REPORT

Tonkin+Taylor

Green Island Landfill - Landfill Gas Risk Assessment

Prepared for

Dunedin City Council

Prepared by

Tonkin & Taylor Ltd

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1 Introduction

1.1 Background

Dunedin City Council (the Council) has engaged Tonkin & Taylor Ltd (T+T) to carry out a landfill gas (LFG) risk assessment to indicate the potential risks associated with the subsurface offsite LFG discharges from the Green Island Landfill to the surrounding environment (hereafter referred to as 'the landfill'), for you as our client.

The Council has applied to Otago Regional Council (ORC) for new resource consents to enable the continued operation of the Green Island Landfill until filling can commence at the proposed new Smooth Hill Landfill. The new resource consent application proposes the placement of an additional 670,000 m^3 of waste within the existing landfill footprint, as well as other ancillary activities associated with the ongoing waste management at the site.

The application for the new resource consents was lodged in March 2023, with LFG aspects supported by the Landfill Gas Masterplan prepared by T+T in May 2021 and a LFG Management letter report. A Section 92 request for further information was issued in relation to the application, and as a result the Landfill Gas Masterplan and LFG Management Letter Report were undated in September 2023[1].

In January 2024, a further Section 92 request was received which included the requirement for a site specific LFG risk assessment. An addendum to the LFG Masterplan was also prepared in response to this information request[2].

1.2 Scope of assessment

The scope for the LFG risk assessment is as follows:

- Review of available LFG data from the existing perimeter monitoring wells.
- Development of a LFG conceptual site model to identify potential receptors in the vicinity of the site and assess potential pathways between the landfill and the receptors.
- Completion of a qualitative LFG risk assessment in general accordance with CIRIA C665.

Risks from LFG to onsite receptors have not been considered in this assessment. These risks are managed through the operation of the landfill.

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[1] Tonkin & Taylor Ltd., September 2023, Landfill Gas Masterplan – Green Island Landfill, prepared for Dunedin City Council. Tonkin & Taylor Ltd., 21 September 2023, Green Island Landfill – LFG Management Letter Report, prepared for Dunedin City Council.

[2] Tonkin & Taylor Ltd., 29 May 2024, Green Island Landfill – Landfill Gas Masterplan – 2024 addendum, prepared for Dunedin City Council.

2 Site description

2.1 Site location

The Green Island Landfill is located at 9 Brighton Road, approximately 7 km south-west of the Dunedin CBD. The landfill occupies approximately 30 ha of the site. Figure 2.1 below shows the location of the landfill within the surrounding suburban area with residential buildings within a 1 km radius of the landfill footprint. Abbots Creek joins the Kaikorai Stream to the north of the landfill site, with the stream running around the western perimeter of the site. The downstream receiving environment is Kaikorai Lagoon, and further downstream the South Pacific Ocean. There is also a recreation reserve 2.4 km south of the site.

Figure 2.1: Site location plan. Sourced from GHD Design report.

The current resource consents for the landfill expire in October 2023 and Council is in the process of applying for new resource consents to allow for additional time for a new disposal facility to come online. It is proposed to continue filling the existing footprint to a revised final profile level as outlined in the Closure Design Report (GHD, 2023[3]). If new resource consents are granted, it is projected that waste placement will continue at the site until 2029.

2.2 Site history

The history of landfilling at the site is summarised in Table 2.1. Tonnage data was first recorded in 1964, although filling is known to have commenced in 1954.

[3] GHD Ltd., 3 March 2023, Waste Futures – Green Island Landfill Closure - Design Report, prepared for Dunedin City Council.

The landfill has been in operation for more than 65 years and is unlined. Landfilling practices in New Zealand have improved over that time, however during the early years of operation of the site, it is likely that conditions were not optimal for controlling leachate and LFG emissions. As a result of these practices, leachate levels are known to be elevated within some parts of the site. This will reduce LFG generation from this waste as saturated waste will inhibit bacterial activity. Historical filling practices also commonly resulted in significant degradation of the waste under aerobic conditions, further reducing the LFG generation potential.

As part of the development of the landfill, in 1994 a perimeter leachate interception trench was constructed around the western, northern, and northeastern boundaries of the landfill. This trench maintains a hydraulic barrier in shallow groundwater which minimises leachate discharges from the site. This will also act to minimise LFG discharges beyond the waste footprint, with water levels close to the ground level. The leachate interception trench is not present along the southern and southeastern boundaries, however as part of the new consents, it is proposed to be extended into these areas for leachate management purposes.

Table 2.1: Summary of landfilling

Filling period	Average fill depth	Description	Capped	LFG extracted
1954 to 1976	6 m	87,600 m^2 area to the east of the current filling area.	This area has been capped with hardfill, soils and topsoil. This area is currently utilised as a transfer station and other logistical activities associated with the site.	No.
1977 to 1992	9 m	119,300 m^2 area in the centre of the site.	This area was capped with an intermediate soil cover. Filling over the cover material recommenced in 2002.	Yes, existing wells.
1993 to 2001	9 m	72,500 m^2 area in the western part of the site.	This area is capped with an intermediate soil cover.	No, extraction is proposed as part of future filling in this area.
2002 to present	12 m	Filling recommenced in the central part of the site in 2002. As of July 2023, the active tipping area is the northern part of the southern area.	Final capping has been installed in the northern and eastern areas as shown in the drawing 12547621-C201 in the Closure Design Report (GHD, 2023).	Yes, the first stage of the final LFG extraction system has been installed in the northern area, and the western ring main was installed in 2022. Existing extraction wells in the eastern area continue to operate.

2.3 Landfill gas management

An initial and unsuccessful LFG collection system was trialled in the early 1990's but abandoned in 1998. Collection and destruction re-commenced in 2009 with the current candlestick flare and 4 gas wells within areas where final capping had recently been completed. The system is owned and operated by Council and monitored and managed on a day-to-day basis by WM New Zealand Ltd (WMNZ). It has been progressively expanded over time as waste placement has progressed.

In 2019, 1.75 mm^3 of LFG was collected and destroyed, increasing to 2 mm^3 in 2022. The Landfill Gas Masterplan[1] for the site describes the ongoing expansion of the extraction system.

The existing LFG collection system is shown in Drawing 1008787-200[4] R4 (Appendix A) and comprises (as of September 2023) of:

- 36 vertical LFG collection wells connected to the pipe network.
- A series of 110 and 225 mm outside diameter (OD) lateral connector pipes connected to a 335 mm header pipe to convey the LFG to the destruction systems installed at the WWTP.
- A northern sub-header (160 mm OD) and western ring-main (250 mm OD) which convey the LFG to the destruction systems at the WWTP.
- An electricity generator (gas engine), that uses LFG and biogas produced from the adjacent WWTP as fuel, and associated blower, power, and alarm systems. The gas engine has a 600 kWhr capacity and operates at a flowrate of approximately 350 m^3/hr. The generated electricity is fed back into the power grid.
- A 450 m^3/hr candlestick flare, and associated blower, power and alarm systems, which is used to destroy the residual LFG that cannot be used by the gas engine.

Council is also in the process of upgrading the candlestick flare to an enclosed flare with a capacity of 1,000 m^3/hr. This is proposed to be operational by the end of 2024 and will increase the destruction capacity and provide redundancy within the LFG destruction system.

The primary purpose of the LFG management system is to minimise onsite LFG discharges for both health and safety and environmental reasons, and to maximise collection and destruction of LFG. This will also assist with managing offsite discharges through the ground surrounding the landfill. In addition, other features of the landfill construction will help minimise lateral migration of LFG beyond the site boundary. These features include the perimeter leachate interception trench on the western, northern and eastern site boundaries, and the perimeter soil bund. The leachate interception trench is a shallow trench which extends below the groundwater level, and maintains a groundwater/leachate dewatering cone. In some areas the trench also incorporates an HDPE geomembrane liner on the outside of the trench. Where the HDPE geomembrane liner is present this will act as an effective barrier for the lateral migration of LFG. In other areas, where no liner is present, the shallow groundwater will limit the depth of unsaturated ground, through which LFG could migrate, and in both cases, the trench will offer a preferential pathway for migration, encouraging LFG to discharge to the surface, rather than continue beyond the landfill boundary. The perimeter soil bund constructed around the western, northern and eastern landfill boundaries will also act to limit lateral flow, and any LFG flow through the bund will be subject to methane oxidising bacteria in the soil which will also limit the concentration of methane in any fugitive emissions from the bund.

[4] This has been compiled using information provided by Council.

2.4 Environmental setting

2.4.1 Surrounding land uses

The landfill is located on the edge of the residential suburb of Green Island, Dunedin. The land uses surrounding the site include:

- The Brighton Road industrial area to the east including light and heavy industrial activities.
- The Clariton Avenue residential area to the east, with the closest residential properties approximately 60 m from the waste footprint.
- Grazing land to the southeast of the waste footprint with isolated rural residential houses. The houses in this area are located 80 to 150 m from the waste footprint, with landfill related activities (excavation for construction materials) occurring in the area between the landfill and the houses. The land and buildings are owned by DCC and leased to the occupants.
- The Dunedin WWTP, including the gas engine, to the southwest of the waste footprint.
- Kaikorai Stream and estuary to the west, with the Fairfield Closed Landfill and low use open space located on the opposite bank of the Stream.

2.4.2 Geology and hydrogeology

The published geological map of the area indicates that the site is underlain by estuarine mudflats of the Kaikorai Estuary Formation comprising of muds and sands, with these sediments underlain by Abbotsford Formation mudstone. The elevated area to the south and east of the landfill is comprised of Abbotsford Formation sandstone, with a small area of Hillgrove Formation loess in the Clariton Avenue area.

Groundwater is present a shallow depths within the Kaikorai Estuary Formation, with measured permeabilities in the upper layers in the order of 1×10^{-6} m/s, and permeabilities as low as 1×10^{-8} m/s in the lower layers (GHD 2023[3]). These low permeability materials limit downward migration of leachate, with groundwater flow expected to be influenced by the surface water bodies surrounding the site.

2.4.3 Topography

The landfill formed a mound on the edge of the Kaikorai Stream. The Kaikorai Stream to the west, is tidal and low lying. The eastern side of the site is also bounded by surface water bodies, with constructed wetlands present between the site and the Brighton Road industrial area, and also between the site and the Clariton Avenue residential area. The adjacent land rises gently, with the development located on low hills. The area of the south also rises gently beyond the landfill boundary.

3 Nature of discharges

3.1 Landfill gas generation process

LFG is a by-product of the decomposition of waste within a landfill. The decomposition process consists of five main phases:

- **During Phase 1**, the decomposable organic components of the waste undergo aerobic decomposition. Phase 1 commences just after the placement of the waste and lasts for a number of months.
- **Phase 2** commences due to the depletion of the resident oxygen and marks the commencement of the anaerobic stage. Phase 2 can last a number of months.
- **Phase 3** is marked by the transformation of complex materials such as cellulose, fats, proteins and carbohydrates into simple organic materials such as fulvic and acetic acids. Phase 3 can last from a number of months to a number of years.
- **Phase 4** represents the consumption of the acids developed in Phase 3 by specialized anaerobic methanogenic bacteria that convert them into methane and carbon dioxide, the principal components of LFG. This phase lasts a significant number of years.
- **Phase 5** signals the decline of LFG production because most of the nutrients required to sustain the methanogenic bacterial population have been depleted during previous phases. This stage lasts a number of years.

These phases of decomposition produce different by-product gases at varying rates as shown in Figure 3.1.

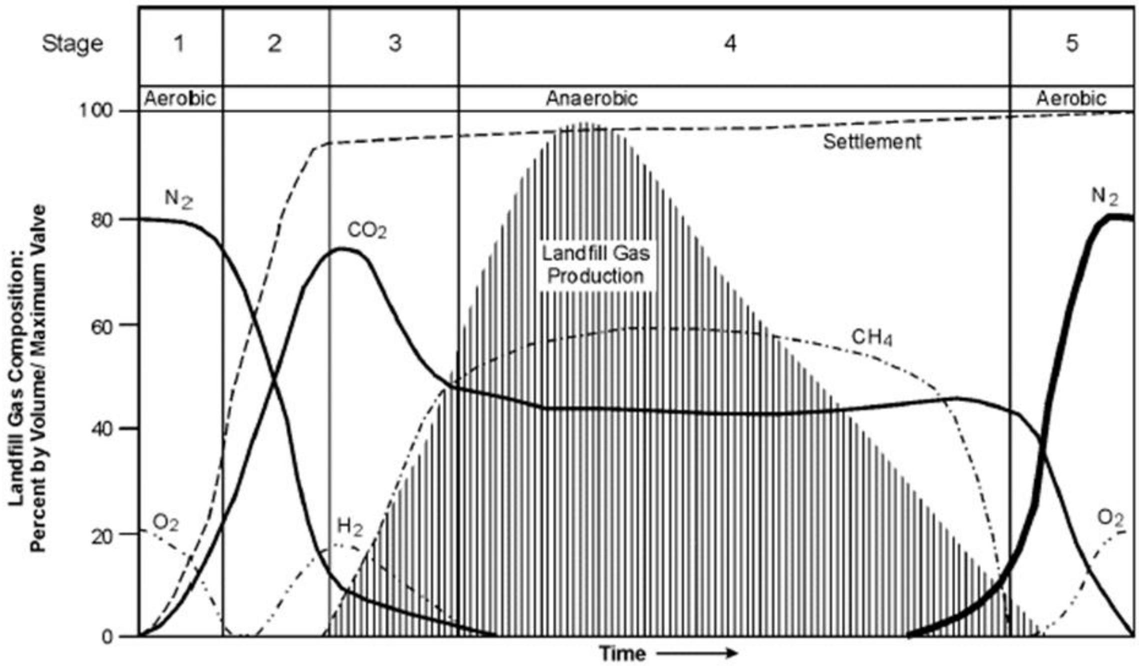

Figure 3.1: Composition of LFG in the decomposition phases (Environment Agency, 2004).

The composition of LFG changes through the various phases of decomposition. In the anaerobic phases, the LFG mixture typically comprises 60 % methane (CH_4) and 40 % carbon dioxide (CO_2) (i.e. a ratio of 1.5:1). In the final aerobic stage of degradation, the LFG is predominantly carbon dioxide. Average methane concentrations collected by the LFG collection system at Green Island Landfill were 56.8 % in 2023, confirming that the landfill is currently within Phase 4 of the degradation process.

3.2 Landfill gas generation and capture at Green Island Landfill

The waste material at Green Island Landfill primarily comprises a mix of municipal waste, commercial and industrial waste, and construction and demolition waste. Two SWAP[5] surveys to assess the composition of the waste entering the site were carried out in 2020[6]. The results of the surveys show that a significant amount of inert material is being brought into the site (76 % of the waste stream in the August 2020 SWAP, and 56 % of the waste stream in the December 2020 SWAP). Much of this material is utilised for construction or cover material. The organic content of the remainder of waste (excluding the inert construction materials) is estimated to be 65 to 77 %. The main forms of organic waste include food, sludge and wood.

LFG generation modelling has been carried out for the site as reported in the LFG Masterplan. The modelling shows that the landfill is expected to be generating significant quantities of LFG, approximately 740 m^3/hr (normalised to 50 % methane) in 2024 increasing to 900 m^3/hr by the proposed new closure date in 2029.

As described in Section 2.3, an active LFG extraction system is in place at the site. This system aims to collect as much of the LFG as possible, which helps to reduce greenhouse gas emissions, manage odour, and minimise lateral migration beyond the landfill.

3.3 Landfill gas perimeter well monitoring

The resource consent for discharges to air requires the monitoring of gas concentrations in the ground adjacent to Clariton Avenue. Three landfill gas monitoring wells (G2, G3, G4) are located in this area, approximately 70 m from the edge of the landfill. The wells were installed in 2020 (replacing pre-existing wells), and are approximately 2 m deep, installed within shallow fill materials and into the underlying clayey silt Loess deposits.

Approximately 40 rounds of monitoring have been carried out at these locations since 2020, with a range of barometric conditions captured. The data is presented in Appendix B. The results show no significant methane concentrations (all results ≤0.1 %), and carbon dioxide concentrations which are typically low (typically <5.0 %). Higher carbon dioxide concentrations of up to 12.2 % have been recorded on some occasions, with approximately half the monitoring results exceeding 5.0 % at G4. The data has been collected over a range of barometric conditions. Groundwater level data from nearby monitoring locations indicates that groundwater levels typically range from 1.8 to 3.3 m below ground level. Flow data was not typically captured during monitoring therefore no assessment of gas flow within the ground can be carried out.

3.4 Landfill gas risks

LFG moves through the landfill in response to changes in air pressure, temperature, and concentration until it is released into the surrounding soil or atmosphere. At elevated concentrations, and under certain conditions, the gases making up LFG have the potential to result in adverse effects on people and property. The principal hazards are detailed as follows.

- Flammability and explosivity:
  - Methane has a lower flammability limit in air (LEL) is 5 % by volume and the upper limit (UEL) is 15 %. There is a risk of explosion or fire occurring due to gas migrating and collecting in confined spaces such as manholes and chambers, and poorly ventilated areas of buildings on or adjacent to landfills.

[5] SWAP = Solid Waste Analysis Protocol, MfE, 2002.

[6] JBL Environmental, Waste Analysis Study, 25-31 August 2020, Green Island Landfill. JBL Environmental, Composition of Waste Study, 2-8 December 2020, Green Island Landfill.

- Asphyxiation:
  - LFG represents a major hazard in any restricted space, due to the risk from asphyxiation by exclusion of oxygen. Methane is lighter than oxygen and will tend to rise up within a confined space. Carbon dioxide is heavier than oxygen and will tend to sink within a confined space.
- Toxicity:
  - Carbon dioxide and some of the trace constituents in LFG can have toxic effects if they are present in high enough concentrations.
- Odour
  - Carbon dioxide and methane are essentially non-odorous. The odorous compounds associated with LFG include ketones, esters, volatile fatty acids, hydrogen sulphide and mercaptans. Very small amounts of these compounds can result in odours and these compounds may be present at all decomposition phases.

4 Landfill gas conceptual site model

4.1 Source

The Green Island Landfill has been receiving municipal waste since 1954 and is known to be generating significant quantities of LFG. This generation will increase over the operational life of the landfill, and is expected to peak when the site is closed, with an expected peak LFG generation rate of 900 m^3/hr.

The northeastern part of the site, which is closest to the adjacent industrial and residential land uses, is the oldest part of the site, with waste placed between 1954 and 1976. This waste is now almost 50 years old and is known to have elevated leachate levels. No LFG extraction is occurring in this area, however the elevated leachate levels, and the age of the waste means that LFG generation in this part of the site will be much lower than in other parts of the site.

There are also elevated leachate levels within the central and western parts of the site, which will supress LFG generation from the older, submerged waste at the base of the landfill. The more recent waste placed over the older waste, will be continuing to generate large quantities of LFG. LFG is actively extracted from this area and the system will be progressively expanded as waste placement progresses.

The additional waste that is proposed to be placed at the site will be placed within the existing footprint and will be mounded up above the current waste levels.

4.2 Pathways

While the landfill is operational, the main pathways for LFG discharges are vertical migration through the waste and the landfill surface prior to placement of the final cap, and discharge through the LFG collection system, where it is safely destroyed.

The perimeter leachate interception trench, perimeter bund and the natural geology are expected to minimise any lateral migration. The trench and the shallow surrounding groundwater level will reduce the depth of unsaturated material through which landfill gas could migrate, and the leachate trench itself will act as a preferential pathway, minimising the potential for LFG to migration beyond the site boundary. The natural geology underlying and surrounding the landfill is low or very low permeability, which will inhibit LFG migration. These features will mean that while the landfill is operational, and not fully capped, lateral migration is unlikely to be occurring, and even following closure and capping of the site, the potential for lateral migration through these materials is likely at be minimal.

Underground services which cross the landfill boundary can act as preferential pathways for LFG migration. These pathways are potentially present in the northeastern part of the landfill where services, enter/exit the site to service onsite activities. Most underground services follow the main Brighton Road entrance. These services cross over the perimeter leachate trench and the culvert which connects the constructed wetlands to the Kaikorai Stream. Due to the shallow nature of these services, LFG migration along the trenches is possible. Underground services also enter the landfill site along the old Taylor Street accessway. A similar situation is present in this area, with shallow service trenches crossing over the pipe which connects the southern constructed wetlands with the northern constructed wetlands. Due to the shallow nature of these services, LFG migration along the trenches is possible.

Wastewater pipes servicing the Clariton Avenue residential area, and one rural residential dwelling to the southeast of the landfill also enter the landfill property, discharging into a wastewater pipe along the southeastern boundary of the site. This pipe is located outside of the waste footprint, and at the topographic low point, where groundwater is expected to be shallow. An open drain is present along the landfill side of the sewer pipe. LFG migration along this pipeline and towards the residential properties is not expected to be occurring, as the pipe servicing the Clariton Avenue properties runs beneath the constructed wetlands and therefore the service trench is likely to be flooded, and equally, given the low lying position of the pipe servicing the rural residential property, shallow groundwater is likely to inhibit gas migration.

Landfill gas monitoring in the ground outside of the landfill has been carried out adjacent to the residential area of Clariton Avenue. The results show no significant methane concentrations, and carbon dioxide concentrations of up to 12.2%. Carbon dioxide is a naturally occurring gas in the ground, being generated through normal bacterial activity during the degradation of organic material within soil. UK guidance[7] states that concentrations in the range of 10 % may be related to made ground, and typical concentrations of 5 – 10 % may be associated with organic rich natural materials. Given the restrictions on landfill gas migration in this part of the site, it is likely that these concentrations are related to natural processes within the fill material and underlying natural materials, than to the migration of landfill gas.

Methane also has the potential to be dissolved into leachate and can be transported away from the landfill within leachate and/or impacted groundwater. This pathway is not expected to be significant at Green Island because the site is actively extracting landfill gas from the more recently placed waste, which will ensure that vertical migration and capture by the LFG collection system will be the dominant migration pathway. If some methane does dissolve into the leachate, this is expected to be captured by the leachate collection system and any methane is likely to come out of solution as part of the leachate pumping system, or further downstream in the main trunk sewer line or Green Island Wastewater Treatment Plant.

Following closure, and placement of the final cap on the landfill, the LFG collection system will continue to be operated and will be the main pathway for LFG discharges. The potential for lateral migration beyond the boundary of the landfill will increase, either through the surrounding geology or along potential preferential pathways, as vertical gas migration is limited by the landfill cap. As described above, these pathways are also considered to be limited due to the environmental setting of the landfill.

4.3 Receptors

Four main receptors groups are present in the immediate vicinity of the landfill, as follows:

- Industrial site users
  - Industrial activities are occurring on land to the east of the landfill.
  - The industrial area is dominated by large buildings and open industrial yards, with both heavy and light industrial activities likely to be occurring.
  - Industrial activities typically occur in large buildings which are likely to be well ventilated, however activities with a potentially increased risk from LFG such as entering belowground pits or carrying out hotworks may also be occurring.
- Residential site users
  - Residential properties are present to the east of the landfill, and to the south (2 x rural residential properties only).
  - Residential site users may be at increased risk from LFG due to the long duration occupancy of the buildings, presence of enclosed spaces, and uncontrolled nature of their activities.

[7] Construction Industry Research and Information Association (CIRIA). (2007). Assessing risks posed by hazardous ground gases to buildings (C665).

- Maintenance workers adjacent to the site
  - Maintenance workers and contractors may be present in the area to the east of the site carrying out works on public assets and/or on private land. Some contractor activities may be a potentially increased risk from LFG such as carrying out works on belowground assets or in confined spaces, and/or carrying out hotworks.
- Agricultural land users
  - The land adjacent to the southeastern boundary of the landfill is utilised for pastoral agriculture, with very few buildings or other structures present. Typical agricultural activities are unlikely to be at increased risk from LFG discharges.

5 Landfill gas risk assessment

A qualitative assessment of the risks from LFG discharges beyond the landfill boundary has been carried out using a likelihood and consequence approach in accordance with the methodology for a qualitative assessment described in the CIRIA guidance[7].

The approach applies a qualitative rating to the likelihood of the activity, receptor and pathway lining up, and an effects rating which considers the consequence of the potential effect. The qualitative likelihood and consequence ratings are described in Table 5.1 and Table 5.2, respectively. The likelihood and consequence ratings are then combined to qualitatively assess the overall level of risk associated with each hazard. The risk assessment matrix is shown in Table 5.3. The results of the qualitative assessment are presented in Table 5.4.

Table 5.1: Qualitative rating of likelihood

Frequency rating	Descriptor	Explanation
A	High	There is a pathway between the source and the receptor and circumstances are such that an event is likely in the short term, and inevitable in the long term.
B	Likely	There is a pathway between the source and the receptor and circumstances are such that if all elements are present the event will occur.
C	Low	There is a pathway between the source and the receptor and circumstances are such that it is possible that an event would occur, however it is not certain that even over a longer period such an event would take place.
D	Unlikely	There is a pathway between the source and the receptor but circumstances are such that it is improbable that an event would occur.
E	Rare	There is limited evidence identifying a pathway between the source and the receptor and circumstances are such that it is improbable that an event would occur.

Table 5.2: Qualitative rating of consequence

Effects rating	Descriptor	Explanation
1	Severe	Human health effects likely to result in “significant harm”. Catastrophic damage to buildings/ property.
2	Medium	Short term (acute) risk to human health likely to result in harm. Chronic harm to human health consistent with “significant harm”. Significant damage to buildings/ property.
3	Mild	First aid treatment required. Moderate damage to property.
4	Minor	Non-permanent health effects. Easily repairable damage to property.
5	Insignificant	No damage to human health or property.

Table 5.3: Landfill gas risk matrix

Consequence / Likelihood	Severity				
	Severe (1)	**Medium (2)**	**Mild (3)**	**Minor (4)**	**Insignificant (5)**
High likelihood (A)	Very high risk	High risk	Moderate risk	Moderate/ low risk	Low risk
Likely (B)	High risk	Moderate risk	Moderate/ low risk	Low risk	Very low risk
Low likelihood (C)	Moderate risk	Moderate/ low risk	Low risk	Very low risk	Very low risk
Unlikely (D)	Moderate/ low risk	Low risk	Very low risk	Very low risk	Negligible
Rare (E)	Low risk	Very low risk	Very low risk	Negligible	Negligible

Table 5.4: Landfill gas risk evaluation for activities adjacent to the Green Island Landfill

Receptor group	Potential pathway	Assessment of risk	Likelihood	Consequence	Risk
Industrial site workers carrying out typical industrial activities to the east of the site.	Lateral migration and discharge through the ground surface or ingress into buildings.	The industrial area is located adjacent to the oldest part of the landfill, which is considered to be well past its peak for LFG generation. The natural geology between this area and the adjacent industrial area, is low to very low permeability. In addition, a constructed wetland is present between the landfill and the industrial area. These two features will limit the migration of LFG beyond the boundary of the site. Underground service trenches are known to be present along the northern edge of the industrial area which could act as migration pathways, however given that they are connected to the oldest part of the landfill, there is likely to be limited driving force for migration to occur. Based on this information, the likelihood of an event occurring within the industrial area is assessed to be **rare to unlikely**. Activities at higher risk from LFG may be occurring in the industrial area however given the expected good ventilation in these areas, and the low volumes of landfill that could potentially be present the consequence of any event is assessed to be **mild**.	Rare to Unlikely	Mild	Very low risk
Residents carrying out typical residential activities to the east of the site.	Lateral migration and discharge through the ground surface or ingress into buildings.	The main residential area, to the east of the site, is located adjacent to the oldest part of the landfill, which is considered to be well past its peak for LFG generation. The natural geology between this area and the adjacent residential area, is low to very low permeability, and the groundwater table is expected to be close to the ground surface. These features will limit the migration of LFG beyond the boundary of the site. Landfill gas monitoring in the vicinity of these properties found no methane, and only slightly elevated concentrations of carbon dioxide, which are likely to be related to natural processes within the ground. Underground service trenches are known to be present between the residential area and the landfill which could act as migration pathways, however given that they are connected to the oldest part of the landfill, there is likely to be limited driving force for migration to occur. Based on this information, the likelihood of an event occurring within the main residential area is assessed to be **unlikely**. Activities at higher risk from LFG may be occurring on residential properties such as long occupancy and activities in enclosed spaces. As such, the consequence of any event occurring is assessed to be **medium**.	Unlikely	Medium	Low risk
Residents carrying out typical residential activities to the southeastern boundary of the site.	Lateral migration and discharge through the ground surface or ingress into buildings.	Two rural residential houses are located close to the southeastern boundary of the site. This area of the landfill contains recently placed waste and is known to be generating significant quantities of LFG. LFG extraction is occurring from this waste. LFG migration beyond the boundary will be restricted by the low permeability nature of the underlying geology, and the presence of a perimeter trench around the site. These features, in addition to the active extraction of LFG, will reduce the likelihood of an event occurring to **unlikely**. Activities at higher risk from LFG may be occurring on residential properties such as long occupancy and activities in enclosed spaces. As such, the consequence of any event occurring is assessed to be **medium**.	Unlikely	Medium	Low risk
Workers carrying out typical **above ground** activities to the east of the site.	Lateral migration followed by vertical migration through the ground surface.	Lateral migration beyond the site boundary, and discharge through the ground surface will be limited due to the low permeability nature of the underlying geology, and the shallow groundwater/presence of surface water between the waste footprint and the industrial and residential areas. The likelihood of an event occurring in relation to above ground maintenance activities is assessed to be **rare**. The consequence of people coming into contact with LFG in external areas will be dependent on the activity they are carrying out, and the amount and concentration of gas that is present. Hotworks or other activities involving sparks, flames or flammable substances are the highest risk activities however the volume of LFG likely to be present in external areas is unlikely to be sufficient to result in a significant consequence. Therefore, the consequence is considered to be **insignificant**.	Rare	Insignificant	Negligible risk
Workers carrying out typical **below ground** activities to the east of the site.	Lateral migration followed by discharging into excavations or confined spaces where people are working.	Lateral migration beyond the site boundary, and ingress into excavations or below ground structures will be limited due to the low permeability nature of the underlying geology, and the shallow groundwater/presence of surface water between the waste footprint and the industrial and residential areas. Landfill gas monitoring in the vicinity of the residential properties found no methane, and only slightly elevated concentrations of carbon dioxide, which are likely to be related to natural processes within the ground. The presence of underground services which connect to the landfill in this area may increase the risk of migration occurring. The likelihood of an event occurring in relation to above ground maintenance activities is assessed to be **rare to unlikely**. The consequence of people coming into contact with LFG in below ground spaces will be dependent on the activity they are carrying out, and the amount and concentration of gas that is present. Entry into below ground structures, and hotworks at or below ground level are the highest risk activities. If an event were to occur without appropriate control measures, the consequences could be **medium**.	Rare to Unlikely	Medium	Very low to Low risk
Agricultural workers carrying out typical agricultural activities to the southeast of the site.	Lateral migration and discharge through the ground surface.	The agricultural area is adjacent to the active landfilling area which contains recently placed waste which is known to be generating significant quantities of LFG. LFG is actively extracted from this waste. LFG migration beyond the boundary will be restricted by the low permeability nature of the underlying geology, and the presence of a perimeter trench around the site. The agricultural area is also located at least 100 m from the landfill footprint. These features, in addition to the active extraction of LFG, will reduce the likelihood of an event occurring to **rare**. Typical agricultural activities are not considered to be at risk from LFG and therefore the consequence of any event occurring is assessed to be **insignificant**.	Rare	Insignificant	Negligible risk

6 Conclusions

This LFG risk assessment has been completed to support a resource consent application by Dunedin City Council for the continued operation of the Green Island Landfill until filling can commence at the proposed new Smooth Hill Landfill. The replacement resource consents propose the placement of an additional 670,000 m^3 of waste within the existing landfill footprint, as well as other ancillary activities associated with the ongoing waste management at the site.

This assessment has identified that the risk of lateral migration impacting current adjacent site users is considered to be negligible to low risk. The main factors influencing the assessment are the low permeability of the natural materials underlying and surrounding the landfill, and the shallow groundwater level. These features will limit the ability for LFG to migrate beyond the boundary.

7 Applicability

This report has been prepared for the exclusive use of our client Dunedin City Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

We understand and agree that our client will submit this report as part of an application for resource consent and that Dunedin City Council as the consenting authority will use this report for the purpose of assessing that application.

Recommendations and opinions in this report are based on data from monitoring data collected from discrete investigation locations. The nature and continuity of subsoil and discharges away from these locations are inferred but it must be appreciated that actual conditions could vary from the assumed model.

Tonkin & Taylor Ltd
Environmental and Engineering Consultants

Report prepared by:

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Jo Ferry
Principal Environmental Consultant

Authorised for Tonkin & Taylor Ltd by:

....

Simonne Eldridge
Project Director

JMC
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Appendix A Drawings

- **Drawing 1008787-200 R4 – Current gas extraction system**

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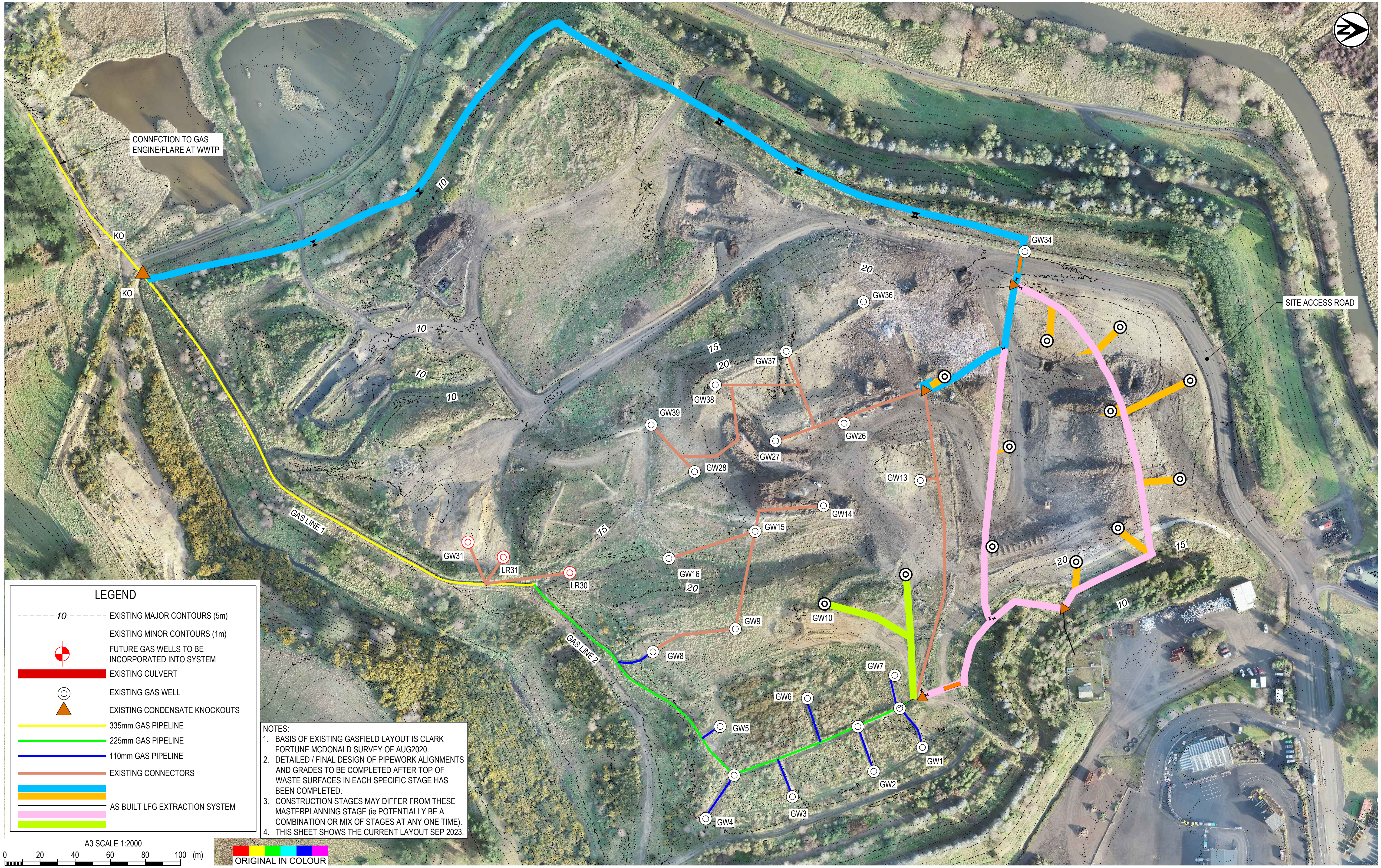
C:\12dSynergy\data\ALBTCAD\Green Island Expansion_215\CAD\DWG\1008787-200.dwg 2023-Sep-19 7:02:04 pm Plotted By: ALEX DE GUZMAN



LEGEND

- EXISTING MAJOR CONTOURS (5m)
- EXISTING MINOR CONTOURS (1m)
- FUTURE GAS WELLS TO BE INCORPORATED INTO SYSTEM
- EXISTING CULVERT
- EXISTING GAS WELL
- EXISTING CONDENSATE KNOCKOUTS
- 335mm GAS PIPELINE
- 225mm GAS PIPELINE
- 110mm GAS PIPELINE
- EXISTING CONNECTORS
- AS BUILT LFG EXTRACTION SYSTEM

NOTES:

1. BASIS OF EXISTING GASFIELD LAYOUT IS CLARK FORTUNE MCDONALD SURVEY OF AUG2020.
2. DETAILED / FINAL DESIGN OF PIPEWORK ALIGNMENTS AND GRADES TO BE COMPLETED AFTER TOP OF WASTE SURFACES IN EACH SPECIFIC STAGE HAS BEEN COMPLETED.
3. CONSTRUCTION STAGES MAY DIFFER FROM THESE MASTERPLANNING STAGE (ie POTENTIALLY BE A COMBINATION OR MIX OF STAGES AT ANY ONE TIME).
4. THIS SHEET SHOWS THE CURRENT LAYOUT SEP 2023.

A3 SCALE 1:2000

0 20 40 60 80 100 (m)

ORIGINAL IN COLOUR

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REV	DESCRIPTION	CAD	CHK	DATE
1	CLIENT REVIEW	EMSO		
2	REPORT ISSUE	EMSO		
3	UPDATE FOR CONSENT EXTENSION APPLICATION	EMSO		
4	UPDATE FOR DETAILED CONCEPT DESIGN	ALDG		

DESIGNED	JOSH	Oct.20
DRAWN	EMSO	Oct.20
DESIGN CHECKED		
DRAWING CHECKED		

NOT FOR CONSTRUCTION

APPROVED DATE

DRAWING STATUS: REPORT ISSUE

THIS DRAWING IS NOT TO BE USED FOR CONSTRUCTION PURPOSES UNLESS SIGNED AS APPROVED

CLIENT: DUNEDIN CITY COUNCIL

PROJECT: GREEN ISLAND LANDFILL

TITLE: STAGED LANDFILL GAS SYSTEM EXPANSION CURRENT GAS EXTRACTION SYSTEM-SEPTEMBER 2023

SCALE (A3) 1:2000 DWG No. 1008787-200 REV 4

Appendix B Perimeter landfill gas monitoring data

Site Name: Green Island Landfill, Dunedin
Table 1: Clariton Avenue Landfill Gas Monitoring Wells Monthly Data
July 2020 to June 2021

Gas Well	Date	Pressure	CH_4 %	CO_2 %	O_2 %	CO%	H_2S%	Balance	Air pressure (mBar)	Weather Comments	Time	Temperature (°C)
G2	31-07-20	-	0.0	4.7	14.4	0.0	0.0	80.9	-	-	10.45	-
G3	31-07-20	-	0.0	2.8	15.7	0.0	0.0	81.6	-	-	10.50	-
G4	31-07-20	-	0.1	12.2	1.3	0.0	0.0	86.4	-	-	10.55	-
G2	05-08-20	-	0.0	4.9	14.7	2.0	2.0	80.4	-	-	13.45	-
G3	05-08-20	-	0.0	2.8	16.3	2.0	3.0	80.9	-	-	13.48	-
G4	05-08-20	-	0.0	8.6	13.8	2.0	3.0	77.5	-	-	13.51	-
G2	20-10-20	-	0.1	5.6	16.4	6.0	0.0	77.9	-	Overcast	16.32	13
G3	20-10-20	-	0.1	5.4	16.2	6.0	0.0	78.2	-	Overcast	16.35	13
G4	20-10-20	-	0.1	6.9	17.0	5.0	1.0	76.0	-	Overcast	16.40	13
G2	15-01-21	-	0.0	0.1	21.5	0.0	0.0	78.4	-	-	-	-
G3	15-01-21	-	0.0	5.7	15.8	0.0	0.0	78.5	-	-	-	-
G4	-	-	-	-	-	-	-	-	-	-	-	-
G2	14-04-21	0.03	0.0	2.3	19.6	0.0	0.0	78.0	1,005	Cloudy, cool, wet	Morning	11
G3	14-04-21	0.01	0.0	1.8	20.4	0.0	0.0	77.8	1,005	Cloudy, cool, wet	Morning	11
G4	14-04-21	0.07	0.0	6.3	14.8	0.0	0.0	79.0	1,005	Cloudy, cool, wet	Morning	11
G2	07-05-21	-	0.0	2.2	20.3	0.0	0.0	77.5	1,034	Clear, cool	Morning	7
G3	07-05-21	-	0.0	1.5	20.2	0.0	0.0	78.3	1,034	Clear, cool	Morning	7
G4	07-05-21	-	0.0	6.1	12.0	0.0	0.0	81.9	1,034	Clear, cool	Morning	7
G2	09-06-21	-	0.0	2.5	18.6	1.0	0.0	78.9	1,024	Clear, mild	Afternoon	11
G3	09-06-21	-	0.0	1.8	18.4	3.0	0.0	79.8	1,024	Clear, mild	Afternoon	11
G4	09-06-21	-	0.0	3.4	17.4	4.0	0.0	79.2	1,024	Clear, mild	Afternoon	11

Landfill gas monitoring well	Date / Time	Temperature (°C)	Pressure	CH_4 %	CO_2 %	O_2 %	CO ppm	H_2S ppm	Balance	Air pressure (mBar)	Weather Comments
G2	05 July 2021 Afternoon	8	-	0.0	3.2	17.4	5.0	0.0	79.4	1,017	Cloudy, cool, frosty
G3	05 July 2021 Afternoon	8	-	0.0	3.5	12.5	6.0	0.0	84.0	1,017	Cloudy, cool, frosty
G4	05 July 2021 Afternoon	8	-	0.0	8.7	12.1	6.0	0.0	79.2	1,017	Cloudy, cool, frosty
G2	05 August 2021 Morning	6	-	0.0	0.2	20.1	0.0	0.0	79.6	997	Cloudy, cool
G3	05 August 2021 Morning	6	-	0.0	0.1	20.4	0.0	0.0	79.5	997	Cloudy, cool
G4	05 August 2021 Morning	6	-	0.0	0.0	20.6	1.0	0.0	79.4	997	Cloudy, cool
G2	01 September 2021 Morning	3	-	0.0	0.1	20.4	0.0	0.0	79.5	1,030	Clear, cool
G3	01 September 2021 Morning	3	-	0.0	5.6	8.4	0.0	0.0	86.0	1,030	Clear, cool
G4	01 September 2021 Morning	3	-	0.0	0.1	20.0	0.0	0.0	79.9	1,030	Clear, cool
G2	19 October 2021 Afternoon	9	-	0.0	6.6	14.4	1.0	0.0	79.0	1,015	Cloudy, cool, wet
G3	19 October 2021 Afternoon	9	-	0.0	9.3	9.1	1.0	0.0	81.5	1,015	Cloudy, cool, wet
G4	19 October 2021 Afternoon	9	-	0.0	5.5	16.0	0.0	0.0	78.6	1,015	Cloudy, cool, wet
G2	02 November 2021 12pm	10	0.03	0.0	7.3	12.5	1.0	0.0	80.1	1,024	Cloudy, cool
G3	02 November 2021 12pm	10	0.05	0.0	10.9	11.7	0.0	0.0	77.4	1,024	Cloudy, cool
G4	02 November 2021 12pm	10	0.02	0.0	5.4	16.3	0.0	0.0	78.3	1,024	Cloudy, cool
G2	01 December 2021 0930	11	-	0.0	5.2	17.1	2.0	0.0	77.7	1,025	Partly cloudy
G3	01 December 2021 0930	11	-	0.0	5.9	15.6	1.0	0.0	78.5	1,025	Partly cloudy
G4	01 December 2021 0930	11	-	0.0	1.4	19.2	1.0	0.0	79.4	1,025	Partly cloudy
G2	05 January 2022 1330	12	-	0.0	4.2	17.5	1.0	0.0	78.2	1,020	Partly cloudy, cool
G3	05 January 2022 1330	12	-	0.0	5.9	17.2	1.0	0.0	77.8	1,020	Partly cloudy, cool
G4	05 January 2022 1330	12	-	0.0	1.8	19.5	1.0	0.0	78.7	1,020	Partly cloudy, cool
G2	02 February 2022 1545	28	-	0.0	3.0	18.2	0.0	0.0	78.8	996	Mostly cloudy, damp, humid
G3	02 February 2022 1545	28	-	0.0	2.7	18.6	0.0	0.0	78.7	996	Mostly cloudy, damp, humid
G4	02 February 2022 1545	28	-	0.0	5.8	13.6	0.0	0.0	80.6	996	Mostly cloudy, damp, humid
G2	16 March 2022 1330	13	-	0.0	3.0	18.6	0.0	0.0	78.4	1,033	Partly cloudy, mild, wet
G3	16 March 2022 1330	13	-	0.0	2.3	19.0	0.0	0.0	78.7	1,033	Partly cloudy, mild, wet
G4	16 March 2022 1330	13	-	0.0	6.5	13.3	0.0	0.0	80.2	1,033	Partly cloudy, mild, wet
G2	06 April 2022 1500	12	-	0.0	2.5	19.0	0.0	0.0	78.4	1,000	Partly cloudy, cool, wet
G3	06 April 2022 1500	12	-	0.0	1.7	19.4	0.0	0.0	78.8	1,000	Partly cloudy, cool, wet
G4	06 April 2022 1500	12	-	0.0	5.4	14.1	0.0	0.0	80.5	1,000	Partly cloudy, cool, wet
G2	03 May 2022 1300	17	-	0.0	2.0	18.9	0.0	0.0	79.1	1,026	Clear, warm, wet
G3	03 May 2022 1300	17	-	0.0	1.3	19.1	0.0	0.0	79.6	1,026	Clear, warm, wet
G4	03 May 2022 1300	17	-	0.0	4.5	13.7	0.0	0.0	81.8	1,026	Clear, warm, wet
G2	01 June 2022 1230	15	-	0.0	1.6	18.9	1.0	0.0	79.3	976	Partly cloudy, mild, dry
G3	01 June 2022 1230	15	-	0.0	1.2	18.9	1.0	1.0	79.9	976	Partly cloudy, mild, dry
G4	01 June 2022 1230	15	-	0.0	2.1	17.2	1.0	1.0	80.7	976	Partly cloudy, mild, dry

Note:

A hyphen (-) indicates that a parameter is not available

Table 8: Clariton Avenue - Landfill Gas Monitoring Well Measurements 2022 / 2023

Landfill gas monitoring well	Date / Time	Temperature (°C)	Pressure	CH_4 %	CO_2 %	O_2 %	CO ppm	H_2S ppm	Balance	Air pressure (mBar)	Weather Comments
G2	July 2022	Landfill gas monitoring well measurements collected in July 2022 are unable to be reported due to missing documentation									
G3											
G4											
G2	01 August 2022 / 1500	13	-	0.0	0.2	20.7	0.0	0.0	79.1	1,014	Partly cloudy, mild, wet
G3				0.0	1.3	18.6	0.0	0.0	80.1		
G4				0.0	0.6	19.4	1.0	0.0	79.9		
G2	12 Septeber 2022 / 1400	16	-	0.0	5.5	14.4	2.0	0.0	80.1	994	Clear, mild, dry
G3				0.0	5.1	11.3	2.0	0.0	83.6		
G4				0.0	5.1	16.8	2.0	0.0	78.1		
G2	03 October 2023 / 1215	10	-	0.0	5.6	15.7	0.0	0.0	78.8	1,005	Partly cloudy, cool, dry
G3				0.0	0.1	20.5	0.0	0.0	79.3		
G4				0.0	0.2	20.6	0.0	0.0	79.2		
G2	04 November 2022 / 0900	10	-	0.0	6.9	15.8	0.0	0.0	77.3	1,004	Clear, mild, dry
G3				0.0	8.2	12.8	0.0	0.0	79.0		
G4				0.0	5.3	19.8	0.0	0.0	79.0		
G2	07 December 2022 / 1430	13	-	0.0	2.6	18.8	2.0	0.0	78.6	1,014	Sunny, dry
G3				0.0	3.9	18.0	2.0	0.0	78.1		
G4				0.0	0.0	20.6	2.0	0.0	79.4		
G2	12 January 2023 / 1600	14	-	0.0	2.5	18.8	3.0	0.0	78.7	1,014	Cloudy, dry, sunny
G3				0.0	2.4	18.9	4.0	0.0	78.7		
G4				0.0	6.8	12.7	3.0	0.0	80.5		
G2	10 February 2023 / Afternoon	15	-	0.0	2.1	18.8	2.0	0.0	79.1	1018	Partly cloudy, dry, sunny
G3				0.0	1.5	19.1	3.0	0.0	79.4		
G4				0.0	4.3	14.4	2.0	0.0	81.4		
G2	02 March 2023 / Afternoon	21	-	0.0	2.2	19.1	0.0	0.0	78.8	1,008	Clear, sunny, dry
G3				0.0	1.8	19.3	0.0	0.0	78.9		
G4				0.0	4.1	15.8	1.0	0.0	80.1		
G2	04 April 2023 / Morning	16	-	0.0	2.2	15.4	0.0	0.0	82.4	1,020	Clear, sunny, dry
G3				0.0	3.6	14.1	0.0	0.0	82.4		
G4				0.0	4.1	14.1	0.0	0.0	81.8		
G2	02 May 2023 / Afternoon	15	-	0.0	4.9	15.3	0.0	0.0	79.8	1,011	Clear, sunny, dry
G3				0.0	5.7	13.3	0.0	0.0	80.9		
G4				0.0	7.2	12.9	0.0	0.0	79.8		
G2	07 June 2023 / Afternoon	7	-	0.0	6.0	12.5	0.0	0.0	81.5	1,030	Clear, sunny, damp
G3				0.0	5.8	10.0	0.0	0.0	84.2		
G4				0.0	6.5	14.0	0.0	0.0	79.5		

Note:
A hyphen (-) indicates that a parameter is not available

Landfill gas monitoring well	Date / Time	Temperature (°C)	CH_4 %	CO_2 %	O_2 %	CO ppm	H_2S ppm	Balance	Air pressure (mBar)	Weather Comments
G2	07 July 2023 / Morning	5	0.0	0.1	21.7	0.0	0.0	78.2	1,013	Partly cloudy, mild, damp
G3			0.0	0.1	21.6	1.0	0.0	78.3		
G4			0.0	0.1	21.5	0.0	0.0	78.5		
G2	04 August 2023 / Afternoon	11	0.0	0.0	20.9	0.0	0.0	79.0	1,023	Cloudy, mild, damp
G3			0.0	3.2	17.1	0.0	0.0	79.5		
G4			0.0	3.1	19.5	0.0	0.0	77.2		
G2	05 September 2023 / Morning	9	0.0	6.2	14.1	0.0	0.0	79.6	1,023	Clear, sunny, dry
G3			0.0	6.3	11.6	1.0	0.0	82.0		
G4			0.0	0.0	21.4	0.0	0.0	78.5		
G2	03 October 2023 / Afternoon	13	0.0	0.1	20.3	0.0	0.0	79.6	1,025	Clear, sunny, dry
G3			0.0	7.0	13.9	0.0	0.0	79.1		
G4			0.0	5.8	14.3	0.0	0.0	79.9		
G2	01 November 2023 / Afternoon	13	0.0	3.0	18.8	1.0	0.0	78.0	1,007	Cloudy, mild, dry
G3			0.0	5.7	17.6	1.0	0.0	76.7		
G4			0.0	0.1	21.0	1.0	0.0	78.9		
G2	06 December 2023 / Afternoon	20	0.0	3.3	18.7	1.0	0.0	78.0	1,005	Clear, sunny, dry
G3			0.0	4.6	17.9	2.0	0.0	77.6		
G4			0.0	0.1	20.7	1.0	0.0	79.2		
G2	08 January 2024 / Afternoon	16	0.0	3.4	18.7	1.0	0.0	77.9	1,021	Cloudy, mild, dry
G3			0.0	3.8	18.2	1.0	0.0	78.0		
G4			0.0	10.2	10.2	2.0	0.0	79.7		
G2	08 February 2024 / Afternoon	21	0.0	1.4	20.0	0.0	0.0	78.6	1017	Clear, sunny, dry
G3			0.0	1.8	19.6	1.0	0.0	78.6		
G4			0.0	0.5	20.6	0.0	0.0	78.9		
G2	04 March 2024 / Afternoon	16	0.0	2.0	19.8	0.0	0.0	78.2	984	Cloudy, mild, damp
G3			0.0	2.1	19.7	0.0	0.0	78.3		
G4			0.0	7.4	13.4	0.0	0.0	79.1		
G2	08 April 2024 / 1515	17	0.0	1.8	20.0	1.0	3.0	78.1	1,020	Sunny, dry, warm
G3			0.0	1.7	20.0	1.0	3.0	78.3		
G4			0.0	5.7	14.8	1.0	2.0	79.5		
G2	09 May 2024 / 1045	7	0.0	1.9	19.8	0.0	0.0	78.3	1,028	Sunny, calm, cool
G3			0.0	2.4	19.6	0.0	0.0	78.6		
G4			0.0	6.3	14.4	0.0	0.0	79.3		
G2	05 June 2024 / 1500	11	0.0	0.1	21.2	2.0	0.0	78.7	1,021	Calm, dry, sunny, mild
G3			0.0	0.8	20.4	2.0	0.0	78.9		
G4			0.0	0.1	21.1	2.0	0.0	78.8		

Note:
A hyphen (-) indicates that a parameter is not available

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