials;
- All organic carbon is converted into methane and carbon dioxide products;
- Methane production is a first order reaction, i.e. there is a direct dependence on the initial substrate concentration;
- A relatively constant temperature is assumed in the waste body;
- The inert portions of the waste contribute only insignificantly to the emission potential via the gas path, fractions such as building rubble and excavated soil and screened aggregates are not considered when estimating the quantities of deposited waste relevant to emissions;
- The biologically convertible carbon content is based on an average total gas potential of G_0 = 170 m^3/Mg dry matter;
- Half-lives of gas production are assumed to be 7 ½, 10 and 12 ½ years;
- The delayed start of relevant anaerobic degradation processes after the start of landfilling is not considered, i.e. the landfill enters the anaerobic phase from the beginning;
- No significant restriction or inhibition of biodegradation processes due to water shortage, water impoundment, biological inhibitors and too high or too low temperatures in the landfill body; and
- Due to the limited data the period between 1980 and 1982 is used for the calculation.

Furthermore, it should be noted that, due to the age of the landfill, higher half-lives of more than 12 ½ years should be expected, since, due to the age of the landfill, a long-term weak gas production by moderately and poorly degradable organic matter occurs.

Based on the emplacement quantities, the gas forecast presented in Table 6. was prepared according to the known calculation models (Krümpelbeck, 2000).

The range in which landfill gas production can change according to different half-lives is shown in Figure 2. According to this, with a half-life of 7.5 years, approximately 18 m³/h of landfill gas would still have to be produced in 2020 (based on a methane content of 50% by volume). If the points described above and the increase in half-life periods with age of landfill are considered, a half-life period of 12.5 years results in landfill gas production of 45 m³/h. It is assumed that the landfill gas produced is completely captured (gas collection rate of 100%). Other relevant forecast values are presented in Table 6.

These assumptions are theoretical and are based on the evaluation of the available information and measurement results. The downward curve of LFG gas production is evident in Figure 2.

Table 6: Gas Forecast

Year	Landfill Gas Nm³ produced per hour
2020	45
2021	43
2025	34
2030	26
2035	20

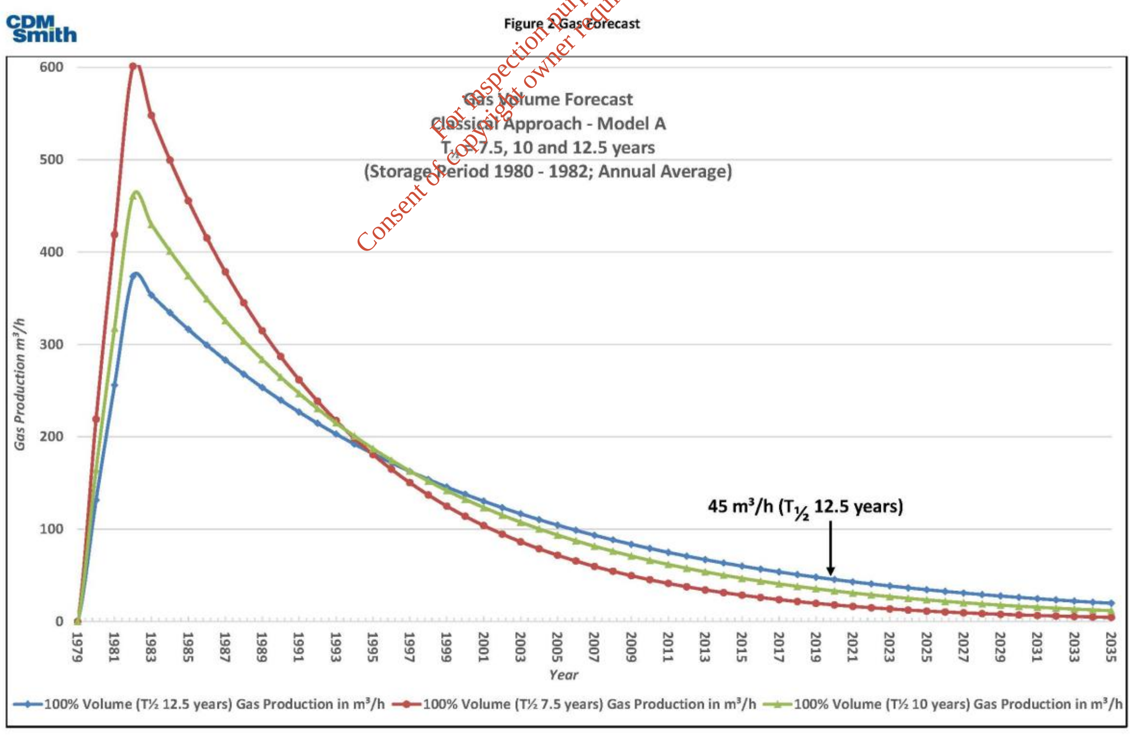


Figure 2: Gas Forecast

3.2.2 First Order Decay Method - IPCC Guidelines of 2006

Due to the end of landfilling of organic municipal waste, it is no longer possible to determine emissions by the default method (German Environment Agency approach, 2002). For this reason, the more complex first-order method is required, which describes the time course of methane emissions as a first-order reaction.

The IPCC Guidelines (2006) offer two methods for estimating CH4 emissions from the disposal of solid waste (i.e. landfills). The IPCC standard method is a simple mass balance calculation that estimates the amount of CH_4 emitted from the landfill, assuming that all the methane formed is formed or released in the same year that the waste is landfilled.

The IPCC Guideline First Order Decay (FOD) method uses the time factors of the decomposition process and considers the annual emission estimates that reflect this process.

The annual emission estimates of the two methods are therefore not comparable. The FOD method leads to better estimates of annual emissions, whereas the IPCC standard method has advantages in general studies. The basic equation for the First Order Model is explained in **Appendix B.2**.

The IPCC's First Order Decay Method contains various factors that can strongly influence landfill gas forecasting. According to the FOD method, these factors can be adapted to the landfill conditions, so that a more realistic landfill gas forecast can be made. According to experience, the k-value (reaction rate constant - production rate as constant for methane over one year) of municipal waste changes up to 0.13 and the degradable organic carbon (DOC) value of municipal waste is reduced to 0.2 (as averaged parameter over the deposited contents).

For the year 2020, this would mean that theoretically a methane gas volume of 47 Nm^3 (normal m^3 CH_4 generated$_{(T)}$) would be produced per hour, shown in Figure 3. Other relevant formation rates are presented in Table 7. The downward curve of methane generation is clear in this representation. Various measures, including optimization of a gas collection system and use of plant technology for gas treatment and utilisation, could make active gas collection viable.

Table 7: Predicted Methane Formation Rates

Year	Methane Gas Nm^3 produced per hour
2020	47
2021	44
2025	36
2030	27
2035	21

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Figure 3 Methane Formation

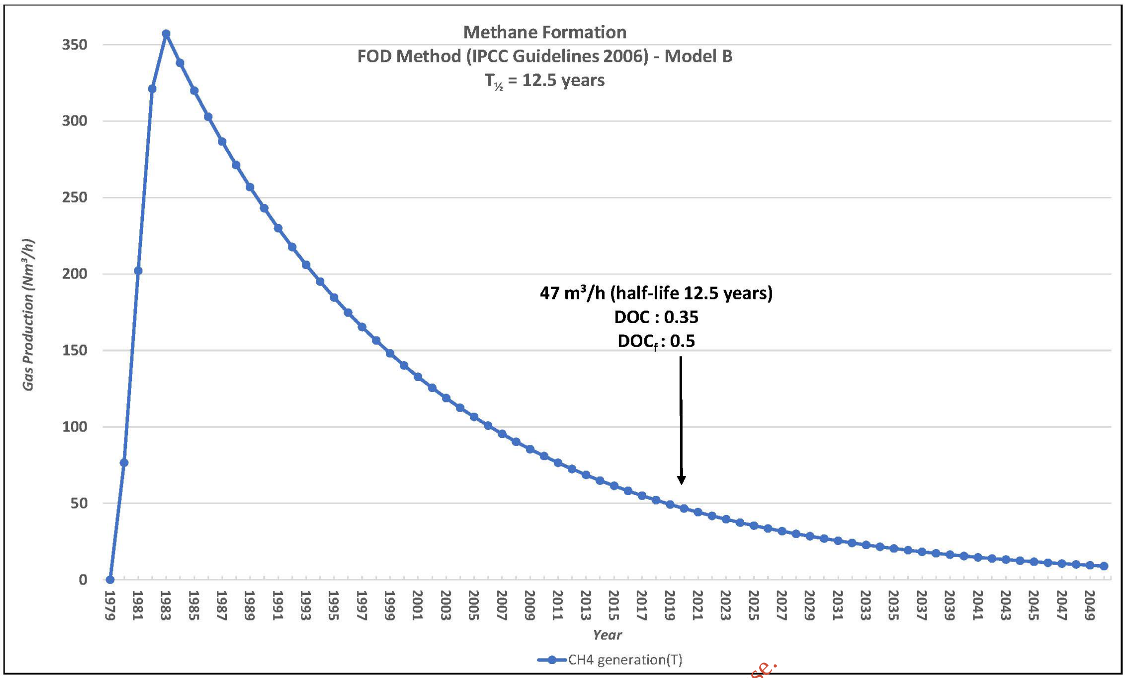

Figure 3: Methane Formation

Section 4 Gas Extraction Tests

4.1 Introduction

The Tier 2 investigation concluded that to complete the Tier 3 Refinement of CSM and Quantitative Risk Assessment, the true nature of the landfill gas within the waste body needed to be understood further. An additional investigation was therefore recommended using time-limited withdrawal of landfill gas while measuring temperature, flow and the concentration of CH4, CO2, CO and O2 at different horizons in monitoring wells.

This additional investigation was required to characterise landfill gas and gas production. The investigation was based on a limited withdrawal of LFG while measuring temperature, flow and the concentration of Methane (CH_4), Carbon Dioxide(CO_2), Carbon Monoxide (CO) Hydrogen Sulphide (H_2S) and Oxygen (O_2). This was accomplished to:

- Determine gas composition;
- Determine organic carbon discharge via the gas path;
- Verify first aerobic degradation in areas of the landfill;
- Verify gas production and gas potential; and
- Determine presence of possible leaks in vertical gas wells.

The data acquired was then used to:

- Assess the risk related to vertical or horizontal migration of LFG;
- Update the Conceptual Site Model CSM for LFG; and
- Provide recommendations to manage any potential risk related to LFG migrations, if there is a risk identified.

The potential for additional gas production, was modelled using the IPPC Worksheet and in line with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Vol. 5, Chapter 3). The outputs from this scope include:

- Model LFG generation:
  - Forecasting LFG production; and
  - Theoretical methane formation;

4.2 Methodology

The additional investigation was undertaken between 15 and 24 January 2020. It involved using a mobile extraction unit at selected monitoring well locations. The mobile LFG extraction unit is a system designed for the extraction of LFG. The unit facilitates the measurement of the extraction rates and the analysis of LFG gas concentrations. The gas was tested using a Gas Analyser 2000. Gas concentrations were analysed and recorded along with depth to leachate before the extraction system was activated.

The operational control and management was carried out by a trained CDM Smith employee. A suction adapter was mounted on the headworks of the monitoring well, which was gas tight and equipped with a flexible line to connect to the gas extraction unit.

The gas extraction system generated a vacuum, which drew LFG from the landfill via the gas monitoring wells, into the extraction system. The flow rate was controlled via an adjustable power control panel on the extraction unit. The following parameters such as gas concentrations and volume flow rate were continuously monitored, which are listed below.

- Gas concentration – Methane, Carbon dioxide, Oxygen, Hydrogen Sulphide and Carbon Monoxide.
- Gas balance;
- Flow rate,
- Relative negative pressure; and
- Gas temperature.

Gas concentrations were recorded were generally recorded every ten minutes, depending on changes in concentrations. The field sheets with the records for flows and gas concentrations over a test are presented in **Appendix C**.

Two gas, two groundwater and five leachate monitoring wells were used for this investigation, which are shown on Figure 4. The properties adjacent to the site are also shown on the Figure 4 and have been assigned numbers for ease of reference.

Monitoring wells outside of the waste body with the aim of assessing the pathway between the waste body and the receptors (nearby properties). A summary of the objective for each well for investigation is shown on Table 8. Borehole logs and installation details are contained in the Tier 2 Report.

Table 8: Monitoring Wells Selected for Tests

Monitoring Well ID	Response zone	Primary Objective
MW08A	Sands and Gravels	Risk
MW05	Sands and Gravels	Risk
MW03	Sands and Gravels	Risk
MW07A	Sands and Gravels	Risk
MW13	Waste	Gas Potential
MW12	Waste	Gas Potential
MW09	Waste	Gas Potential
MW14	Waste	Gas Potential

0 50 100 m

N S W E

Legend

- Site Boundary
- Waste Body
- Boreholes
- Internal Gas Measurements

Source:
- *ESRI World Imagery. © ESRI (Vivid-UK imagery courtesy of Digital Globe, acquired on 13/08/2015)*

Coordinates are in Irish Transverse Mercator

Client:	Kildare County Council
Consultant:	CDM Smith
Project Code:	117838
Project:	DIGBY BRIDGE
Drawing Title:	FIGURE 4: MONITORING LOCATIONS AND ADJACENT PRPERTIES
Drawn By: SM	Date: 08/05/2020

4.3 Gas Extraction Test Results and Discussion

4.3.1 MW03

MW03 is a monitoring well installed with a response zone in the Gravel Formation and Landfill Cover (Made Ground/Fill over waste material), is located close to the outer boundary of the site, with the waste body approximately 10m away. The nearest building to MW03 is Property 4, located approximately 25m away, as shown on Figure 4. During the gas extraction test carried out on 23/01/2020, the mobile LFG extraction unit extracted 41 m^3 of gas over four hours from MW03. Over the test period atmospheric pressure reduced from 1028 to 1024 hPa. An average negative pressure of -1.1 hPa was maintained in the monitoring well during the test. The temperature of the abstracted gas ranged from 10.4 to 16.2 °C and averaged 14.9°C.

A graphical presentation of the concentrations (CH_4, CO_2, O_2) and flow rate during the extraction test on MW03 is plotted on the chart presented on Figure 5. Carbon dioxide concentrations increased from 7.9 to 23.1% v/v. Methane concentrations rose throughout the test and remained below 1% volume until the last reading of 1.3% volume. Over the test, the oxygen concentration dropped from 15.1% to 0.1% volume. The data shows predominant aerobic degradation processes taking place at this boundary of the waste body.

The changes in gas concentrations during the extraction of gas test has shown that there is a pathway for LFG between the monitoring well and the landfill.

Using the Darcy Equation and the data from the extraction test on MW03, a permeability for the Gravel Formation was derived, 1.43E-06 m^2, which is in the range of permeabilities presented in Bear (1972).

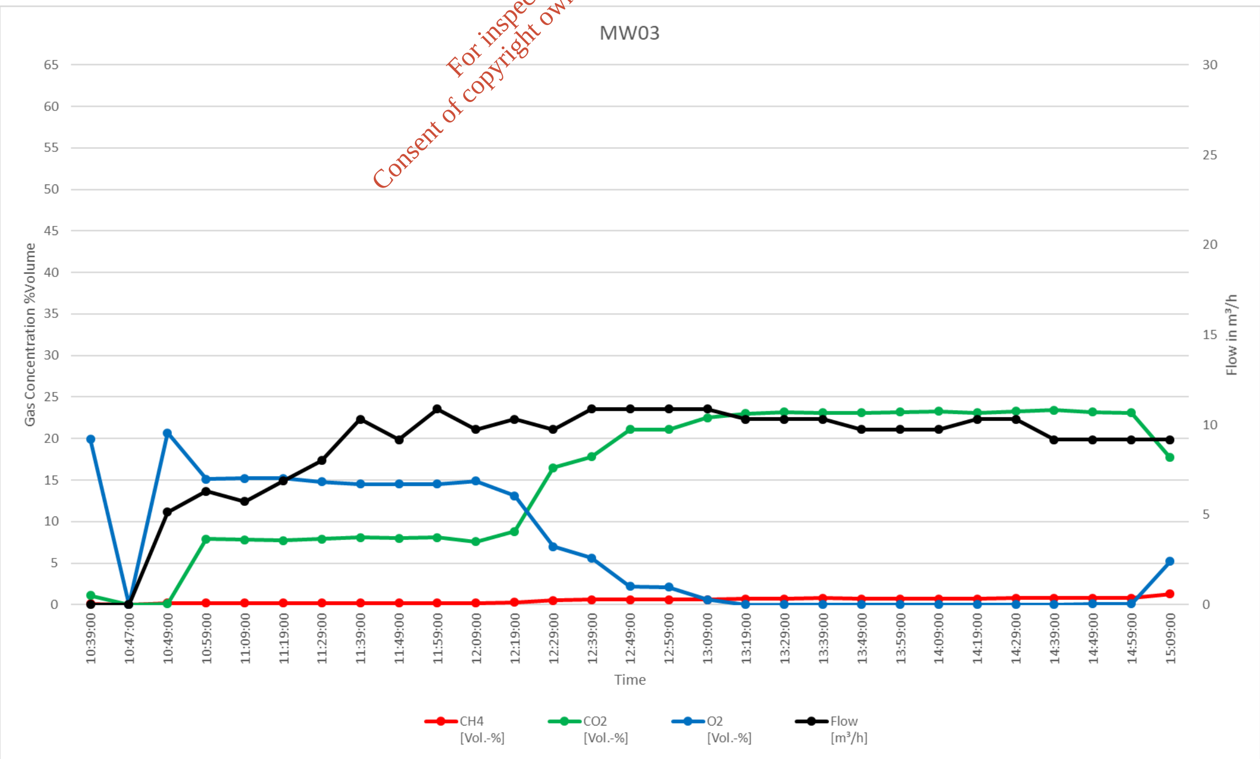

Figure 5: MW03 Extraction Test Results

4.3.2 MW05

MW05 is a monitoring well installed with a response zone in the Gravel Formation, is located close to the outer boundary of the site, with the waste body approximately 15m away. The nearest building to MW05 is Property 3, located approximately 10m away, as shown on Figure 4. During the gas extraction test carried out on 17/01/2020, the mobile LFG extraction unit extracted 48 m^3 of gas over six hours from MW05. Over the test period atmospheric pressure increased from 1005 to 1009 hPa and a negative pressure of -1.4 hPa in the monitoring well was maintained. The temperature of the abstracted gas ranged from 7.0 to 12.7 °C and averaged 11.2°C.

A graphical presentation of gas concentrations (CH_4, CO_2, O_2) and flow rate during the gas extraction test was plotted and is presented on Figure 6. Gas extraction rate ranged between 4.5 to 16.6 m^3/h and averaged 7.94 m^3/h, with a final rate of 2.0 m^3/h. Oxygen concentrations increased throughout the test. Methane concentrations were nominal at ≤ 0.2% v/v. Carbon dioxide concentrations decreased from 17.5% v/v to 11.7% v/v. The data shows first aerobic degradation processes taking place at this boundary of the waste body.

Over the gas extraction test there was an increase in oxygen and decrease in carbon dioxide, indicating that oxygen was entering the subsurface through the topsoil, diluting the LFG captured during the test. The topsoil could be thinner here allowing more interaction with atmospheric gases.

Using the Darcy Equation and the data from the extraction test on MW05, a permeability for the Gravel Formation was derived, 5.69E-07 m^2.

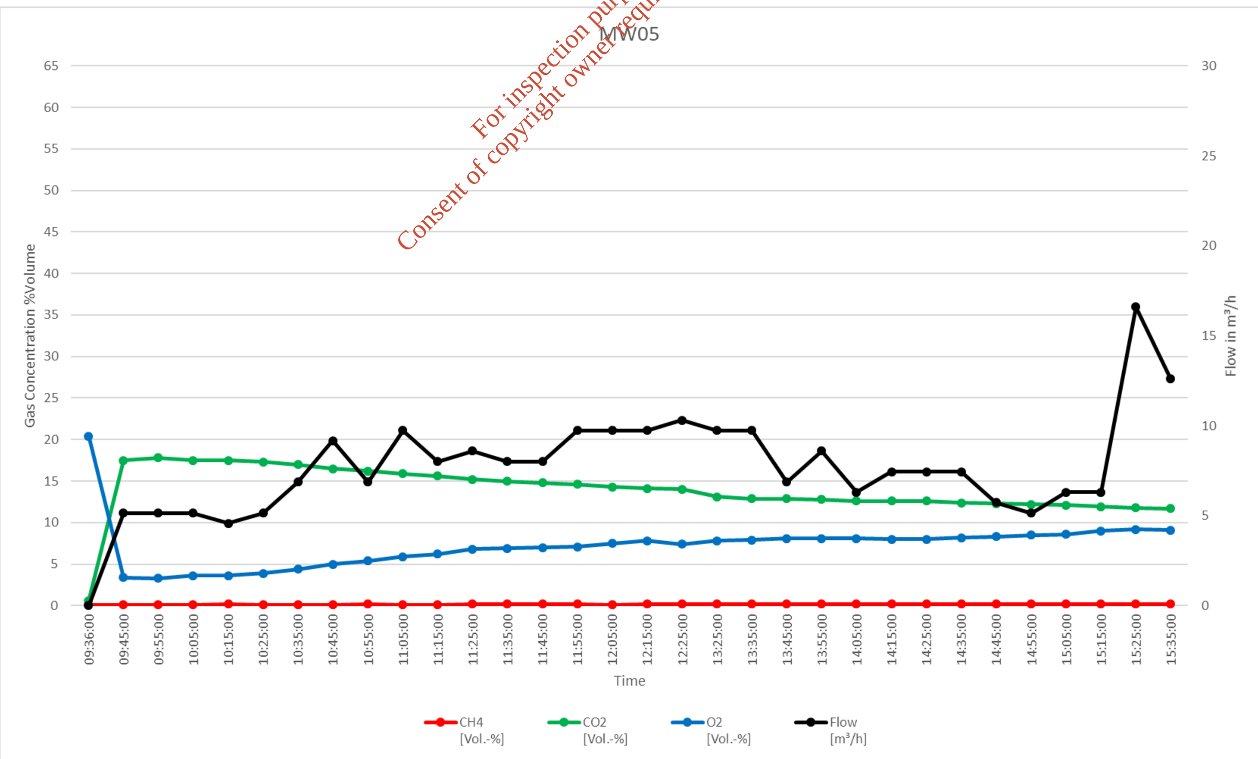

Figure 6: MW05 Extraction Test Results

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4.3.3 MW07A

MW07A is a monitoring well installed with a response zone in the Gravel Formation, located close to the outer boundary of the site, with the waste body approximately 20m away. The nearest building to MW07A is Property 5, located approximately 15m away, as shown on Figure 4. During the gas extraction test carried out on 20/01/2020, the mobile LFG extraction unit extracted 50 m^3 of gas over almost six hours from MW07A. Over the test period atmospheric pressure reduced from 1043 to 1040 hPa and a negative pressure of -33 hPa was maintained in the monitoring well. The temperature of the abstracted gas ranged from 7.8 to 18. °C and averaged 11.1°C.

A graphical presentation of gas concentrations (CH_4, CO_2, O_2) and flow rate during the gas extraction test was plotted and is presented on Figure 7. Gas extraction rate ranged between 6 to 12 m^3/h and averaged 8.87 m^3/h. Carbon dioxide concentrations increased from 6.5% v/v to 8.7% v/v. Oxygen levels decreased from 17.3 to 14.2% v/v. Methane concentrations were nominal at ≤ 0.1% v/v. The data shows first aerobic degradation processes taking place at this boundary of the waste body.

Over the gas extraction there is an increase carbon dioxide and decrease in oxygen, indicating that there is connectivity/pathway between the landfill and monitoring well MW07A.

Using the Darcy Equation and the data from the extraction test on MW07A, a permeability for the Gravel Formation was derived, 1.60E-08 m^2.

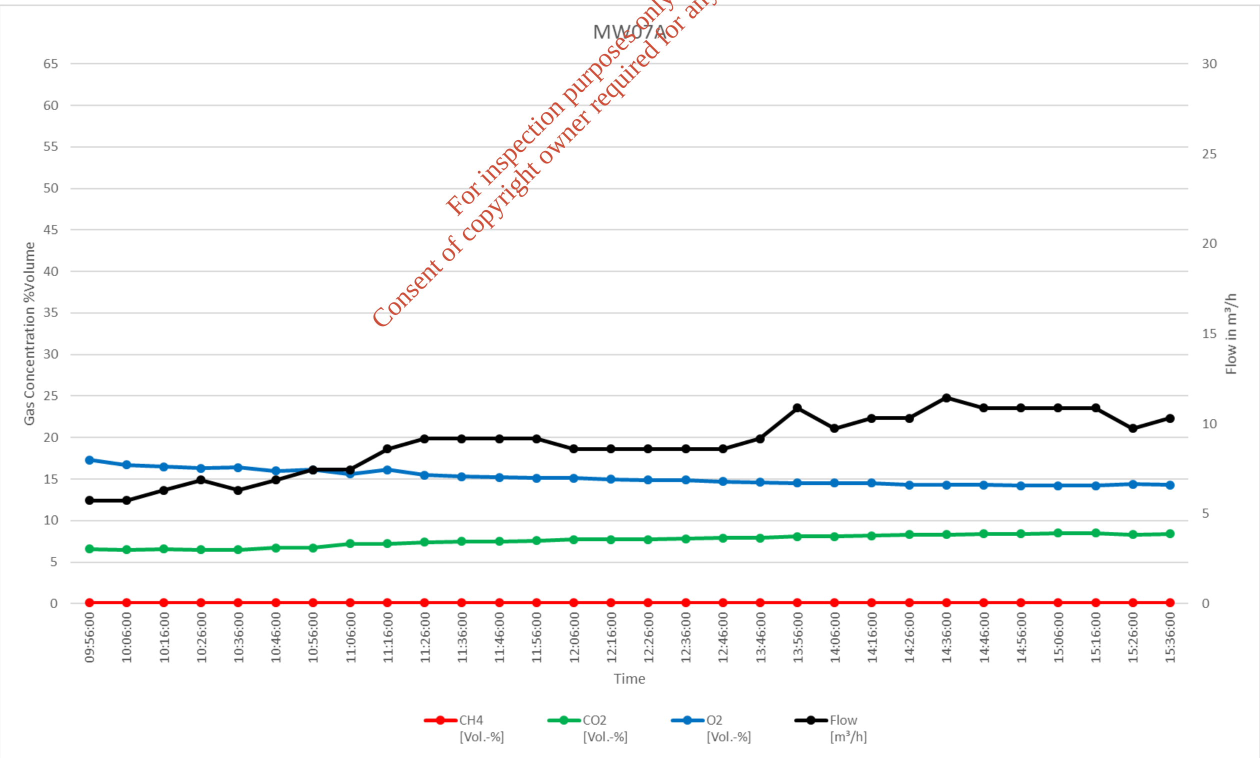

Figure 7: MW07A Extraction Test Results

4.3.4 MW08A

MW08A is a monitoring well installed with a response zone in the Gravel Formation, located close to the outer boundary, with the waste body approximately 5m away. The nearest building to MW08A is Property 1, located approximately 40m away, as shown on Figure 4. During the gas extraction test carried out on 15/01/2020, the mobile LFG extraction unit extracted 45 m^3 of gas over 4 hours from MW08A. Over the test period atmospheric pressure increased from 997 to 998 hPa and the negative pressure ranged from -9.0 to -15.0 hPa in the monitoring well. The temperature of the abstracted gas ranged from 8.0 to 13.0 °C and averaged 10.3 °C.

A graphical presentation of gas concentrations (CH_4, CO_2, O_2) and flow rate during the gas extraction test was plotted and is presented on Figure 8. Gas extraction rate ranged between 5 to 17 m^3/h and averaged 11.34 m^3/h. During the test, methane concentrations decreased slightly from 9.4 to 7.6% v/v and carbon dioxide increased marginally from 15.1 to 15.7% v/v. Oxygen concentrations fluctuated regularly, falling between 5.7 and 1.1% v/v and generally decreasing with time. First aerobic degradation conditions are identified in this boundary region of the waste body

There is a pathway/connection between the waste mass and the monitoring well. The MW08A is the nearest monitoring well screened in the Gravel Formation to the waste mass, when compared to MW03, MW05 and MW07A.

Using the Darcy Equation and the data from the extraction test on MW08A, a permeability for the Gravel Formation was derived, 4.12E-08 m^2.

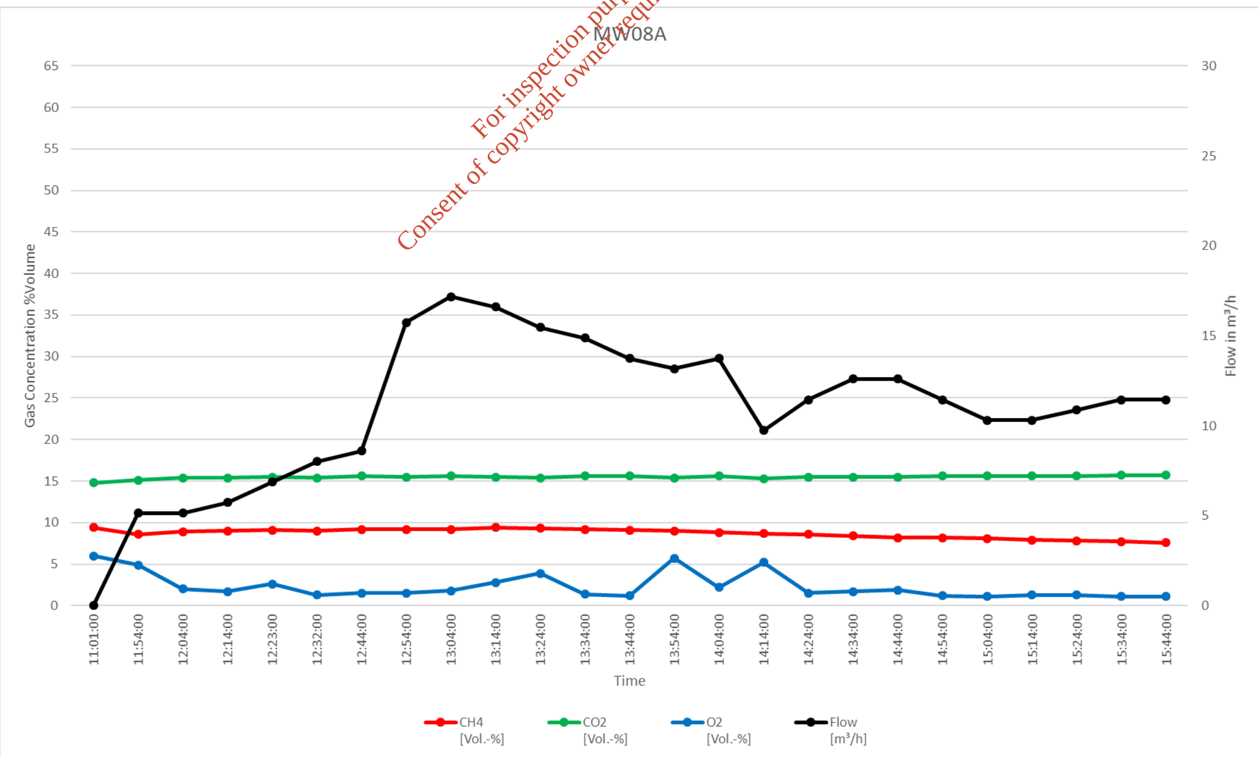

Figure 8: MW08A Extraction Test Results

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4.3.5 MW09

MW09 is a monitoring well installed with a response zone in the Waste Material and located on the western side of the waste body as shown on Figure 4. The nearest buildings to MW09 are at Property 6 and 7, which are located approximately 120 m and 130 m respectively from MW09. During the gas extraction test carried out on 16/01/2020, the mobile LFG extraction unit extracted 67 m^3 of gas over 6 hours from MW09. Over the test period atmospheric pressure reduced from 992 to 986 and back to 990 hPa and an average negative pressure of -1.3 hPa was maintained in the monitoring well. The temperature of the abstracted gas ranged from 10.2 to 14.0 °C and averaged 11.6°C.

A graphical presentation of gas concentrations (CH_4, CO_2, O_2) and flow rate during the gas extraction test was plotted and is presented on Figure 9. Gas extraction rate ranged between 5 to 18.3 m^3/h and averaged 11.87 m^3/h. During the test, methane concentrations remained stable with differing extraction rates, 51.4 to 51.9% v/v. Carbon dioxide concentrations showing similar variances, 26.5 to 27.0% v/v. Oxygen values remained less than 0.6% v/v throughout. Anaerobic conditions are prevalent in this area of the waste body.

The lack of oxygen extracted would indicate that the landfill cap/cover material can act as barrier to gas flow. There is therefore the potential for a pressure differential between the gas in the landfill below the cap/cover and the gas in the atmosphere resulting in atmospheric pumping. Assuming that the landfill material has a porosity of 0.3, potentially gas was drawn from 222.5 m^3 of the waste mass.

Using the Darcy Equation and the data from the extraction test on MW09, a permeability for waste material was derived, 1.96E-07 m^2.

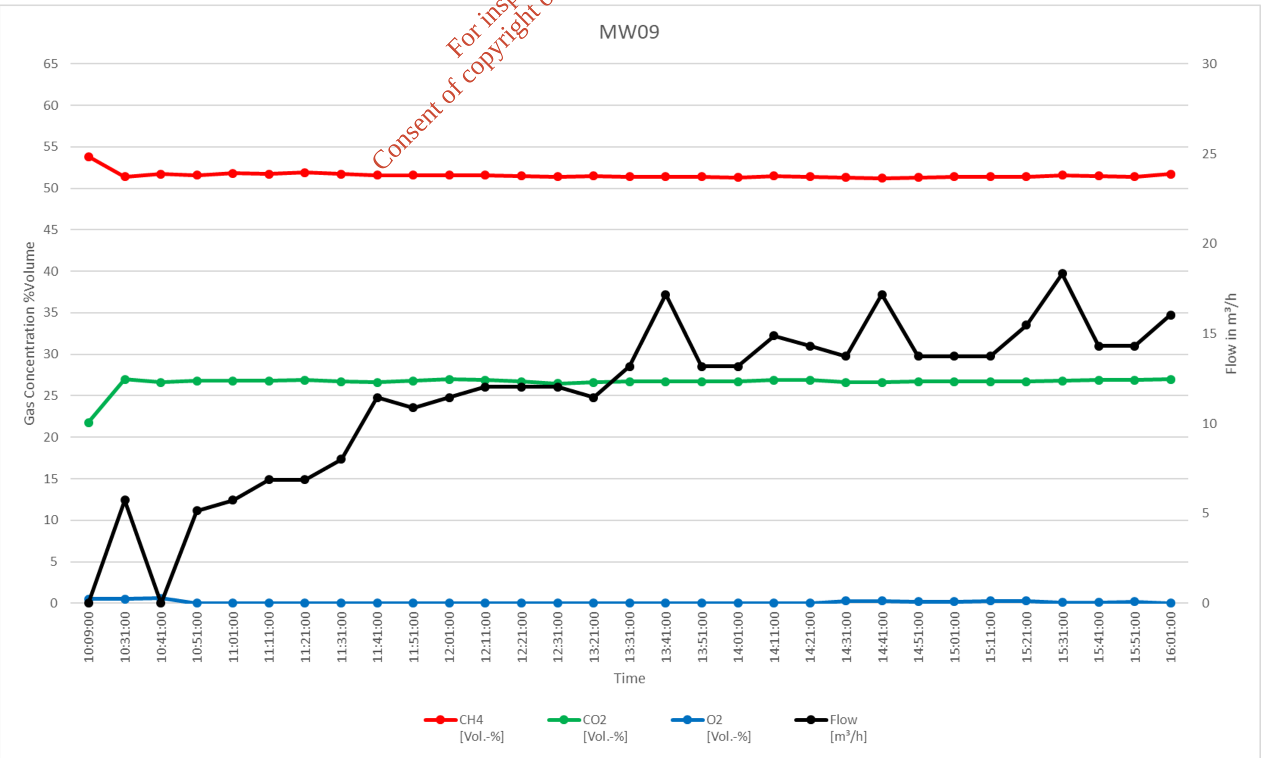

Figure 9: MW09 Extraction Test Results

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4.3.6 MW12

MW12 is a monitoring well installed with a response zone in the Waste Material and is located in the mid-section of the northern side of the waste body shown on Figure 4. The nearest buildings to MW12 are at Property 5 and 3and are located approximately 80m and 115 m respectively from MW12. During the gas extraction test carried out on 22/01/2020, the mobile LFG extraction unit extracted around 50m^3 of gas over 6 hours from MW12. Over the test period atmospheric pressure reduced from 1036 to 1033 hPa and an average negative pressure of -0.9 hPa was maintained in the monitoring well. The temperature of the abstracted gas ranged from 8.5 to 12.9 °C and averaged 10.8°C. Gas concentrations were also monitored at MW13 during the test.

A graphical presentation of gas concentrations (CH4, CO2, O2) and flow rate from MW12 during the gas extraction test was plotted and is presented on Figure 10, also plotted are gas concentrations measured in MW13 during the test. Throughout the test methane concentrations in MW12 increased slightly from 30.5 to 31.4% v/v and carbon dioxide remained relatively constant, ranging from 27.4 to 28.0% v/v. In MW12, there was an initial oxygen concentration of 1.2% v/v, levels were measured below 0.5% v/v thereafter. Anaerobic conditions are prevalent in this area of the waste body, but first aerobic degradation conditions are also observed.

The results of the gas extraction from MW12, showed methane levels were constant. The lack of oxygen extracted would indicate that the landfill cap/cover material can act as barrier to gas flow. There is therefore the potential for a pressure differential between the gas in the landfill below the cap/cover and the gas in the atmosphere resulting in atmospheric pumping. Assuming that the landfill material has a porosity of 0.3, potentially gas was drawn from 165.6 m^3 of the waste mass.

The gas concentrations in MW13 appeared to respond to extraction from MW12, indicating that there is connectivity in the waste mass. Methane and carbon dioxide concentrations had an initial short period of decrease, followed by a long period of increase. The last hour of the test saw a significant decrease in methane and carbon dioxide and an increase in oxygen, which may show the outer edge of the gas plume being drawn back to the waste mass.

Using the Darcy Equation and the data from the extraction test on MW12, a permeability for waste material was derived, 6.67E-07 m^2.

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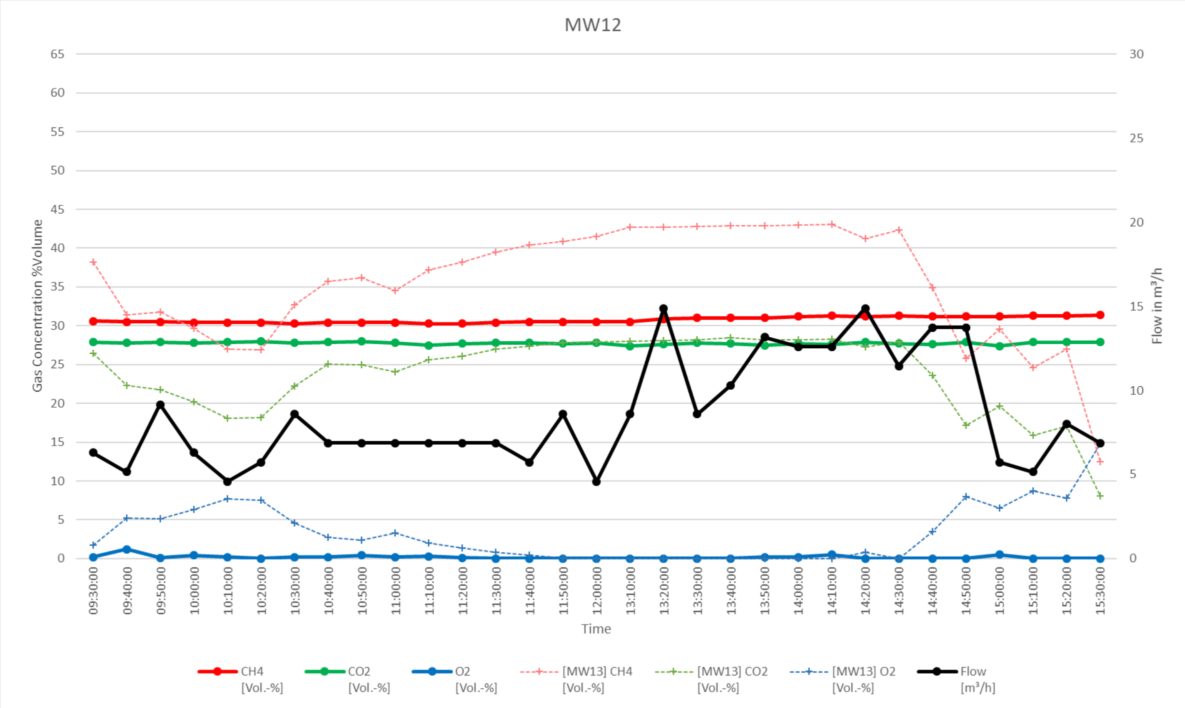


Figure 10: MW12 Extraction Test Results (with Observation Well MW13 Results)

4.3.7 MW13

MW13 is a monitoring well installed with a response zone in the Waste Material and is located on the western side of the waste body as shown on Figure 4. The nearest buildings to MW13 are at Property 5 and Property 3 are located approximately 65m and 125 m respectively from MW13. During the gas extraction test carried out on 21/01/2020, the mobile LFG extraction unit extracted 56 m^3 of gas over6 hours from MW13. Over the test period atmospheric pressure reduced from 1040 to 1037 hPa and an average negative pressure of -4.2 hPa was maintained in the monitoring well. The temperature of the abstracted gas ranged from 7.0 to 10.7 °C and averaged 8.25°C.

A graphical presentation of gas concentrations (CH_4, CO_2, O_2) and flow rate during the gas extraction test was plotted and is presented on Figure 11, also plotted are gas concentrations measured in MW12 during the test. Gas extraction rate ranged between 4.5 to 20.6 m^3/h and average 10.27 m^3/h. Throughout the test methane concentrations decreased gradually from 45.1 to 34.7% v/v and carbon dioxide remained relatively constant, ranging from 25.9 to 27.0% v/v. Oxygen remained below 2.2% v/v during the test. Anaerobic conditions are prevalent in this area of the waste body, but first aerobic degradation conditions are also observed.

The lack of oxygen extracted would indicate that the landfill cap/cover material can act as barrier to gas flow. The decrease in methane concentration was most likely due to the location of MW13 on the edge of the waste mass. Assuming that the landfill material has a porosity of 0.3, potentially gas was drawn from 186.6 m^3 of the waste mass.

The gas concentrations in MW12 appeared to respond to extraction from MW13, indicating that there is connectivity in the waste mass. Methane concentrations had an initial short period of increase, followed by a period of decrease which continued until the end of the test. Carbon dioxide remained relatively stable for the duration of the test. There was an initial oxygen concentration of 1.9% v/v, levels were measured at 0.0% v/v for most of the test with a level of 0.1 %, 0.6% 2.8% and v/v also recorded.

Using the Darcy Equation and the data from the extraction test on MW13, a permeability for waste material was derived, 1.02E-07 m^2.

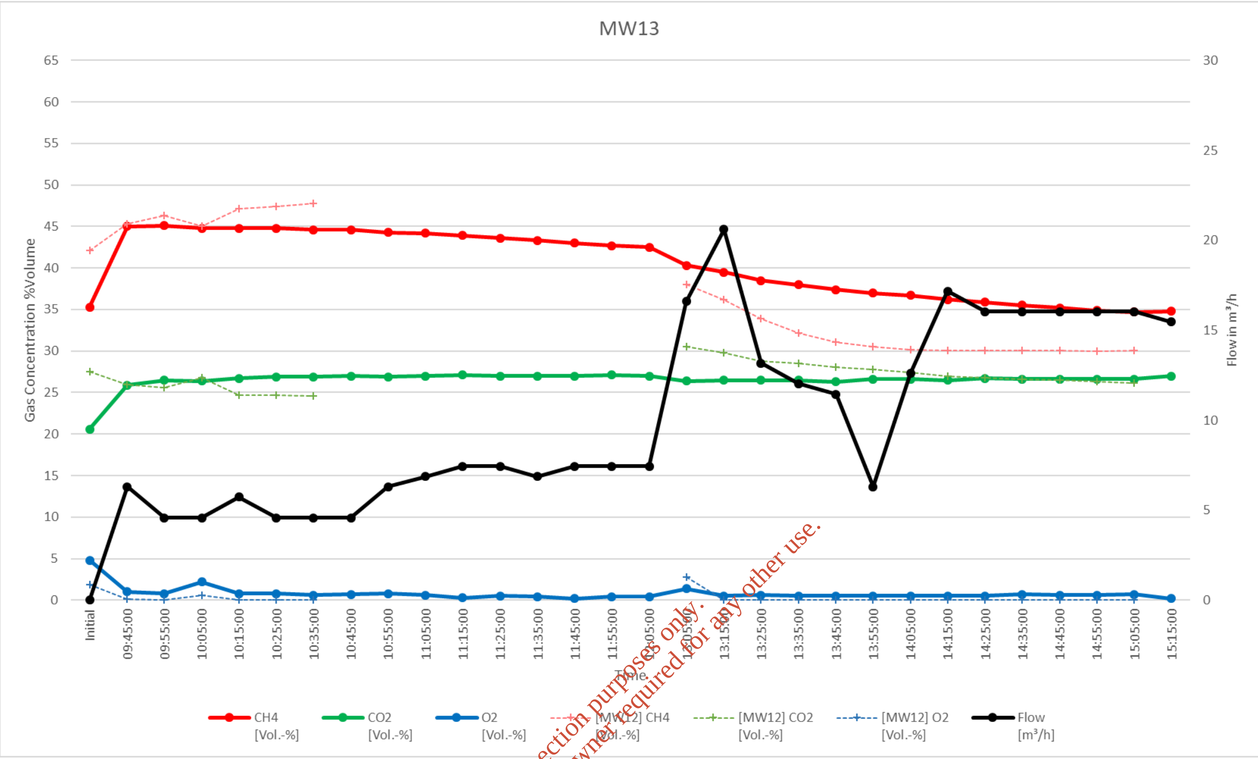


Figure 11: MW13 Extraction Test Results (with Observation Well MW12 Results)

4.3.8 MW14

MW14 is a monitoring well installed with a response zone in the Waste Material and is located on the southern side of the waste body as shown on Figure 4. The nearest buildings to MW13 are at Property 3, 1, 4 and 6 are located approximately 110m, 120m, 135m, 150m from MW14. During the gas extraction test carried out on 24/01/2020, the mobile LFG extraction unit extracted 110 m^3 of gas for almost 6 hours from MW13. Over the test period atmospheric pressure decreased from 1021 to 1016 hPa and an average negative pressure of -1.4 hPa was maintained in the monitoring well over the test. The temperature of the abstracted gas ranged from 8.0 to 13.8 °C and averaged 11.8°C.

A graphical presentation of gas concentrations (CH_4, CO_2, O_2) and flow rate during the gas extraction test was plotted and is presented on Figure 12. Gas extraction rate ranged between 12.02 to 25.76 m^3/h and average 19.9 m^3/h. Throughout the test methane concentrations increased from 54.6 to 57.2% v/v and carbon dioxide remained relatively constant, ranging from 31.0 to 36.9% v/v. Oxygen remained below 0.8% v/v during the test except for one measurement at 11:00. Anaerobic conditions are prevalent in this area of the waste body.

The lack of oxygen extracted would indicate that the landfill cap/cover material is acting as barrier to gas flow. Methane and carbon dioxide concentrations remained stable over the test and at high extraction rates, indicating this part of the landfills capacity to produce methane.

Using the Darcy Equation and the data from the extraction test on MW13, a permeability for waste material was derived, 2.84E-05 m^2.

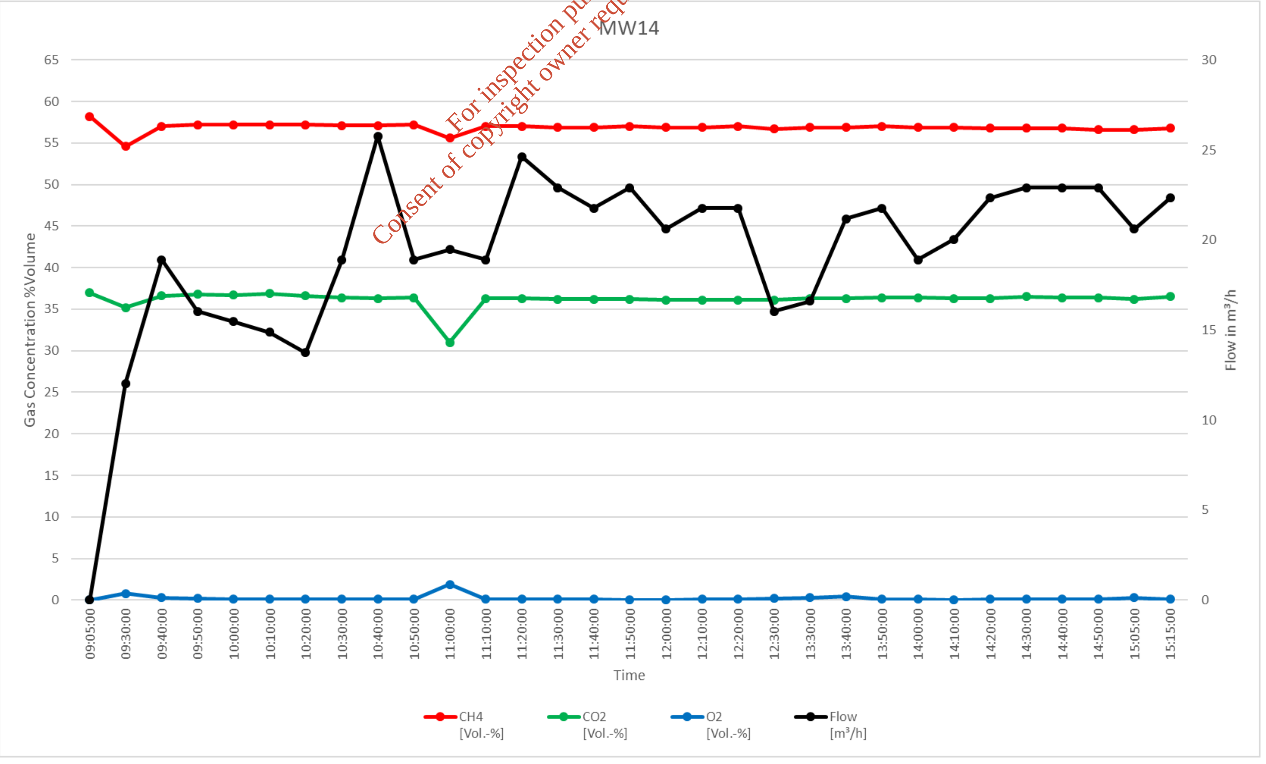


Figure 12: MW14 Extraction Test Results

4.4 Summary of the Gas Extraction Test

The LFG extraction test has demonstrated several key aspects pertaining to LFG migration:

- The cap/cover of the landfill can act as barrier to gas movement, as such, changes in atmospheric pressure have the potential to generate a differential between the gas in the landfill and atmosphere. Under a pressure differential atmospheric pumping can take place.
- Results from MW05 indicate oxygen was entering the subsurface through the topsoil during the extraction test.
- The Gravel Formation can act as a pathway for LFG;
- LFG can move inside the waste mass;
- The site is producing considerable amounts of methane and carbon dioxide; and
- Methane and Carbon dioxide remained stable in extraction wells at 'high' rates of gas extraction.

The zone of influence from the extraction test has been determined and is detailed in Table 9**.**

Table 9: Extraction Test Summary and Results

ID	Formation	Extraction Time (hh:mm)	Gas Extracted (m^3)	Volume of subsurface influenced (m^3)	Estimated Permeability (m^2)
MW03	Gravel Formation	04:20	54	181	1.43E-06
MW05	Gravel Formation	05:50	47.7	159.0	5.69E-07
MW07A	Gravel Formation	05:40	50.4	168.1	1.60E-08
MW08A	Gravel Formation	03:50	44.5	148.4	4.12E-08
MW09	Waste Mass	05:30	66.8	222.5	1.96E-07
MW12	Waste Mass	05:50	49.7	165.6	6.67E-07
MW13	Waste Mass	05:30	56.0	186.6	1.02E-07
MW14	Waste Mass	05:45	110.6	368.7	2.84E-05

Section 5 LFG Risk Assessment and Conceptual Site Model

5.1 Risk Posed by LFG Lateral Migration

The factors involved with lateral landfill gas migration are both complex and dynamic, including:

- **Waste mass producing LFG;**
  - The waste mass has been shown to be producing significant LFG.
- **Landfill construction and LFG management;**
  - There is no gas control system at Digby Bridge and the waste mass is unlined on the sides and base.
  - The cover and cap material are of sufficiently low permeability to allow for pressure differential to be established. A prerequisite of atmospheric pumping.
- **Native geology;**
  - The gas extraction test has also shown that LFG can migrate laterally through the native geology.
  - Degrees of saturation and if the topsoil is frozen or not, also impacts gas migration (seasonal function).
- **Atmospheric pressure changes;**
  - As shown in data presented in **Appendix A.3**, there are significant (magnitude and duration) atmospheric pressure drops to induce atmospheric pumping.
  - Analysis of the atmospheric pressure data showed that most of the significant pressure drops occur in winter months (seasonal function).
- **Groundwater table or leachate level movement;**
  - Gravel Formation permeable and with high storage coefficient as such large movements in the groundwater table not anticipated.
- **Microbial transformations of carbon dioxide and methane; and**
  - This is significant and much harder to quantify and is also influenced by climatic conditions
- **Wind.**
  - This is a minor component.

There is significant potential at Digby Bridge for lateral migration and potentially vertical migration where the cap is thin.

5.2 Risk Posed by LFG Vertical Migration

The gas extraction test has shown that the landfill cap/cover acts as barrier to gas flow. FID measurements taken at ground level over the cap had no detections of bulk or trace LFG. There may be areas of localized emissions through the landfill cap/cover where the cover is thin. Gases emanating from the cap/cover would be diluted (highly) by atmosphere.

5.3 Modelling Lateral Gas Migration

To assess risk and estimate the potential for LFG to travel laterally through the subsurface, a simple but conservative approach to modelling lateral gas migration is required. The Darcy Equation is used to calculate the velocity at which that the gas migrates lateral through the largest pores/fissures assuming a one-dimensional linear pathway. The model does not consider:

- Buoyancy driven flow;
- Pore water;
- Compressibility;
- Temperature driven flow;
- Diffusion driven flow; and
- No biological oxidation, dispersion, retardation or other related processes.

The biological oxidation, dispersion, retardation processes that occur will reduce the concentration of the gas and the distance methane can travel.

This approach can be considered conservative and a 'worst case' model, which would be close to a winter scenario, where the top soil is saturated or frozen and soil temperatures are low. This scenario would lead to:

- Reduce microbial activity (methane oxidation); and
- Prevent methane being lost to the atmosphere / forced to exit the subsurface at a different location.

Using the Darcy Equation in **Appendix A.1**. The largest rate in pressure drop observed over the longest period was 3.21 h Pa/h over a 14-hour period, see **Appendix A.3**. Assuming there is an hour lag between the landfill pressure and surrounding geology. Using the median value for intrinsic permeability of the monitoring wells screened in the Gravel Formation from the gas extraction testing, 3.1E-07 m^2. The velocity of the LFG travelling through the subsurface as result of has been estimated at 0.014 m/s. Considering the event lasted 14hours, the LFG could travel up to 692 metres from the source. As previously stated this calculation does not consider some of the factors related to LFG migration and is an over estimation, but there is clearly a potential for LFG to migrate laterally to offsite receptors.

Potential for slower diffusion driven migration through permeable native geology and potential to build up in a confined space in properties nearest the landfill.

5.4 Risk Posed by LFG Solubility in Groundwater

LFG can dissolve into groundwater and migrate offsite with the groundwater. The solubility and diffusion coefficients of methane and carbon dioxide are shown in Table 10. The solubility of methane can be considered low, when compared to carbon dioxide and this is one of the reasons for the variations in bulk gas composition.

Table 10: Solubility and Diffusion Coefficients of Methane and Carbon Dioxide

Gas	Solubility in Water at 25°C	Diffusion Coefficient (liquid) at 25°C (dissolved)
Methane	25 mg/L	1.49E-05 cm^2/s **
Carbon Dioxide	1450 mg/L *	1.92E-05 cm^2/s **

** pH dependent. ** At atmospheric pressure*

The solubility of a gas increases with pressure and a this may effectively dissolve them in groundwater. If methane, carbon dioxide or VOCs are dissolved, they can be mobilised via groundwater and move offsite with groundwater. A pressure drop could then cause the release of dissolved gas from groundwater into pore spaces and subsequently into atmosphere or overlying structures. Generally, groundwater has a stable temperature, atmospheric temperature changes won't be a factor in degassing if gases are dissolved in groundwater.

Methane is less dense in respect to both nitrogen and oxygen, while carbon dioxide is denser. The waste body at Digby Bridge is situated above the groundwater table, therefore the potential for methane and carbon dioxide becoming dissolved in groundwater is minimised, particularly methane. There were no VOCs and only low level SVOC detected in the groundwater samples taken from groundwater monitoring wells around the landfill.

There were no indicators of this from the Tier 2 round of monitoring, see **Tier 3 DQRA (Volume 2)**.

5.5 Conceptual Site Model (Landfill Gas)

Risk assessment generally involves the identification of the hazard source (landfill waste material generating LFG), the exposure pathway(s) for the hazard, and the effect of the exposure on a receptor. This is commonly referred to as the source-pathway-receptor linkage model and is best illustrated by use of a conceptual site model (CSM). A graphical CSM is presented in Figure 13.

5.5.1 Source

Biodegradable waste material deposited into the gravel pits at Digby Bridge is the source of LFG emission at the site. The waste material type has been estimated in Section 3.1.2. The landfill sides and base are unlined, and soil has been deposited over the waste material forming a cap/cover, discussed in **Appendix A.4**.

The modelling in Section 3 estimates that the waste material has the potential to continue generating LFG. The LFG extraction test demonstrated that waste material contains significant quantities of the bulk gases carbon dioxide and methane, with a capacity to sustain the extraction of these gases over a period of time.

The extraction test also demonstrated the landfill cap/cover can sustain a pressure differential between the atmosphere and the gases within the waste mass, thus atmospheric pumping can take place.

Drops in atmospheric pressure shown in Table 15 of **Appendix A.3** show that over a 30-year period there are 6 to 21 annual events considered to have the potential to drive atmospheric pumping. The highest rate of pressure drop of 3.31 hPa/h was in 2007, as discussed in **Appendix A.3**.

5.5.2 Pathway

Vertical

The gas extraction test has shown that the landfill cap/cover acts as a barrier to gas flow. Where the cap/cover has been noted to be thin, there is potential for some gas migration, but this will be diluted by atmospheric gases.

Lateral / Horizontal

The local geology of sand and gravel (Gravel Formation) provides a permeable pathway for LFG to migrate laterally. The LFG extraction from MW03, MW04, MW07 and MW08A showed that there was connectivity with monitoring wells in the Gravel Formation. The testing in MW09, MW14 and particularly MW12, MW13, showed that LFG could migrate through the waste mass.

Solubility in Groundwater

Methane, carbon dioxide and VOCs can become dissolved in groundwater under the right conditions. They can then become mobilised via groundwater and move offsite with groundwater.

5.5.3 Receptors

Onsite Receptors

The risk to site workers can be considered **LOW.** As a precaution, gas monitoring wells should be locked. There exists a potential for foul play on site and the LFG being set alight.

Offsite Receptors

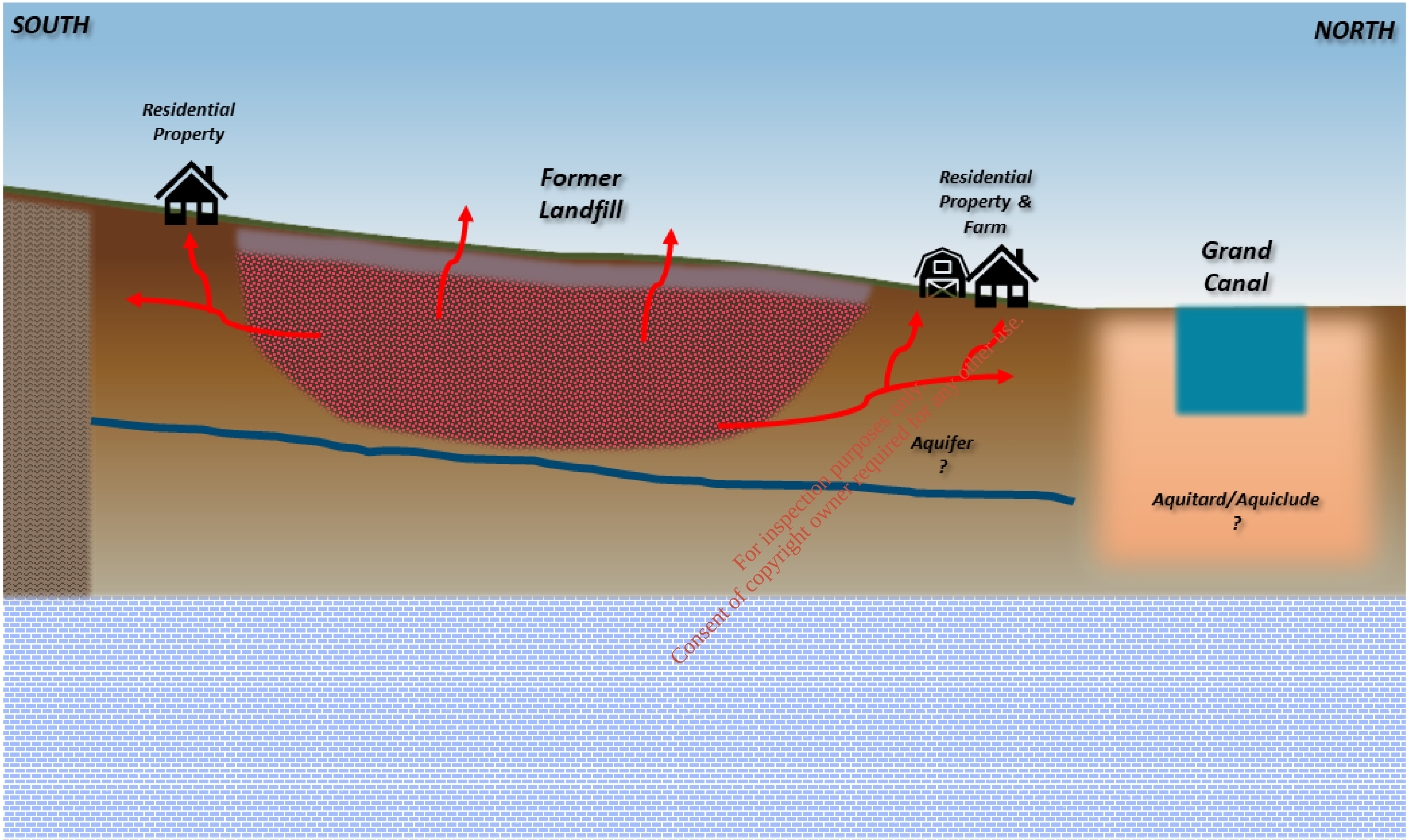
Domestic properties and farm yard buildings near the landfill are receptors to LFG. LFG in the landfill has migration pathways and there is potential for atmospheric pumping of LFG into the surrounding native geology, man-made structures and overlying buildings.

There is a potential risk of accumulation of carbon dioxide and/or methane in the buildings, which could pose a risk of asphyxiation or an explosive risk to potentially harm occupants. The risk can be considered **HIGH.**

No VOCs were detected in groundwater and one SVOC was detected in groundwater at one location, as such trace gas migration in groundwater does not present a risk. Methane in groundwater is not considered a high risk due its low solubility and buoyancy relative to other gases but this should be confirmed with testing for methane and carbon dioxide in future groundwater sampling rounds.

From the methodology that follows the EPA Code of Practice, the scores of the assigned components from the SPR linkages are listed in Table 11. The SPR values after Tier 3 are calculated in Table 12 and summarised in Table 13, the risk classification is outlined in Table 14. These have been limited to LFG associated SPR linkages.

LOW PRESSURE EVENT



Potential Sources

Potential sources of contamination on the site comprise:
Landfill Gas generated by anaerobic decay of organic material

Potential Pathways

Landfill Gas/Vapors Pathway

Potential Receptors

Potential receptors comprise the following:

Onsite
Site users (farmer / farm animals)

Offsite
Residential dwellings, farm related buildings

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Legend

Made Ground	
	Landfill Cover
	Landfill Mass
Quaternary Deposits	
	Top Soil
	Gravel (GLs)
	Alluvium (A)
	Till (TLs)
Bedrock	
	Rickardstown Formation (CDRICK)

Rev.	Description	By	Date	Chk'd	Auth

Purpose of Issue	Rev	Date	Authorised
FOR INFORMATION / COMMENT	-		

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Client: Kildare County Council

Project: Digby Bridge

Title: LFG Site Conceptual Model

Original Scale	Drawn		Authorised	
NTS	CF Date 22/04/20	CMC Date 23/04/20	RO'C Date 24/04/20	A4

Drawing Number: FIGURE 13 — Rev: A

Drawing Number FIGURE 13 Rev. A

Table 11: LFG SPR Linkage Scores

EPA Ref	Risk	Points	Rationale
1b	Landfill gas; source/hazard scoring matrix, based on waste footprint.	7	Municipal waste and a footprint of >1 and ≤5 ha (Section 3.1.1)
2d	Landfill gas: Pathway (Lateral migration potential)	3	Gravels (Section 2.3, 4.3, 4.4, 5.3. **Appendix A.2**, **A.4**.)
2e	Landfill gas: Pathway (Upwards migration potential)	2*	Clay and Sand (Section 2.3, 4.3, 4.4, 5.3, **Appendix A.4**). * It has been proven that the landfill cap/cover acts as a barrier to gas flow
3f	Landfill Gas: Receptor (Human presence)	5	Residential properties and buildings within 50 m of the waste mass

Table 12: LFG SPR Values for each SPR Linkage as per CoP with Normalised Scores

Calculator		SPR Values	Maximum	Linkage	Normalised Score (%)
Landfill gas migration pathway (lateral & vertical)					
SPR10	1b x 2d x 3f	105	150	Landfill Gas => Human Presence	70
SPR11	1b x 2e x 3f	70	250	Landfill Gas => Human Presence	28
Site maximum SPR Score					**70**
Risk Classification					**Highest Risk (Class A)**

Table 13: SPR Linkages After Tier 3

SPR	Linkage	Tier 3
Landfill gas migration pathway (lateral & vertical)		
SPR10	Landfill Gas => Human Presence	Risk from atmospheric pumping
SPR11	Landfill Gas => Human Presence	Risk from vertical migration considered low

Highest Risk (Class A)	Moderate Risk (Class B)	Lowest Risk (Class C)

Table 14: Risk Classification

Risk Classification	Range of Risk Scores
Highest Risk (Class A)	Greater than or equal to 70% for any individual SPR linkage
Moderate Risk (Class B)	Between 40-70% for any individual SPR linkage
Lowest Risk (Class C)	Less than or equal to 40% for any individual SPR linkage

Section 6 Conclusion

The information obtained from the gas investigation at Digby Bridge has been used to screen the SPR scores for the relevant linkages (SPR10 & SPR11). These have been applied to CSM and the model has been updated. The site remains in the Highest Risk (Class A) category.

Considering the requirements for LFG management in the EU Landfill Directive (1999), EPA Management of Low Levels of Landfill Gas (2011), EPA Landfill Site Design (2000) and EPA Landfill Operational Practices (1997). The landfill site at Digby Bridge cannot be considered as following the requirements for LFG management.

There are several control systems that could be used to manage the risk posed by LFG migration. The requirements for LFG management, remedial techniques, the appraisal of these options and the recommendation of CDM Smith have been provided in the Remediation Plan (Doc. Ref. 117838/40/DG/14).

Section 7 References

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Appendix A
Gas Migration

A.1 Mechanisms of Gas Migration

The two mechanisms of gas migration in the ground/soils are diffusion flow and advective flow, or gas migration can also be a combination of both mechanisms.

Diffusion flow

Diffusion is the net movement of anything from a region of higher concentration to a region of lower concentration. Diffusion is driven by a gradient in concentration (diffusive flow according to Fick's Law):

- $C = D_a.\Delta C.\Delta t \,/\, \Delta x$
  - where C is the gas concentration ($M \cdot L^{-3}$);
  - t is time (T), D is the binary diffusion coefficient in air ($L^2 \cdot T^{-1}$);
  - x is the distance along the axis of flow (L); and
  - M = mass, L = volume, T = time.

In soil, not air, the equation becomes:

- $D_a = D_0.\mathrm{e}.\mathrm{T}$
  - e is the soil air-filled porosity (m3 air m-3 soil); and
  - T is the tortuosity of the soil.

The magnitude of diffusion is inversely proportional to compound molecular weight of the gas, porous media bulk density, and soil-water content. The magnitude of diffusion is directly proportional to temperature.

Advective flow

Adjective flow requires a pressure gradient to exist between the landfill and the surrounding geology. The pressure differential is as a result of a change in atmospheric pressure and lag between the change in atmospheric pressure and the change of gas pressure in the landfill. As atmospheric pressure drops gas will flow from the landfill into surrounding geology, conversely air from the surrounding geology will flow into the landfill when atmospheric pressure increases. The gas flow from points of higher to those of lower pressure, is often referred to as 'atmospheric pumping of gases'. The Darcy Equation is valid for describing the gas flow between points with pressure differential at low flow velocity, where turbulence in the gas flow is low - gas flow is laminar.

$$v = \frac{k}{\mu} . \frac{\Delta P}{\Delta x} \text{ (for linear flow)}$$

v = gas flow rate (m/s);

k = intrinsic permeability (m^2);

μ = dynamic viscosity of gas (Pa s);

ΔP = pressure differential (Pa); and

Δx = thickness of porous medium (soil/rock) (m).

Regarding LFG, the rate of gas flow will generally reflect the pressure differential over the migration pathway and the co-efficient of permeability (gas) of the migration pathway, which in turn may be influenced by the mechanical characteristics of the waste deposit, its degree of saturation and the surrounding geology.

A.2 Horizontal / Lateral Migration

Advective flow is considered the dominant mechanism for lateral migration of gas. Advective flows are the result of pressure differentials between locations, especially in the upper soil but also in the deeper horizons. Slower, diffusional flow will still exist in these situations, but flow will be predominantly advective. The risk posed by the slow diffusional flow of landfill gas into confined spaces should not be underestimated. Both advective and diffusional are significant, as the build-up of gases can lead to potentially harmful situations (EA 2004).

Practical experience has shown that the critical rate of fall in pressure is approximately 5 hectopascals (hPa) per 3 hours for at least 3 hours (EA 2004). A large and rapid drop in atmospheric pressure of around 30 hPa can provide a significant driving force if the slight positive pressure within a landfill (compared with atmosphere) is only a few hPa. This effect is much more dramatic if the rate of change of pressure is fast, i.e. it takes place over a few hours rather than over a few days.

Horizontal/lateral migration can also be caused by changing groundwater and/or leachate levels at the site or by the rapid relief of pressure, which has built up behind a gas barrier (e.g. a clay liner) if the barrier fails.

A.3 Atmospheric Pressure Changes

As discussed in **Appendix A2**, a drop in atmospheric pressure is the most significant driver of lateral migration of LFG. Hourly atmospheric data for Ireland is available from the Met Eireann database back to 1990 from Parnell Park. The data was filtered based on events when pressure has dropped for 3 hours or more and the rate in pressure change is greater than 5 hPa/3 h (rate of 1.67 hPa/h), as discussed by Young 1993 as the duration and rate critical to generate lateral gas migration. The data was plotted and is presented on Figure 14, a summary of the data is presented in Table 15. The number of occurrences is shown for each year representing the number of events with a change of 5 hPa/3 h (rate of 1.67 hPa/h), the longest event duration, the largest pressure changes and the relevant rate for this change.

There is a seasonal pattern to events as shown on Table 16, the winter months have a greater frequency of events which have both longer duration and larger pressure changes.

Figure 14: Processed Atmospheric Pressure Data from Parnell Park

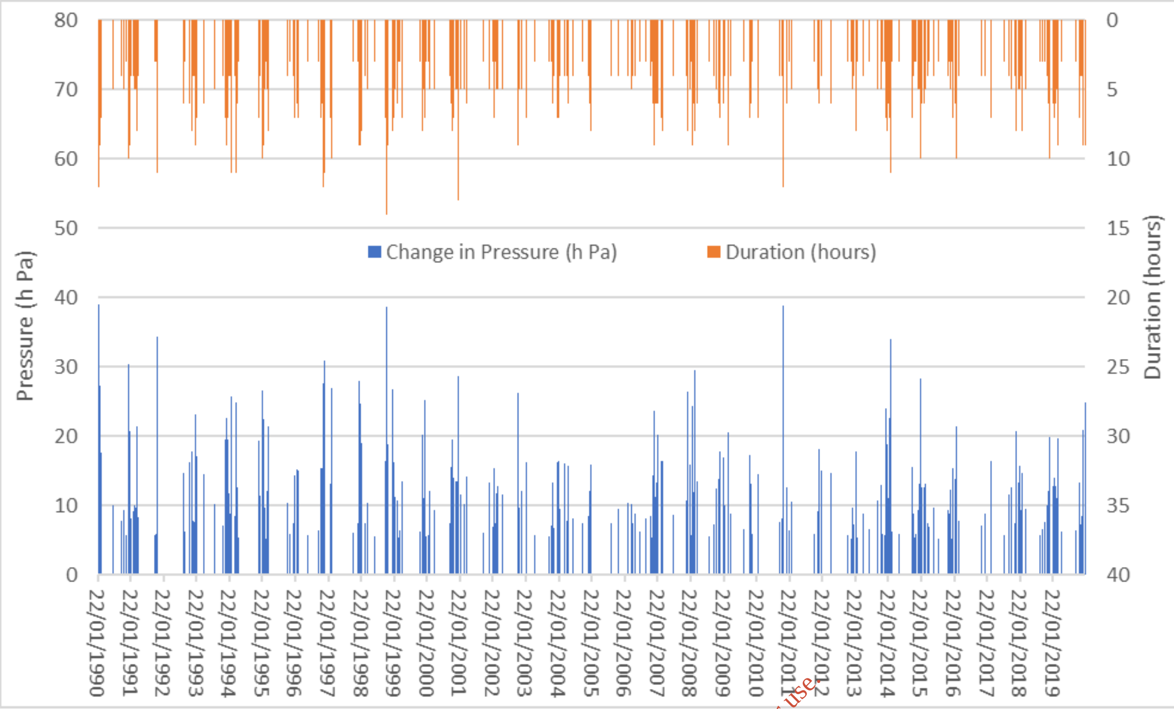

Table 15: Summary of Data for Atmospheric Events in Each Year Since 1990

Year	No. of Occurrences	Longest Event (h) of Year	Maximum Change in Pressure (hPa) over a Single Event	Rate of Change in Pressure / Time (hPa/h)
1990	16	12	39	3.25
1991	13	11	34.3	3.12
1992	11	8	17.8	2.23
1993	17	9	23.2	2.58
1994	19	11	25.7	2.34
1995	15	10	26.7	2.67
1996	16	12	30.9	2.58
1997	9	10	28	2.80
1998	14	14	38.7	2.76
1999	20	8	25.3	3.16
2000	23	13	28.7	2.21
2001	7	6	14.2	2.37
2002	21	9	26.2	2.91
2003	8	7	16.2	2.31
2004	14	7	16.4	2.34
2005	7	8	15.9	1.99
2006	15	9	23.7	2.63
2007	11	8	26.5	3.31
2008	18	9	29.5	3.28
2009	13	9	20.6	2.29
2010	6	12	38.9	3.24
2011	8	6	18.1	3.02

Year	No. of Occurrences	Longest Event (h) of Year	Maximum Change in Pressure (hPa) over a Single Event	Rate of Change in Pressure / Time (hPa/h)
2012	8	6	15.1	2.52
2013	16	8	24	3.00
2014	21	11	34.1	3.10
2015	18	10	28.4	2.84
2016	9	10	21.5	2.15
2017	9	8	20.8	2.60
2018	18	10	19.9	1.99
2019	18	9	20.9	2.32
2020	3	9	24.9	2.77

Table 16: Summary of Data for Atmospheric Events in Each Month Since 1990

Month	No. of Occurrences	Longest Event (h) of Month	Maximum Change in Pressure (hPa) over a Single Event
January	95	12	39
February	61	11	34.1
March	33	11	29.5
April	21	8	21.4
May	5	6	15.8
June	4	4	9.8
July	5	5	10
August	7	6	14.7
September	10	5	11.6
October	35	14	38.7
November	62	12	38.9
December	83	13	30.9

The highest number of events happened in 2000 and the longest duration event was in 1998 with a 14-hour event. The largest pressure change occurred in 1990 with a change of 39 hPa and the greatest rate of change happened in 2007 with 3.31 hPa/h.

A.4 Landfill Construction and Management

LFG migration is influenced by the construction and management of the landfill. A landfill with an intact engineered cap with active full site gas collection will have lower emissions relative to the soil cap only. Lateral migration through the sides of the landfill will be influenced by the following:

- Intact engineered cap with active full site gas collection;
- Liners – natural or engineered and/or geomembrane/composite liner;
- No liner – geology: low permeability clay/silt; high permeability sand/gravel; fractured bedrock;
- Lateral liner but no basal liner; and

- The presence or absence of a vent trench or cut-off wall.

EA (2004) modelling has shown that the bulk of landfill gas produced within the waste will generally flow through the cap, even if this is well engineered. Only when a cap is installed on an unlined landfill will lateral emissions dominate. This is due to the permeability differences between the liner and surrounding natural deposits. If there is no gas collection, over 90 percent of the methane generated by a landfill can be lost through surface emissions and the rate of emission on poorly capped sites can match that of generation (EA 2004).

The cap or cover material must be of sufficiently low permeability and of sufficient extents to allow a for pressure differential between the atmosphere and the landfill. If the cap/cover is sufficiently permeable a pressure gradient cannot be generated, and atmospheric pumping will not take place.

Massmann and Farrier (1992) carried out a two-dimensional finite element analysis of a capped permeable layer. The cap layer had a permeability (k) of 10^{-6} cm^2 equivalent permeability of a medium sand. Their modelling showed that a 25 mbar atmospheric pressure drop over 48 hours induced a lateral migration event of 45 m.

At Digby Bridge, the topsoil layer was found to range between 0.2 to 1.5 m in thickness. The Topsoil is predominately silty sandy gravelly clay with rootlets and an occasional piece of plastic. Topsoil was found directly overlying landfill waste at several locations. The landfill cap/cover ranges in thickness between 0.3 to 2.4 m and is absent in places. The layer is predominantly composed of a clayey silty gravelly sand fill, which underlies the Topsoil.

The cap/cover is of variable thickness and consistency, in places where the landfill cap/cover is thin there is the possibility of significant vertical gas migration. There is no gas control system and the waste mass is unlined on the sides and base. The top of the landfill has a cap/cover on top of the waste mass with a variable thickness and composition.

There is significant potential at Digby Bridge for both lateral migration and vertical migration. Lateral migration will dominate where the cap is more competent and vertical migration will occur where the cap is thin.

A.5 Site Geology / Native Geology

The geological characteristics of the strata beneath and around a landfill will have a clear impact on the behaviour of ground gas. Where highly permeable strata exist, preferential pathways for ground gas migration will be present. Geological factors influencing gas migration include fissures, bedding, faults, fractures and joints within consolidated strata. Grain size, grain shape and packing will all affect permeability within unconsolidated materials. It has been noted that direct seepage of ground gases through isolated fissures may have a greater potential impact than a more generalized seepage of ground gas through a permeable material such as gravel or sand.

LFG flow in the subsurface, is controlled by the permeability of the strata. Anisotropy is the property of being directionally dependent. Permeability anisotropy, shown on Figure 15, can have significant influence on the direction of LFG migration. Most sedimentary deposits have graded bedding as shown on Figure 15 (top right corner) with fining upwards sequences -coarse fractions at their base and finer fractions at their top. Sedimentary sequences often have horizontal permeability greater than the vertical by a factor of 10 and where clay and silt layers are present the difference can be as great as a factor of 100. A greater horizontal permeability versus vertical also holds true for most anthropogenic deposits, such as engineered fill, made ground and landfill, which have been subjected to systematic deposition and compaction in layers.

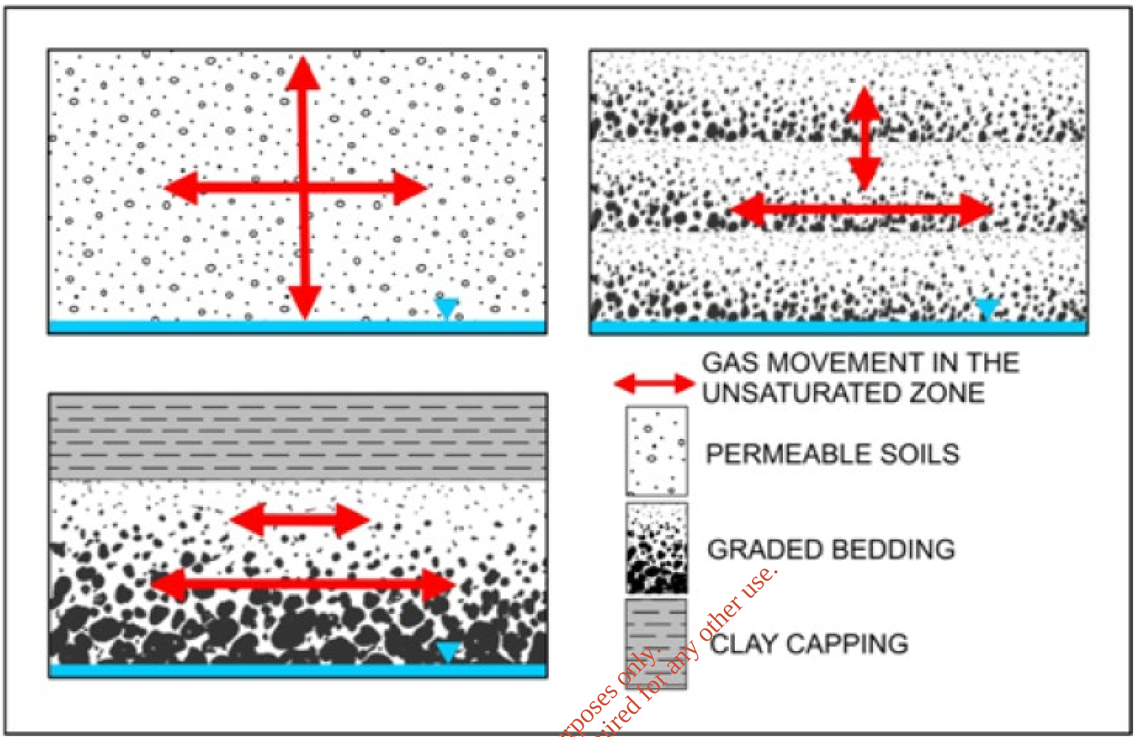

Figure 15: Permeability Anisotropy

Top left - poorly graded bedding; Top right - normally graded bedding; Bottom left - capped graded bedding. (Source Talbot & Card 2019)

Where the permeable stratum is trapped beneath a capping layer, gas migration will only be controlled by the horizontal permeability as shown on Figure 15.

Another effect of precipitation or freezing temperatures (especially in clay-rich soil) would be a temporary sealing of the ground surface, either trapping ground gases within the ground or causing emissions of ground gases in a different location. Where the ground gas is trapped, generation is likely to continue at the same rate, which will result in increased gas pressure.

Methane will be saturated in water at 25 mg/l at standard temperature and pressure (STP), while carbon dioxide will be saturated in water at 1,450 mg/l at STP. The concentrations of carbon dioxide and methane can be significantly modified by the carbon dioxide being preferentially 'stripped out' by going into solution when it passes through wet soils. The resulting percentage of methane left in the gas plume will be 'enriched' as the total must still add up to 100 percent.

A.6 Groundwater Table or Leachate Level Movement

A rise in water table level due to precipitation with subsequent groundwater recharge would raise the water table and increase gas pressure in soil pore spaces, hence increasing flow of ground gases. The effects of the tide can have a marked impact on ground gas behaviour. The changing tide results in rises and falls in the groundwater table, this effect can be termed the 'piston effect', which effectively describes the interaction between the expanding groundwater table and the upward or outward movement of ground gas because of this. At Digby Bridge we have not observed any rapid changes in the groundwater table over the study period, reported in the Tier 2 report.

A.7 Microbial Transformations of Carbon Dioxide and Methane

Aerobic microbial oxidation of the methane to water and carbon dioxide is predominant in the upper layers of the soil, where such bacteria are abundant and oxygen is readily available close to the atmosphere. Microbial activity is influenced by temperature, nutrient availability, and oxygen concentration.

An LFG plume migrating through the subsurface soils/fractured rock will be characterised by a source of gas at one end and a leading edge that travels back and forth in direct response to any atmospheric pumping, which is caused by atmospheric pressure changes or to any groundwater level changes. The LFG plume will have its composition altered by the microbes present in the soil. In some cases, a landfill gas will have a methane leading edge that lags behind a carbon dioxide leading edge due to the progressive oxidation of the methane to carbon dioxide as shown on Figure 16.

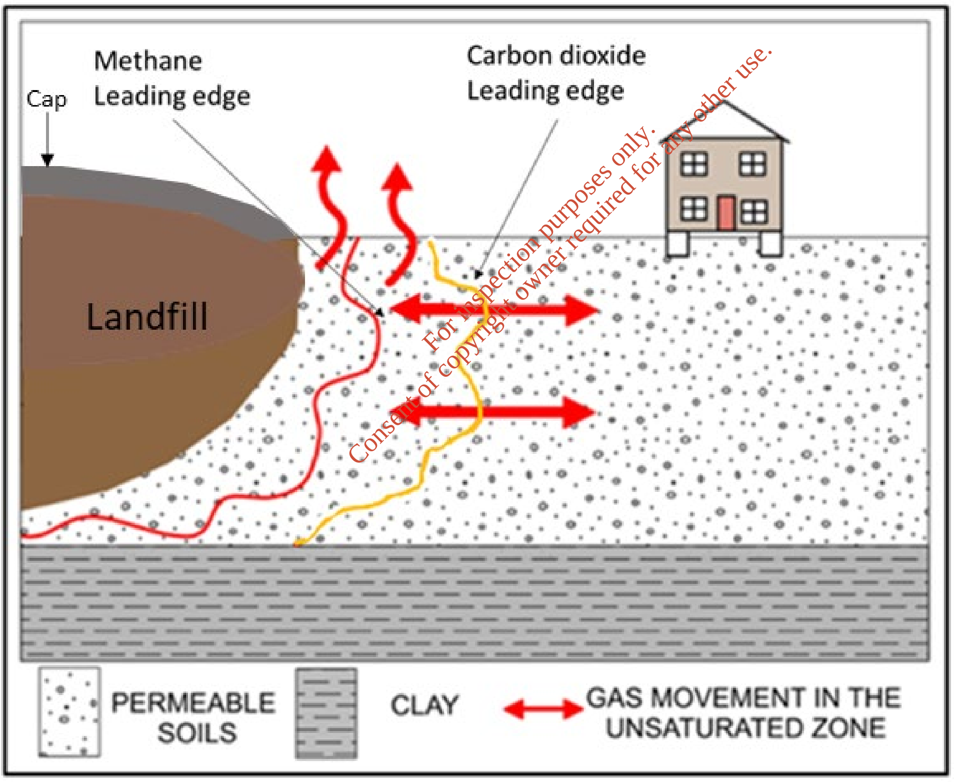

Figure 16: LFG Plume Migrating Within the Subsurface

A carbon dioxide leading edge followed by a methane leading edge. (Modified from Talbot & Card 2019)

There have been many investigations of methane oxidation in landfill top covers and only a few investigations have looked at methane oxidation in soils adjacent to a landfill (Christophersen et al. 2001). Many older landfills, which are placed in abandoned gravel pits are unlined. Compacted waste and impermeable top covers encourage lateral gas migration as there is potential for pressure differential and lateral gas migration.

Microbial methane oxidation is temperature dependent. A significant seasonal variation in emissions exists with high carbon dioxide and low methane fluxes in the summer (May to October), while a lower flux of carbon dioxide and a higher methane flux exists in the winter (November to April).

Estimates of the fraction of LFG which could be oxidised by methanotrophs and which is actually oxidised, range from 10 – 46% (Borjesson et al 2000). GasSimLite model assumes a mean value of 25%. Some studies have shown 80% of LFG can be oxidized.

A.8 Wind Induced Dispersion

Riley et al. (1999) found gas pressure fluctuations near the soil surface of magnitude 0.02–0.04 hPa at an average wind speed of 8.3 m/s. These pressure fluctuations cause both horizontal and vertical movement of the soil gas.

In Denmark, wind speeds of 10–15 m/s are often observed which would correspond to pressure fluctuations of 0.6–1.5 hPa, the subsoil of the study area was predominantly course sand and gravel. The hourly wind from the Met Éireann station at Parnell Park is summarized in Table 17.

Table 17: Summary of Wind Speed and Duration since 1990 at Parnell Park

Wind Speed (m/s)	No of hours	As % of time	Totalling percentage
0	984	0.37	0.4
1	19134	7.26	7.63
2	31890	12.09	19.72
3	33830	12.83	32.55
4	34327	13.02	45.57
5	33521	12.71	58.28
6	27048	10.26	68.53
7	22376	8.48	77.02
8	18158	6.89	83.90
9	14095	5.34	89.25
10	9732	3.69	92.94
11	6647	2.52	95.46
12	4828	1.83	97.29
13	2945	1.12	98.41
14	1720	0.652	99.06
15	1137	0.431	99.49
16	633	0.240	99.73
17	338	0.128	99.86
18	186	0.071	99.93
19	70	0.0265	99.96
20	48	0.0182	99.975
21	35	0.0133	99.988
22	22	0.0083	99.997
23	6	0.0023	99.999
25	1	0.0004	99.999
26	2	0.0008	100.000

The subsoil material at Digby Bridge is predominately gravely sand, with sandy gravelly clay topsoil on top. It is reasonable to conclude that wind induced dispersion is a factor in gas transport in the subsoil, if the top layer is not completely saturated or frozen.

A.9 Modelling Lateral LFG Movement and Risk Assessment

Lateral movement of landfill gases in soils is a significant risk. The literature concerning lateral landfill gas movement in soils surrounding old landfills is very limited (Poulsen *et al*. 2001). A search of the literature by CDM Smith have found that there has been limited additional work in this field. There is no guidance document outlining a framework for the assessment of the risk related to lateral migration of LFG issued by Ireland/UK/Germany that adequately defines the testing and information required of a site investigation to begin modelling/assessing the risk to offsite receptors by lateral/horizontal LFG migration, compared to the assessments accrued out for detailed quantitative risk assessment for groundwater.

GasSim does not simulate acute time frame, low probability events, e.g. rapid lateral migration of gases into buildings that could result in the development of an explosive atmosphere, as these events do not lie within the context of a long-term risk assessment model.

There are empirical approaches, to assessing the risk which involve probing and spot measurements. The measurements reflect gas concentrations at fixed point in time and even with multiple rounds of measurement. They may not capture an event of significant pressure change and as such fail to capture the worst case. The greatest risk exists during a significant pressure change, if a monitoring round were to occur in the summer with higher microbial degradation rates, lower soil moisture content, with the least number and size of pressure differentials, it is likely the risk will not be captured by the assessment.

CIRIA publication R152 (O'Riordan et al, 1995) looks at the fault tree analysis (FTA) for gas assessment and had previously been adapted to assess risk from landfill gas. FTA is a top-down, deductive failure analysis in which an undesired state of a system is analysed using Boolean logic to combine a series of lower-level events. This analysis method is mainly used in safety engineering and reliability engineering to understand how systems can fail, to identify the best ways to reduce risk and to determine (or get a feeling for) event rates of a safety accident or a particular system level (functional) failure. FTA fits an engineered landfill and assessing the risk if an engineered system fails. FTA is not detailed quantitative risk assessment, which estimates/predicts a concentration at the receptor based on a concentration at the source, while understanding the pathway processes and their potential to reduce contaminant concentration by dilution, attenuation and biodegradation.

Appendix B
Approach to Modelling Gas Generation

B.1 Classical Method – Model A

The gas potential is defined as the amount of gas produced from one tonne (Mg) of waste under the conditions encountered at a landfill. In the laboratory, this amount of gas can be determined in relatively short periods of time. It has been shown that between 120 and 300 m^3 of biogas (landfill gas) can be obtained from one tonne of household waste under laboratory conditions. For the present assessment an average gas potential of 170 m^3/Mg-waste was used. This is based on studies of long-term LFG potential from landfill waste (Kruempelbeck, 2000), see Table 18.

Table 18 LFG Potential from Landfill Waste

Author	LFG Potential m^3/Mg of Waste	Comments
Tabasaran, 1976	60-180	From practice
Ham et al., 1979	60-350	predicts a gas rate of 6-35 m^3/Mg annually over 10 years
Stegmann und Dernbach, 1982	150-200	Determined experimentally
Bingemer and Crutzen, 1987 cited in Schön et al., 1993	300	Determined from carbon content, premise of: CH_4: CO_2 = 1:1
Tabasaran and Rettenberger, 1987	375	Calculated from carbon content
Grassl etal., 1991 cited in Schön et al., 1993	150-200	-
Ehrig, 1991	128-230	-
Rettenberger and Mezger, 1992	150-235	-

B.2 First Order Decay Method - IPCC Guidelines of 2006

The basic equation for the First Order Model (according to IPCC Guidelines) is:

1. $DDOCm = DDOCm_{(0)} * e^{-kt}$

DDOC	decomposable degradable organic carbon (under anaerobic conditions)
DDOCm	mass of DDOC at all times
$DDOCm_{(0)}$	mass of degradable organic carbon (DOC) at the start of the reaction when t = 0 and e^{-kt} = 1
k	reaction constant
t	time in years (half-life)
e	base of the natural logarithm (mathematical constant)

From equation 1. it is easy to see that at the end of year 1 (from point 0 to point 1 on the time axis) the mass of remaining DDOC not degraded in the solid waste disposal site is as follows:

2. $DDOCm_{(1)} = DDOCm_{(0)} * e^{-k}$

$DDOCm_{(1)}$	mass of degradable organic carbon (DOC) at the end of the reaction when t = 1 year

And the mass of the DDOC; divided into CH_4 and CO_2 will be as follows:

3. $DDOCm\ decomp_{(1)} = DDOCm_{(0)} * (1 - e^{-k})$	
$DDOCm\ decomp_{(1)}$	total mass of DDOC decomposed in one year

In the first order reaction, the amount of product (here $DDOCm\ decomp_{(1)}$) is always proportional to the amount of reactant (here $DDOCm_{(0)}$). This means that it does not matter when the DDOCm was deposited. Thus, CH_4 production can be calculated as if every year was the year number one in the time series. Then all calculations can be made by equations *2.* and *3*. in a simple table.

By default, it is assumed that CH_4 formation from all annually deposited waste starts on the 1st of January of the year following the deposit. This corresponds to an average delay of six months before significant CH_4 formation starts (the time taken for anaerobic conditions to develop or become established).

However, the present calculation also includes the possibility of an earlier start of the reaction in the year in which the waste is landfilled. This requires a separate calculation for the year of landfilling.

To calculate the mass of degradable DDOC (DDOCm) from the quantity of waste (W)

4. $DDOCm\ d_{(T)} = W_{(T)} * DOC * DOC_f * MCF$	
T	the year of inventory
$DDOCm\ d_{(T)}$	mass of DDOC deposited in year T
$W_{(T)}$	amount of waste deposited in year T
DOC	degradable organic carbon (under aerobic conditions)
DOC_f	fraction of DOC decomposing under anaerobic conditions
MCF	methane correction factor

The quantity of deposited DDOCm that is not removed at the end of storage year T:

5. $DDOCm\ rem_{(T)} = DDOCm\ d_{(T)} * e^{(-k * ((13-M)/12)}$	
$DDOCm\ rem_{(T)}$	mass of DDOC deposited in inventory year T, remaining not decomposed at the end of year
M	Month of reaction start (= delay time + 7)

The quantity of deposited DDOCm that was removed during the storage year T:

6. $DDOCm\ dec_{(T)} = DDOCm\ d_{(T)} * (1 - e^{(-k * ((13-M)/12))})$	
$DDOCm\ dec_{(T)}$	mass of DDOC deposited in inventory year T, decomposed during the year

The DDOCm amount accumulated in the landfill at the end of the year, amounting to T

7. $DDOCm\ a_{(T)} = DDOCm\ rem_{(T)} + (DDOCm\ a_{(T-1)} * e^{-k})$	
$DDOCm\ a_{(T)}$	total mass of DDOC left not decomposed at end of year T
$DDOCm\ a_{(T-1)}$	total mass of DDOC left not decomposed at end of year T-1

The total amount of DDOCm that is degraded in year T is given below:

8. $DDOCm\ decomp_{(T)} = DDOCm\ dec_{(T)} + (DDOCm\ a_{(T-1)} * (1 - e^{-k)}))$	
$DDOCm\ decomp_{(1)}$	total mass of DDOC decomposed in one year

The amount of CH_4 that is removed from the DOC.

9. $CH_4\ generated_{(T)} = DDOCm\ decomp_{(T)} * F * 16/12$	
$CH_4\ generated_{(T)}$	CH_4 generated in year T
F	Fraction of CH4 by volume in generated landfill gas
16/12	molecular weight ratio CH_4/C

Determination of the amount of CH_4 emitted - Methane release:

10. $CH_4\text{-Emissions per year} = (\Sigma x CH_4\ generated_{(x,T)} - R_{(T)}) - (1- OX_{(T)})$	
x	material fraction/waste category
$R_{(T)}$	recovered CH_4 in year T
$OX_{(T)}$	oxidation factor in year T (fraction)

Appendix C
Field Data from LFG Extraction Tests

CDM Smith

Gas Investigation - Extraction & Measurement

Project:	Digby Bridge	**Hole ID:**	MW03	**Analyser:**	GA 2000
Location:	Co. Kildare, Ireland	**Site Staff:**	Colin Fitzgerald & David Tynan		
Date:	23/01/2020	**Weather Conditions:**	Dense fog, mild		

All depths from Top of Casing

Time Start/End	Depth of Intake [m bToC]	Depth of Temp. Sensor [m bToC]	CH_4 [Vol.-%]	CO_2 [Vol.-%]	O_2 [Vol.-%]	Balance [Vol.-%]	H_2S [ppm]	LEL [CH_4 -%]	Baro Pressure [hPa]	Relative Pressure ["H_2O]	Temp. [°C]	Velocity [m/s]	Flow [m³/h]	Negative pressure [-hPa]
10:39:00	0	-	0.1	1.1	19.9	78.8	0	2	1028.1	-0.05	-	-	-	-
10:47:00	-	5.8	-	-	-	-	-	-	-	-	15.6	-	-	-
10:49:00	0	5.8	0.2	0.1	20.7	79.0	0	3	1027.4	-0.13	15.8	0.9	5.15	-1.0
10:59:00	0	5.8	0.2	7.9	15.1	76.8	0	4	1027.4	-0.13	16.2	1.1	6.30	-1.0
11:09:00	0	5.8	0.2	7.8	15.2	76.6	0	3	1026.8	-0.13	15.9	1.0	5.73	-1.0
11:19:00	0	5.8	0.2	7.7	15.2	76.9	0	3	1026.8	-0.03	15.5	1.2	6.87	-0.9
11:29:00	0	5.8	0.2	7.9	14.8	77.1	0	3	1026.8	0.00	14.9	1.4	8.02	-1.1
11:39:00	0	5.8	0.2	8.1	14.5	77.2	0	4	1026.4	-0.19	14.9	1.8	10.31	-1.1
11:49:00	0	5.8	0.2	8.0	14.5	77.3	0	4	1026.4	-0.20	15.0	1.6	9.16	-1.1
11:59:00	0	5.8	0.2	8.1	14.5	77.2	0	4	1026.1	0.63	15.1	1.9	10.88	-1.2
12:09:00	1	1	0.2	7.6	14.9	77.3	0	4	1025.7	-0.03	10.4	1.7	9.73	-1.2
12:19:00	2	2	0.3	8.8	13.1	77.7	0	5	1025.4	-0.05	11.8	1.8	10.31	-1.1
12:29:00	3	3	0.5	16.5	7.0	76.0	0	9	1025.4	-0.10	13.5	1.7	9.73	-1.1
12:39:00	4	4	0.6	17.8	5.6	76.0	0	11	1025.1	-0.06	14.9	1.9	10.88	-1.1
12:49:00	5	5	0.6	21.1	2.2	76.1	0	11	1024.7	-0.07	15.5	1.9	10.88	-1.1
12:59:00	6	6	0.6	21.1	2.1	76.2	0	11	1024.7	-0.07	15.7	1.9	10.88	-1.1
13:09:00	7	7	0.6	22.5	0.6	76.2	0	11	1024.7	-0.06	16.0	1.9	10.88	-1.1
13:19:00	8	8	0.7	23.0	0.0	76.5	0	14	1024.4	-0.08	16.0	1.8	10.31	-1.1
13:29:00	9	9	0.7	23.2	0.0	76.3	0	14	1024.4	-0.12	15.9	1.8	10.31	-1.1
13:39:00	10	10	0.8	23.1	0.0	76.1	0	15	1024.7	-0.09	15.4	1.8	10.31	-1.1
13:49:00	11	11	0.7	23.1	0.0	76.2	0	14	1024.4	-0.05	14.9	1.7	9.73	-1.1
13:59:00	12	12	0.7	23.2	0.0	76.0	0	14	1024.4	-0.08	14.4	1.7	9.73	-1.1
14:09:00	11	11	0.7	23.3	0.0	76.0	0	11	1024.4	-0.08	14.5	1.7	9.73	-1.1
14:19:00	10	10	0.7	23.1	0.0	76.0	0	14	1024.4	-0.08	15.1	1.8	10.31	-1.1
14:29:00	9	9	0.8	23.3	0.0	75.9	0	16	1024.4	-0.08	14.6	1.8	10.31	-1.1
14:39:00	8	8	0.8	23.4	0.0	75.8	0	16	1024.0	-0.11	14.5	1.6	9.16	-1.0
14:49:00	7	7	0.8	23.2	0.1	75.8	0	16	1024.0	-0.08	15.3	1.6	9.16	-1.0
14:59:00	5	5	0.8	23.1	0.1	75.9	0	16	1023.7	-0.09	15.6	1.6	9.16	-1.0
15:09:00	3	3	1.3	17.7	5.2	75.6	0	25	1023.7	-0.09	14.4	1.6	9.16	-1.0

Gas Investigation - Extraction & Measurement

Project:	Digby Bridge	**Hole ID:**	MW05	**Analyser:**	GA 2000
Location:	Co. Kildare, Ireland	**Site Staff:**	Colin Fitzgerald and David Tynan		
Date:	17/01/2020	**Weather Conditions:**	Sunny, clear, intermittent cloud and drizzle later in the day		

All depths from Top of Casing

Time Start/End	Depth of Intake [m bToC]	Depth of Temp. Sensor [m bToC]	CH_4 [Vol.-%]	CO_2 [Vol.-%]	O_2 [Vol.-%]	Balance [Vol.-%]	H_2S [ppm]	LEL [CH_4 -%]	Baro Pressure [hPa]	Relative Pressure ["H_2O]	Temp. [°C]	Velocity [m/s]	Flow [m³/h]	Negative pressure [-hPa]
09:36:00	0	3.5	0.1	0.6	20.4	78.9	0	2	1005.1	-0.24	-	-	-	-
09:45:00	0	3.5	0.1	17.5	3.4	78.9	0	2	1005.8	-11.07	3.4	0.9	5.15	-1.1
09:55:00	0	3.5	0.1	17.8	3.3	78.9	0	2	1006.1	-0.52	13.1	0.9	5.15	-1.0
10:05:00	0	3.5	0.1	17.5	3.6	78.5	0	2	1006.4	0.09	12.7	0.9	5.15	-1.0
10:15:00	0	3.5	0.2	17.5	3.6	78.7	0	3	1006.8	-0.27	12.4	0.8	4.58	-1.0
10:25:00	0	3.5	0.1	17.3	3.9	78.7	0	2	1006.8	-16.66	12.6	0.9	5.15	-1.0
10:35:00	0	3.5	0.1	17.0	4.4	78.5	0	2	1007.1	-0.43	12.3	1.2	6.87	-1.5
10:45:00	0	3.5	0.1	16.5	5.0	78.4	0	2	1007.5	-0.43	11.2	1.6	9.16	-1.5
10:55:00	0	3.5	0.2	16.2	5.4	78.3	0	3	1007.8	-0.38	12.5	1.2	6.87	-1.8
11:05:00	0	3.5	0.1	15.9	5.9	78.3	0	2	1007.8	-107.26	12.3	1.7	9.73	-1.8
11:15:00	0	3.5	0.1	15.6	6.2	78.0	0	2	1007.8	0.92	11.0	1.4	8.02	-1.6
11:25:00	0	3.5	0.2	15.2	6.8	77.9	0	3	1008.1	-137.69	11.4	1.5	8.59	-1.5
11:35:00	0	3.5	0.2	15.0	6.9	77.9	0	3	1008.1	-106.30	11.2	1.4	8.02	-1.5
11:45:00	0	3.5	0.2	14.8	7.0	78.0	0	3	1008.1	-0.41	11.0	1.4	8.02	-1.5
11:55:00	0	3.5	0.2	14.6	7.1	78.1	0	3	1008.1	-0.52	11.0	1.7	9.73	-1.5
12:05:00	0	3.5	0.1	14.3	7.5	78.0	0	3	1008.1	-35.84	10.3	1.7	9.73	-1.5
12:15:00	0	3.5	0.2	14.1	7.8	78.1	0	3	1008.1	0.30	10.8	1.7	9.73	-1.0
12:25:00	0	3.5	0.2	14.0	7.4	78.5	0	3	1008.1	3.57	10.7	1.8	10.31	-2.0
13:25:00	0	3.5	0.2	13.1	7.8	78.9	0	4	1008.1	0.80	11.9	1.7	9.73	-1.7
13:35:00	0	3.5	0.2	12.9	7.9	78.7	0	4	1008.1	0.32	11.3	1.7	9.73	-1.8
13:45:00	0	3.5	0.2	12.9	8.1	78.9	0	4	1008.1	0.44	10.8	1.2	6.87	-1.5
13:55:00	0	3.5	0.2	12.8	8.1	78.9	0	4	1007.8	0.06	10.4	1.5	8.59	-1.3
14:05:00	0	3.5	0.2	12.6	8.1	79.1	0	4	1007.8	0.03	10.5	1.1	6.30	-1.5
14:15:00	0	3.5	0.2	12.6	8.0	79.2	0	4	1007.8	-0.37	10.4	1.3	7.44	-1.3
14:25:00	0	3.5	0.2	12.6	8.0	79.2	0	4	1007.5	-0.05	11.1	1.3	7.44	-1.3
14:35:00	0	3.5	0.2	12.4	8.2	79.2	0	4	1007.8	-0.05	11.4	1.3	7.44	-1.5
14:45:00	0	3.5	0.2	12.3	8.3	79.2	0	4	1007.8	-0.04	9.3	1.0	5.73	-1.3
14:55:00	0	3.5	0.2	12.2	8.5	79.1	0	4	1008.1	-0.03	8.7	0.9	5.15	-1.2
15:05:00	0	3.5	0.2	12.1	8.6	79.1	0	4	1008.1	-0.04	7.0	1.1	6.30	-1.4
15:15:00	0	3.5	0.2	11.9	9.0	79.0	0	4	1008.5	-0.32	12.3	1.1	6.30	-1.2
15:25:00	0	3.5	0.2	11.8	9.2	79.0	0	4	1008.8	-0.70	12.4	2.9	16.60	-2.0
15:35:00	0	3.5	0.2	11.7	9.1	79.1	0	4	1009.1	-0.77	12.6	2.2	12.60	-2.0

Gas Investigation - Extraction & Measurement

Project: Digby Bridge | **Hole ID:** MW07A | **Analyser:** GA 2000

Location: Co. Kildare, Ireland | **Site Staff:** Colin Fitzgerald & David Tynan

Date: 20/01/2020 | **Weather Conditions:** Partly sunny, cool

All depths from Top of Casing

Time Start/End	Depth of Intake [m bToC]	Depth of Temp. Sensor [m bToC]	CH_4 [Vol.-%]	CO_2 [Vol.-%]	O_2 [Vol.-%]	Balance [Vol.-%]	H_2S [ppm]	LEL [CH_4 -%]	Baro Pressure [hPa]	Relative Pressure ["H_2O]	Temp. [°C]	Velocity [m/s]	Flow [m³/h]	Negative pressure [-hPa]
09:56:00	0	2.45	0.1	6.6	17.3	76.2	0	2	1043.3	2.24	8.3	1.0	5.73	-22.1
10:06:00	0	2.45	0.1	6.5	16.7	76.8	0	2	1043.7	-0.12	8.7	1.0	5.73	-22.4
10:16:00	0	2.45	0.1	6.6	16.5	76.8	0	2	1044.7	-0.04	8.5	1.1	6.30	-22.4
10:26:00	0	2.45	0.1	6.5	16.3	77.1	2	2	1044.7	-0.04	8.3	1.2	6.87	-28.4
10:36:00	0	2.45	0.1	6.5	16.4	77.1	0	2	1043.0	0.66	9.4	1.1	6.30	-30.0
10:46:00	0	2.45	0.1	6.7	16.0	77.2	0	2	1037.6	-11.94	8.6	1.2	6.87	-30.0
10:56:00	0	2.45	0.1	6.7	16.1	77.2	4	2	1044.0	-11.87	10.9	1.3	7.44	-30.0
11:06:00	0	2.45	0.1	7.2	15.6	77.1	2	2	1043.7	-0.04	13.9	1.3	7.44	-39.8
11:16:00	0	2.45	0.1	7.2	16.1	76.0	6	2	1043.7	-15.57	14.4	1.5	8.59	-39.8
11:26:00	0	2.45	0.1	7.4	15.5	76.0	6	2	1043.3	-15.43	13.8	1.6	9.16	-39.0
11:36:00	0	2.45	0.1	7.5	15.3	77.1	0	2	1041.7	-15.61	13.6	1.6	9.16	-38.9
11:46:00	0	2.45	0.1	7.5	15.2	77.3	0	2	1042.7	-15.20	8.1	1.6	9.16	-38.5
11:56:00	0	2.45	0.1	7.6	15.1	77.2	4	2	1022.4	-3.13	8.4	1.6	9.16	-37.4
12:06:00	0	2.45	0.1	7.7	15.1	77.1	0	2	1042.3	-10.40	8.2	1.5	8.59	-37.0
12:16:00	0	2.45	0.1	7.7	15.0	77.2	5	2	1042.0	-6.85	8.2	1.5	8.59	-36.5
12:26:00	0	2.45	0.1	7.7	14.9	77.2	0	2	1042.0	-14.39	8.2	1.5	8.59	-36.1
12:36:00	0	2.45	0.1	7.8	14.9	77.2	6	2	1042.0	-14.23	8.0	1.5	8.59	-36.0
12:46:00	0	2.45	0.1	7.9	14.7	77.3	0	2	1040.6	-0.19	7.8	1.5	8.59	-35.3
13:46:00	0	2.45	0.1	7.9	14.6	77.4	8	2	1041.3	-0.06	18.0	1.6	9.16	-33.5
13:56:00	0	2.45	0.1	8.1	14.5	77.3	2	2	1041.0	-0.05	16.5	1.9	10.88	-39.2
14:06:00	0	2.45	0.1	8.1	14.5	77.3	0	2	1040.6	-0.04	14.2	1.7	9.73	-37.8
14:16:00	0	2.45	0.1	8.2	14.5	77.3	0	2	1040.6	-10.15	15.6	1.8	10.31	-36.8
14:26:00	0	2.45	0.1	8.3	14.3	77.3	0	2	1040.0	-14.24	13.0	1.8	10.31	-36.0
14:36:00	0	2.45	0.1	8.3	14.3	77.3	5	2	1040.0	-14.13	12.9	2.0	11.45	-32.1
14:46:00	0	2.45	0.1	8.4	14.3	77.3	0	2	1040.3	-12.32	12.5	1.9	10.88	-31.0
14:56:00	0	2.45	0.1	8.4	14.2	77.3	0	2	1040.3	-12.17	11.9	1.9	10.88	-30.8
15:06:00	0	2.45	0.1	8.5	14.2	77.2	0	2	1040.3	-12.15	12.4	1.9	10.88	-30.6
15:16:00	0	2.45	0.1	8.5	14.2	77.2	0	2	1040.3	-11.99	12.1	1.9	10.88	-30.2
15:26:00	0	2.45	0.1	8.3	14.4	77.2	0	2	1040.3	-13.51	10.0	1.7	9.73	-34.0
15:36:00	0	2.45	0.1	8.4	14.3	77.2	0	2	1040.3	-13.16	9.6	1.8	10.31	-33.0

Gas Investigation - Extraction & Measurement

Project:	Digby Bridge	**Hole ID:**	MW08A	**Analyser:** GA 2000
Location:	Co. Kildare, Ireland	**Site Staff:**	Colin Fitzgerald and David Tynan	
Date:	15/01/2020	**Weather Conditions:**	Partly sunny, cool	

All depths from Top of Casing

Time Start/End	Depth of Intake [m bToC]	Depth of Temp. Sensor [m bToC]	CH_4 [Vol.-%]	CO_2 [Vol.-%]	O_2 [Vol.-%]	Balance [Vol.-%]	H_2S [ppm]	LEL [CH_4 -%]	Baro Pressure [hPa]	Relative Pressure ["H_2O]	Temp. [°C]	Velocity [m/s]	Flow [m³/h]	Negative pressure [-hPa]
11:01:00	0	2	9.4	14.8	6.0	71.1	0	>>>	996.6	-0.06	9.0	-	-	-
11:54:00	0	2	8.6	15.1	4.9	72.5	0	>>>	997.0	-0.05	9.8	0.9	5.15	-9.0
12:04:00	0	2	8.9	15.4	2.0	73.9	0	>>>	997.0	-0.05	8.1	0.9	5.15	-9.0
12:14:00	0	2	9.0	15.4	1.7	73.9	0	>>>	997.0	-0.05	8.2	1.0	5.73	-9.0
12:23:00	0	2	9.1	15.5	2.6	73.4	0	>>>	997.0	-0.05	8.7	1.2	6.87	-9.0
12:32:00	0	2	9.0	15.4	1.3	74.0	0	>>>	997.0	-0.05	9.3	1.4	8.02	-9.0
12:44:00	0	2	9.2	15.6	1.5	73.8	0	>>>	997.0	-0.05	9.9	1.5	8.59	-9.0
12:54:00	0	2	9.2	15.5	1.5	73.9	0	>>>	997.0	-0.05	11.1	2.8	15.75	-9.0
13:04:00	0	2	9.2	15.6	1.8	73.5	0	>>>	997.0	-0.05	11.8	3.0	17.18	-15.0
13:14:00	0	2	9.4	15.5	2.8	72.5	0	>>>	996.3	-0.03	11.4	2.9	16.60	-
13:24:00	0	2	9.3	15.4	3.9	72.0	0	>>>	996.6	-0.04	9.3	2.7	15.46	-
13:34:00	0	2	9.2	15.6	1.4	73.9	0	>>>	997.0	2.33	12.9	2.6	14.89	-
13:44:00	0	2	9.1	15.6	1.2	74.1	0	>>>	997.0	-0.39	11.0	2.4	13.74	-
13:54:00	0	2	9.0	15.4	5.7	70.9	0	>>>	997.0	-5.91	13.0	2.3	13.17	-
14:04:00	0	2	8.8	15.6	2.2	73.6	0	>>>	997.0	-4.06	11.6	2.4	13.74	-
14:14:00	0	2	8.7	15.3	5.2	71.6	0	>>>	997.0	-5.32	12.6	1.7	9.73	-14.0
14:24:00	0	2	8.6	15.5	1.5	74.4	0	>>>	997.3	-0.64	12.5	2.0	11.45	-15.0
14:34:00	0	2	8.4	15.5	1.7	74.5	0	>>>	997.3	-5.92	11.2	2.2	12.60	-15.0
14:44:00	0	2	8.2	15.5	1.9	74.7	0	>>>	997.6	-1.31	11.3	2.2	12.60	-15.0
14:54:00	0	2	8.2	15.6	1.2	75.1	0	>>>	997.6	-1.31	11.1	2.0	11.45	-15.0
15:04:00	0	2	8.1	15.6	1.1	75.1	0	>>>	997.6	-1.31	10.7	1.8	10.31	-15.0
15:14:00	0	2	7.9	15.6	1.3	75.3	0	>>>	997.6	-1.31	8.3	1.8	10.31	-15.0
15:24:00	0	2	7.8	15.6	1.3	75.4	0	>>>	997.6	-1.31	8.4	1.9	10.88	-15.0
15:34:00	0	2	7.7	15.7	1.1	75.5	0	>>>	997.6	-1.31	8.2	2.0	11.45	-15.0
15:44:00	0	2	7.6	15.7	1.1	75.6	0	>>>	997.6	-1.31	8.0	2.0	11.45	-15.0

>>>	Overrange reading. When Methane exceeds 4.8%, the LEL exceeds 100% and is then overrange.

CDM Smith

Gas Investigation - Extraction & Measurement

Project: Digby Bridge
Location: Co. Kildare, Ireland
Date: 16/01/2020

Hole ID: MW09
Site Staff: Colin Fitzgerald and David Tynan
Weather Conditions: Intermittent cloud, heavy rain, mild

Analyser: GA 2000

All depths from Top of Casing

Time Start/End	Depth of Intake [m bToC]	Depth of Temp. Sensor [m bToC]	CH_4 [Vol.-%]	CO_2 [Vol.-%]	O_2 [Vol.-%]	Balance [Vol.-%]	H_2S [ppm]	LEL [CH_4 -%]	Baro Pressure [hPa]	Relative Pressure ["H_2O]	Temp. [°C]	Velocity [m/s]	Flow [m³/h]	Negative pressure [-hPa]
10:09:00	0	3.8	53.8	21.8	0.5	23.9	4	>>>	991.9	0.06	11.1	-	-	-
10:31:00	0	3.8	51.4	27.0	0.5	21.3	0	>>>	991.2	-0.08	11.5	1.0	5.73	-0.5
10:41:00	0	3.8	51.7	26.6	0.6	21.1	0	>>>	990.9	-0.04	11.4	0.0	0.00	-1.0
10:51:00	0	3.8	51.6	26.8	0.0	21.6	0	>>>	990.5	-0.06	11.6	0.9	5.15	-0.5
11:01:00	0	3.8	51.8	26.8	0.0	21.4	0	>>>	990.2	1.67	12.0	1.0	5.73	-1.0
11:11:00	0	3.8	51.7	26.8	0.0	21.4	0	>>>	989.8	0.50	12.6	1.2	6.87	-0.9
11:21:00	0	3.8	51.9	26.9	0.0	21.2	0	>>>	989.2	1.01	11.9	1.2	6.87	-0.9
11:31:00	0	3.8	51.7	26.7	0.0	21.6	0	>>>	989.2	-0.12	11.8	1.4	8.02	-0.9
11:41:00	0	3.8	51.6	26.6	0.0	21.8	0	>>>	988.8	-138.49	11.9	2.0	11.45	-1.0
11:51:00	0	3.8	51.6	26.8	0.0	21.6	0	>>>	988.8	-138.49	11.9	1.9	10.88	-1.0
12:01:00	0	3.8	51.6	27.0	0.0	21.5	0	>>>	988.8	-138.49	10.6	2.0	11.45	-1.0
12:11:00	0	3.8	51.6	26.9	0.0	21.4	0	>>>	988.8	-138.49	10.6	2.1	12.02	-0.9
12:21:00	0	3.8	51.5	26.7	0.0	21.8	0	>>>	986.5	-33.66	10.6	2.1	12.02	-0.9
12:31:00	0	3.8	51.4	26.5	0.0	21.7	0	>>>	987.8	-0.20	10.5	2.1	12.02	-0.9
13:21:00	0	3.8	51.5	26.6	0.0	21.9	0	>>>	987.5	0.45	10.2	2.0	11.45	-1.0
13:31:00	0	3.8	51.4	26.7	0.0	21.9	0	>>>	987.5	1.09	10.2	2.3	13.17	-1.3
13:41:00	0	3.8	51.4	26.7	0.0	21.9	0	>>>	987.5	0.63	13.4	3.0	17.18	-1.4
13:51:00	0	3.8	51.4	26.7	0.0	22.0	0	>>>	987.5	0.77	13.9	2.3	13.17	-1.5
14:01:00	0	3.8	51.3	26.7	0.0	21.8	10	>>>	987.5	0.25	14.0	2.3	13.17	-1.5
14:11:00	0	3.8	51.5	26.9	0.0	21.6	4	>>>	987.5	-0.04	14.0	2.6	14.89	-1.4
14:21:00	0	3.8	51.4	26.9	0.0	21.7	4	>>>	987.5	0.34	13.9	2.5	14.31	-1.5
14:31:00	0	3.8	51.3	26.6	0.3	21.8	0	>>>	987.5	-0.40	10.2	2.4	13.74	-1.9
14:41:00	0	3.8	51.2	26.6	0.3	22.0	10	>>>	988.1	0.85	10.3	3.0	17.18	-1.9
14:51:00	0	3.8	51.3	26.7	0.2	21.7	8	>>>	988.5	-0.46	10.3	2.4	13.74	-1.9
15:01:00	0	3.8	51.4	26.7	0.2	21.7	10	>>>	988.8	-0.25	10.3	2.4	13.74	-1.5
15:11:00	0	3.8	51.4	26.7	0.3	21.6	4	>>>	987.8	-0.73	12.1	2.4	13.74	-1.9
15:21:00	0	3.8	51.4	26.7	0.3	21.7	0	>>>	989.5	-1.20	11.9	2.7	15.46	-1.9
15:31:00	0	3.8	51.6	26.8	0.1	21.5	3	>>>	989.8	-0.45	11.7	3.2	18.32	-1.9
15:41:00	0	3.8	51.5	26.9	0.1	21.5	3	>>>	989.2	1.48	10.9	2.5	14.31	-1.5
15:51:00	0	3.8	51.4	26.9	0.2	21.6	6	>>>	990.5	-0.11	11.1	2.5	14.31	-1.5
16:01:00	0	3.8	51.7	27.0	0.0	21.3	0	>>>	989.5	-0.04	11.2	2.8	16.03	-1.6

Gas Investigation - Extraction & Measurement

Project:	Digby Bridge	**Hole ID:**	MW12 (Extraction)	**Analyser:**	GA 2000
Location:	Co. Kildare, Ireland	**Site Staff:**	Ellen Waters & David Tynan		
Date:	22/01/2020	**Weather Conditions:**	Dense fog, mild		

All depths from Top of Casing

Time Start/End	Depth of Intake [m bToC]	Depth of Temp. Sensor [m bToC]	CH_4 [Vol.-%]	CO_2 [Vol.-%]	O_2 [Vol.-%]	Balance [Vol.-%]	H_2S [ppm]	LEL [CH_4 -%]	Baro Pressure [hPa]	Relative Pressure ["H_2O]	Temp. [°C]	Velocity [m/s]	Flow [m³/h]	Negative pressure [-hPa]
09:30:00	0	3.5	30.6	27.9	0.2	41.3	0	>>>	1036.2	-159.22	11.4	1.1	6.30	-1.0
09:40:00	0	3.5	30.5	27.8	1.2	40.7	0	>>>	1035.9	-116.89	8.8	0.9	5.15	-1.0
09:50:00	0	3.5	30.5	27.9	0.1	41.5	0	>>>	1035.9	-78.38	8.6	1.6	9.16	-1.0
10:00:00	0	3.5	30.4	27.8	0.4	41.2	0	>>>	1035.9	0.81	8.5	1.1	6.30	-1.0
10:10:00	0	3.5	30.4	27.9	0.2	41.5	0	>>>	1035.9	1.78	8.7	0.8	4.58	-1.0
10:20:00	0	3.5	30.4	28.0	0.0	41.6	0	>>>	1035.9	-111.61	8.7	1.0	5.73	-1.0
10:30:00	0	3.5	30.3	27.8	0.2	41.7	0	>>>	1035.6	-0.17	9.0	1.5	8.59	-1.0
10:40:00	0	3.5	30.4	27.9	0.2	41.5	0	>>>	1035.6	0.44	9.1	1.2	6.87	-1.0
10:50:00	0	3.5	30.4	28.0	0.4	41.3	0	>>>	1035.6	-0.18	9.3	1.2	6.87	-1.0
11:00:00	0	3.5	30.4	27.8	0.2	41.5	0	>>>	1035.6	2.18	9.4	1.2	6.87	-1.0
11:10:00	0	3.5	30.3	27.5	0.3	41.6	0	>>>	1035.2	-0.16	10.1	1.2	6.87	-1.0
11:20:00	0	3.5	30.3	27.7	0.1	41.8	0	>>>	1035.2	-0.15	10.4	1.2	6.87	-1.0
11:30:00	0	3.5	30.4	27.8	0.0	41.8	0	>>>	1035.2	1.25	11.6	1.2	6.87	-1.0
11:40:00	0	3.5	30.5	27.8	0.0	41.7	0	>>>	1034.9	-74.51	11.0	1.0	5.73	-1.0
11:50:00	0	3.5	30.5	27.7	0.0	41.8	0	>>>	1034.9	-74.23	11.8	1.5	8.59	-1.0
12:00:00	0	3.5	30.5	27.8	0.0	41.7	0	>>>	1034.5	0.26	11.8	0.8	4.58	-1.0
13:10:00	0	3.5	30.5	27.4	0.0	42.1	0	>>>	1034.5	-0.32	12.2	1.5	8.59	-1.0
13:20:00	0	3.5	30.9	27.6	0.0	41.6	0	>>>	1034.2	0.29	12.9	2.6	14.89	-1.0
13:30:00	0	3.5	31.0	27.8	0.0	41.2	0	>>>	1033.9	-0.04	12.7	1.5	8.59	-1.0
13:40:00	0	3.5	31.0	27.7	0.0	41.3	0	>>>	1033.9	0.02	12.3	1.8	10.31	-1.0
13:50:00	0	3.5	31.0	27.5	0.2	41.3	0	>>>	1033.5	-0.39	12.2	2.3	13.17	-0.7
14:00:00	0	3.5	31.2	27.7	0.2	41.1	0	>>>	1033.5	0.57	11.9	2.2	12.60	-0.7
14:10:00	0	3.5	31.3	27.6	0.5	40.0	0	>>>	1033.2	-110.39	11.6	2.2	12.60	-0.7
14:20:00	0	3.5	31.2	27.9	0.0	40.8	0	>>>	1033.2	-110.39	11.6	2.6	14.89	-0.7
14:30:00	0	3.5	31.3	27.7	0.0	40.9	0	>>>	1032.8	-0.44	11.6	2.0	11.45	-0.7
14:40:00	0	3.5	31.2	27.6	0.0	40.9	0	>>>	1032.8	-109.96	11.6	2.4	13.74	-0.7
14:50:00	0	3.5	31.2	27.9	0.0	40.9	0	>>>	1033.2	0.73	11.6	2.4	13.74	-0.7
15:00:00	0	3.5	31.2	27.4	0.5	40.8	0	>>>	1032.8	1.53	11.7	1.0	5.73	-1.0
15:10:00	0	3.5	31.3	27.9	0.0	40.8	0	>>>	1033.5	0.75	11.1	0.9	5.15	-0.9
15:20:00	0	3.5	31.3	27.9	0.0	40.8	0	>>>	1032.8	0.26	10.6	1.4	8.02	-0.9
15:30:00	0	3.5	31.4	27.9	0.0	40.7	0	>>>	1032.8	-0.48	10.5	1.2	6.87	-0.8

>>>	Overrange reading. When Methane exceeds 4.8%, the LEL exceeds 100% and is then overrange.

Gas Investigation - Extraction & Measurement

Project: Digby Bridge
Location: Co. Kildare, Ireland
Date: 22/01/2020

Hole ID: MW13 (Observation during MW12 Extraction)
Site Staff: Ellen Waters & David Tynan
Weather Conditions: Dense fog, mild

Analyser: GA 2000

All depths from Top of Casing

Time Start/End	Depth of Intake [m bToC]	Depth of Temp. Sensor [m bToC]	CH_4 [Vol.-%]	CO_2 [Vol.-%]	O_2 [Vol.-%]	Balance [Vol.-%]	H_2S [ppm]	LEL [CH_4 -%]	Baro Pressure [hPa]	Relative Pressure ["H_2O]	Temp. [°C]	Velocity [m/s]	Flow [m³/h]	Negative pressure [-hPa]
09:30:00	0	-	38.2	26.4	1.7	33.6	0	>>>	1036.2	-159.22	-	-	-	-
09:40:00	0	-	31.4	22.3	5.2	41.7	0	>>>	1035.9	-116.89	-	-	-	-
09:50:00	0	-	31.8	21.8	5.1	41.1	0	>>>	1035.9	-78.38	-	-	-	-
10:00:00	0	-	29.7	20.2	6.3	44.3	0	>>>	1035.9	0.81	-	-	-	-
10:10:00	0	-	27.0	18.1	7.7	47.2	0	>>>	1035.9	1.78	-	-	-	-
10:20:00	0	-	26.9	18.2	7.5	47.1	0	>>>	1035.9	-111.61	-	-	-	-
10:30:00	0	-	32.7	22.2	4.6	40.3	0	>>>	1035.6	-0.17	-	-	-	-
10:40:00	0	-	35.7	25.1	2.7	36.5	0	>>>	1035.6	0.44	-	-	-	-
10:50:00	0	-	36.2	25.0	2.4	36.4	0	>>>	1035.6	-0.18	-	-	-	-
11:00:00	0	-	34.5	24.1	3.3	38.1	0	>>>	1035.6	2.18	-	-	-	-
11:10:00	0	-	37.2	25.6	2.0	35.1	0	>>>	1035.2	-0.16	-	-	-	-
11:20:00	0	-	38.2	26.1	1.4	34.1	0	>>>	1035.2	-0.15	-	-	-	-
11:30:00	0	-	39.5	27.0	0.8	32.7	0	>>>	1035.2	1.25	-	-	-	-
11:40:00	0	-	40.4	27.4	0.4	31.8	0	>>>	1034.9	-74.51	-	-	-	-
11:50:00	0	-	40.9	27.8	0.1	31.1	0	>>>	1034.9	-74.23	-	-	-	-
12:00:00	0	-	41.5	27.9	0.0	30.7	0	>>>	1034.5	0.26	-	-	-	-
13:10:00	0	-	42.7	28.0	0.0	29.2	0	>>>	1034.5	-0.32	-	-	-	-
13:20:00	0	-	42.7	28.1	0.0	29.2	0	>>>	1034.2	0.29	-	-	-	-
13:30:00	0	-	42.8	28.2	0.0	29.0	0	>>>	1033.9	-0.04	-	-	-	-
13:40:00	0	-	42.9	28.5	0.0	28.8	0	>>>	1033.5	0.02	-	-	-	-
13:50:00	0	-	42.9	28.2	0.0	28.8	0	>>>	1033.5	-0.39	-	-	-	-
14:00:00	0	-	43.0	28.2	0.0	28.7	0	>>>	1033.5	0.57	-	-	-	-
14:10:00	0	-	43.1	28.3	0.0	28.6	0	>>>	1033.2	-110.73	-	-	-	-
14:20:00	0	-	41.2	27.3	0.8	31.0	0	>>>	1033.2	-110.39	-	-	-	-
14:30:00	0	-	42.3	27.9	0.0	29.6	0	>>>	1032.8	-0.44	-	-	-	-
14:40:00	0	-	34.9	23.6	3.5	37.9	0	>>>	1032.8	-109.96	-	-	-	-
14:50:00	0	-	25.8	17.2	8.0	49.7	0	>>>	1033.2	0.73	-	-	-	-
15:00:00	0	-	29.6	19.6	6.5	44.8	0	>>>	1032.8	1.53	-	-	-	-
15:10:00	0	-	24.6	15.9	8.7	50.8	0	>>>	1032.8	0.75	-	-	-	-
15:20:00	0	-	27.0	17.1	7.8	48.0	0	>>>	1032.8	0.26	-	-	-	-
15:30:00	0	-	12.5	8.1	14.8	4.8	0	>>>	1032.8	-0.48	-	-	-	-

>>>	Overrange reading. When Methane exceeds 4.8%, the LEL exceeds 100% and is then overrange.

CDM Smith

Gas Investigation - Extraction & Measurement

Project:	Digby Bridge	**Hole ID:**	MW13 (Extraction)	**Analyser:**	GA 2000
Location:	Co. Kildare, Ireland	**Site Staff:**	David Tynan and Ellen Waters		
Date:	21/01/2020	**Weather Conditions:**	Dry, overcast, cool		

All depths from Top of Casing

Time Start/End	Depth of Intake [m bToC]	Depth of Temp. Sensor [m bToC]	CH_4 [Vol.-%]	CO_2 [Vol.-%]	O_2 [Vol.-%]	Balance [Vol.-%]	H_2S [ppm]	LEL [CH_4 -%]	Baro Pressure [hPa]	Relative Pressure ["H_2O]	Temp. [°C]	Velocity [m/s]	Flow [m³/h]	Negative pressure [-hPa]
Initial	0	1.3	35.3	20.6	4.8	39.2	0	>>>	1039.6	-0.05	-	-	-	-
09:45:00	0	1.3	45.0	25.9	1.0	28.0	0	>>>	1039.3	1.13	10.7	1.1	6.30	-3.5
09:55:00	0	1.3	45.1	26.5	0.8	27.6	0	>>>	1039.3	-0.35	7.0	0.8	4.58	-3.0
10:05:00	0	1.3	44.8	26.4	2.2	26.8	0	>>>	1039.6	-1.00	7.1	0.8	4.58	-3.0
10:15:00	0	1.3	44.8	26.7	0.8	27.7	0	>>>	1039.6	2.04	7.0	1.0	5.73	-3.0
10:25:00	0	1.3	44.8	26.9	0.8	27.6	0	>>>	1039.3	1.56	7.3	0.8	4.58	-3.5
10:35:00	0	1.3	44.6	26.9	0.6	27.9	0	>>>	1039.3	2.70	7.4	0.8	4.58	-3.1
10:45:00	0	1.3	44.6	27.0	0.7	27.7	0	>>>	1039.3	-0.04	7.5	0.8	4.58	-3.0
10:55:00	0	1.3	44.3	26.9	0.8	27.9	0	>>>	1039.3	-0.08	7.5	1.1	6.30	-2.5
11:05:00	0	1.3	44.2	27.0	0.6	28.3	0	>>>	1039.6	0.88	7.7	1.2	6.87	-3.1
11:15:00	0	1.3	43.9	27.1	0.3	28.7	0	>>>	1038.3	-1.06	7.6	1.3	7.44	-2.1
11:25:00	0	1.3	43.6	27.0	0.5	29.1	0	>>>	1039.3	-0.40	7.5	1.3	7.44	-2.0
11:35:00	0	1.3	43.3	27.0	0.4	29.3	0	>>>	1039.3	-0.73	7.6	1.2	6.87	-2.1
11:45:00	0	1.3	43.0	27.0	0.2	29.8	0	>>>	1039.3	-0.73	7.7	1.3	7.44	-2.0
11:55:00	0	1.3	42.7	27.1	0.4	29.8	0	>>>	1039.3	-0.69	7.8	1.3	7.44	-2.1
12:05:00	0	1.3	42.5	27.0	0.4	30.1	0	>>>	1039.3	-0.67	8.1	1.3	7.44	-2.1
13:05:00	0	1.3	40.3	26.4	1.4	31.8	0	>>>	1038.9	-2.72	9.2	2.9	16.60	-7.0
13:15:00	0	1.3	39.5	26.5	0.5	33.4	0	>>>	1038.6	-0.28	8.8	3.6	20.61	-7.0
13:25:00	0	1.3	38.5	26.5	0.6	34.2	0	>>>	1038.3	1.72	8.9	2.3	13.17	-6.5
13:35:00	0	1.3	38.0	26.5	0.5	35.0	0	>>>	1038.3	-2.22	9.0	2.1	12.02	-6.0
13:45:00	0	1.3	37.4	26.3	0.5	35.0	0	>>>	1037.9	1.90	8.9	2.0	11.45	-6.0
13:55:00	0	1.3	37.0	26.6	0.5	35.9	0	>>>	1037.9	-0.16	8.9	1.1	6.30	-5.5
14:05:00	0	1.3	36.7	26.6	0.5	36.2	0	>>>	1037.6	-2.08	9.0	2.2	12.60	-5.5
14:15:00	0	1.3	36.2	26.5	0.5	36.7	0	>>>	1037.3	0.15	8.9	3.0	17.18	-5.8
14:25:00	0	1.3	35.9	26.7	0.5	37.0	0	>>>	1037.3	-0.40	8.9	2.8	16.03	-5.5
14:35:00	0	1.3	35.5	26.6	0.7	37.2	0	>>>	1037.3	-2.13	8.9	2.8	16.03	-5.5
14:45:00	0	1.3	35.2	26.6	0.6	37.6	0	>>>	1036.2	-2.33	8.8	2.8	16.03	-5.8
14:55:00	0	1.3	34.9	26.6	0.6	37.9	0	>>>	1037.3	-2.10	8.8	2.8	16.03	-5.7
15:05:00	0	1.3	34.7	26.6	0.7	38.1	0	>>>	1036.9	1.17	8.5	2.8	16.03	-5.8
15:15:00	0	1.3	34.8	27.0	0.2	37.9	0	>>>	1037.3	-0.42	8.3	2.7	15.46	-5.5

>>>	Overrange reading. When Methane exceeds 4.8%, the LEL exceeds 100% and is then overrange.

Gas Investigation - Extraction & Measurement

Project: Digby Bridge
Location: Co. Kildare, Ireland
Date: 21/01/2020

Hole ID: MW12 (Observation during MW13 Extraction)
Site Staff: Ellen Waters & David Tynan
Weather Conditions: Dry, overcast, cool

Analyser: GA 2000

All depths from Top of Casing

Time Start/End	Depth of Intake [m bToC]	Depth of Temp. Sensor [m bToC]	CH_4 [Vol.-%]	CO_2 [Vol.-%]	O_2 [Vol.-%]	Balance [Vol.-%]	H_2S [ppm]	LEL [CH_4 -%]	Baro Pressure [hPa]	Relative Pressure ["H_2O]	Temp. [°C]	Velocity [m/s]	Flow [m³/h]	Negative pressure [-hPa]
Initial	0	-	42.1	27.5	1.9	28.6	27	>>>	1039.3	-0.04	-	-	-	-
09:45:00	0	-	45.3	26.0	0.1	28.6	17	>>>	1039.3	1.13	-	-	-	-
09:55:00	0	-	46.3	25.6	0.0	28.1	18	>>>	1039.3	-0.35	-	-	-	-
10:05:00	0	-	45.0	26.8	0.6	27.6	0	>>>	1039.6	-1.00	-	-	-	-
10:15:00	0	-	47.1	24.7	0.0	28.2	11	>>>	1039.6	2.04	-	-	-	-
10:25:00	0	-	47.4	24.7	0.0	27.9	18	>>>	1039.3	1.56	-	-	-	-
10:35:00	0	-	47.8	24.6	0.0	27.6	13	>>>	1039.3	-0.82	-	-	-	-
13:05:00	0	-	38.0	30.5	2.8	28.7	0	>>>	1038.9	-2.72	-	-	-	-
13:15:00	0	-	36.2	29.8	0.0	34.0	0	>>>	1038.6	-0.28	-	-	-	-
13:25:00	0	-	33.9	28.8	0.0	37.3	0	>>>	1038.3	1.72	-	-	-	-
13:35:00	0	-	32.2	28.5	0.0	39.3	0	>>>	1038.3	-2.22	-	-	-	-
13:45:00	0	-	31.1	28.1	0.0	40.8	0	>>>	1037.9	1.90	-	-	-	-
13:55:00	0	-	30.5	27.8	0.0	41.7	0	>>>	1037.9	-0.16	-	-	-	-
14:05:00	0	-	30.2	27.4	0.0	42.4	0	>>>	1037.6	-2.08	-	-	-	-
14:15:00	0	-	30.1	27.0	0.0	42.9	0	>>>	1037.3	0.15	-	-	-	-
14:25:00	0	-	30.1	26.8	0.0	43.1	0	>>>	1037.3	-0.40	-	-	-	-
14:35:00	0	-	30.1	26.6	0.0	43.3	0	>>>	1037.3	-2.13	-	-	-	-
14:45:00	0	-	30.1	26.5	0.0	43.4	0	>>>	1036.2	-2.33	-	-	-	-
14:55:00	0	-	30.0	26.3	0.0	43.7	0	>>>	1037.3	-2.10	-	-	-	-
15:05:00	0	-	30.1	26.1	0.0	43.8	0	>>>	1036.9	1.17	-	-	-	-

>>> Overrange reading. When Methane exceeds 4.8%, the LEL exceeds 100% and is then overrange.

Gas Investigation - Extraction & Measurement

Project: Digby Bridge
Location: Co. Kildare, Ireland
Date: 24/01/2020

Hole ID: MW14
Site Staff: Colin Fitzgerald & David Tynan
Weather Conditions: Intermittent cloud, Mild

Analyser: GA 2000

All depths from Top of Casing

Time Start/End	Depth of Intake [m bToC]	Depth of Temp. Sensor [m bToC]	CH_4 [Vol.-%]	CO_2 [Vol.-%]	O_2 [Vol.-%]	Balance [Vol.-%]	H_2S [ppm]	LEL [CH_4 -%]	Baro Pressure [hPa]	Relative Pressure ["H_2O]	Temp. [°C]	Velocity [m/s]	Flow [m³/h]	Negative pressure [-hPa]
09:05:00	0	3.15	58.2	37.0	0.0	4.8	6	>>>	1020.7	-0.41	-	-	-	-
09:30:00	0	3.15	54.6	35.2	0.8	9.0	0	>>>	1020.3	1.17	8.0	2.1	12.02	-2.0
09:40:00	0	3.15	57.0	36.6	0.3	6.1	0	>>>	1020.0	1.89	8.2	3.3	18.89	-2.0
09:50:00	0	3.15	57.2	36.8	0.2	6.0	0	>>>	1020.0	5.22	8.3	2.8	16.03	-1.0
10:00:00	0	3.15	57.2	36.7	0.1	6.0	0	>>>	1020.0	0.10	12.7	2.7	15.46	-1.0
10:10:00	0	3.15	57.2	36.9	0.1	5.8	0	>>>	1020.0	-68.59	13.8	2.6	14.89	-0.9
10:20:00	0	3.15	57.2	36.6	0.1	6.1	0	>>>	1020.0	-93.67	13.1	2.4	13.74	-0.9
10:30:00	0	3.15	57.1	36.4	0.1	6.4	0	>>>	1019.6	-106.91	13.1	3.3	18.89	-0.9
10:40:00	0	3.15	57.1	36.3	0.1	6.4	0	>>>	1019.6	3.03	13.0	4.5	25.76	-0.9
10:50:00	0	3.15	57.2	36.4	0.1	6.3	0	>>>	1019.3	6.42	13.1	3.3	18.89	-0.9
11:00:00	0	3.15	55.6	31.0	1.9	11.5	0	>>>	1019.0	-0.52	9.8	3.4	19.47	-0.9
11:10:00	0	3.15	57.0	36.3	0.1	6.6	0	>>>	1019.0	-107.00	9.8	3.3	18.89	-0.9
11:20:00	0	3.15	57.0	36.3	0.1	6.6	0	>>>	1018.6	-0.53	9.9	4.3	24.62	-0.9
11:30:00	0	3.15	56.9	36.2	0.1	6.8	0	>>>	1018.6	-100.41	12.9	4.0	22.90	-0.9
11:40:00	0	3.15	56.9	36.2	0.1	6.9	0	>>>	1018.6	-0.50	9.9	3.8	21.76	-0.9
11:50:00	0	3.15	57.0	36.2	0.0	6.8	0	>>>	1018.3	-105.47	12.5	4.0	22.90	-0.9
12:00:00	0	3.15	56.9	36.1	0.0	7.0	0	>>>	1017.9	-0.51	12.9	3.6	20.61	-0.8
12:10:00	0	3.15	56.9	36.1	0.1	6.9	0	>>>	1017.9	-0.06	11.7	3.8	21.76	-0.9
12:20:00	0	3.15	57.0	36.1	0.1	6.9	0	>>>	1017.6	-0.47	12.2	3.8	21.76	-0.9
12:30:00	0	3.15	56.7	36.1	0.2	7.1	0	>>>	1017.3	0.17	13.0	2.8	16.03	-1.8
13:30:00	0	3.15	56.9	36.3	0.3	6.5	0	>>>	1017.9	-0.50	12.6	2.9	16.60	-1.7
13:40:00	0	3.15	56.9	36.3	0.4	6.4	0	>>>	1017.6	-0.42	10.8	3.7	21.18	-1.7
13:50:00	0	3.15	57.0	36.4	0.1	6.5	0	>>>	1017.3	0.37	9.0	3.8	21.76	-1.8
14:00:00	0	3.15	56.9	36.4	0.1	6.6	0	>>>	1016.9	-0.49	12.9	3.3	18.89	-1.9
14:10:00	0	3.15	56.9	36.3	0.0	6.8	0	>>>	1016.9	-69.48	13.0	3.5	20.04	-1.9
14:20:00	0	3.15	56.8	36.3	0.1	6.8	0	>>>	1016.6	-0.52	12.7	3.9	22.33	-2.0
14:30:00	0	3.15	56.8	36.5	0.1	6.7	0	>>>	1016.6	6.00	13.2	4.0	22.90	-1.9
14:40:00	0	3.15	56.8	36.4	0.1	6.7	0	>>>	1016.6	4.97	13.0	4.0	22.90	-1.9
14:50:00	0	3.15	56.6	36.4	0.1	6.7	0	>>>	1016.6	-0.51	13.3	4.0	22.90	-1.9
15:05:00	0	3.15	56.6	36.2	0.3	6.9	0	>>>	1016.6	-108.00	13.0	3.6	20.61	-2.0
15:15:00	0	3.15	56.8	36.5	0.1	6.6	0	>>>	1015.9	-12.97	13.0	3.9	22.33	-2.0

>>> Overrange reading. When Methane exceeds 4.8%, the LEL exceeds 100% and is then overrange.

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