REPORT

Tonkin+Taylor

Landfill Gas Masterplan

Green Island Landfill

Prepared for
Dunedin City Council

Prepared by
Tonkin & Taylor Ltd

Date
September 2023

Job Number
1008787.5010.v3

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Document control

Title: Landfill Gas Masterplan – Green Island Landfill					
Date	**Version**	**Description**	**Prepared by:**	**Reviewed by:**	**Authorised by:**
Oct. 2020	1	Draft for Client Review	A. de Guzman	J. Ferry J. Shamrock	S. Eldridge
May 2021	2	Final	A. de Guzman	J. Ferry J. Shamrock	S. Eldridge
Sept. 2023	3	Update to reflect ongoing landfill operation and ORC S92 request	A. de Guzman	J. Ferry	J. Shamrock

Distribution:

Dunedin City Council 1 PDF copy

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1 Introduction

Tonkin & Taylor Ltd (T+T) has been engaged by Dunedin City Council (Council) to develop a Landfill Gas (LFG) Masterplan for Green Island Landfill (the site) located at 9 Brighton Road, Dunedin.

The development of a LFG Masterplan will direct the detailed design work and gas collection wellfield expansion required to maximise gas collection and destruction at the site. Efficient LFG collection and destruction will allow the Council to comply with their regulatory responsibilities and apply to the Environmental Protection Agency (EPA) for a Unique Emissions Factor (UEF) for the site, which will result in a reduction in their obligations under the Emissions Trading Scheme (ETS), payable to the EPA.

The objective of the LFG Masterplan is to provide Council with a conceptual layout of the final LFG collection system.

The LFG Masterplan has been updated in September 2023 to address questions raised by Otago Regional Council (ORC) in a Section 92 request as part of the resource consent currently being sought for the continued operation of the site to a revised final profile until the end of 2029 (depending on actual incoming waste tonnage and status of consenting).

This work has been carried out in accordance with our agreed scope of work under purchase order 780221-518339 for LFG related works at Green Island Landfill.

1.1 Scope of work

The initial LFG Masterplan was developed in late 2020 and included the following scope of work:

1. Reviewing available information regarding the LFG extraction system at the site.
2. Video conference with the Council and relevant site staff to discuss the current operation and proposed future activities at the site.
3. Site visit conducted on 11 August 2020.
4. Development of a draft LFG management Masterplan, and submission as a draft to Council in October 2020.
5. Regular contact with the Council during development and finalisation of the LFG Masterplan.

The LFG Masterplan has been developed based on our understanding of the future development and filling of the landfill within the current footprint. It has been updated in September 2023 following a Section 92 Request during the application for a resource consent to extend the operation of the landfill until the end of 2029. It should be reviewed periodically, including as part of any significant changes in the design or filling plan for the site.

The LFG masterplan has been compiled to the end of expected filling, in 2029, based on current tonnages and the remaining available airspace. The key assumption is that the consent being sought is granted to extend landfill operations to 2029. The assumptions on available airspace, annual airspace consumption, and projected annual tonnages are based on the Design Report *Waste Futures – Green Island Landfill Closure* prepared by GHD, 3 March 2023, Rev 01 (referred to as the Closure Design Report).

1.2 Purpose of landfill gas management

LFG is a by-product of the anaerobic decomposition of organic waste in a landfill and is comprised primarily of methane and carbon dioxide. Other constituents such as sulphur compounds and volatile organic compounds are present in trace amounts typically in parts per million concentrations. Oxygen can be present at various concentrations in extracted LFG due to barometric pressure changes (i.e., barometric pumping) or as a as a result of the vacuum applied by the extraction system.

An active LFG management system typically incorporates a number of vertical wells and/or horizontal collectors, a network of LFG conveyance pipes, and a LFG blower system to generate the vacuum required for the system. Treatment or end use options for the collected LFG include flaring, electricity generation, and fuel for heating.

LFG management is an important part of modern landfill operations for many reasons. The design objectives of LFG management, as stated in the WasteMINZ disposal to land guidelines[1] include:

- Minimise the risk to human health and safety.
- Minimise the potential impact on air quality and the uncontrolled emissions of greenhouse gases to atmosphere.
- Control the ingress of air into the landfill and thereby minimise the risk of fires.
- Control of off-site migration of methane through surrounding soils: methane forms an explosive mixture with air at concentrations between 5 and 15 % by volume. LFG infiltration and accumulation in confined spaces and structures can create an explosion hazard if not controlled properly.
- Odour control: LFG, particularly sulphur compounds in the gas, can create significant odour problems around the landfill. Collection and combustion of LFG effectively destroys odorous compounds.
- Control of hazardous volatilized components in LFG.
- Minimise the damage to soils and vegetation within restored landfill areas.
- Regulatory compliance.
- Energy recovery.

These objectives can be accomplished with LFG collection and flaring, or generating power through the destruction of the LFG. Other direct uses of LFG as an energy source or heating source are also possible.

2 Green Island Landfill

The landfill is located at 9 Brighton Road, approximately 7 km south-west of the Dunedin CBD. The site is in a suburban area with residential buildings within a 1 km radius of the landfill footprint. Abbots Creek runs along the western perimeter of the site. The downstream receiving environment is Kaikorai Lagoon, and further downstream is the South Pacific Ocean. There is also a recreation reserve 2.4 km south of the site. The current resource consent for the landfill expires in October 2023 and Council is engaged in a process to extend this to allow additional time for a new facility to come online and to continue filling the existing footprint to a revised final profile level as outlined in the Closure Design Report (GHD, 2023). This is projected to include filling of the site until 2029.

2.1 Overview

The landfill currently operates under resource consent 94524_V1 granted by the ORC, and can accept putrescible waste, solid inert waste, and hazardous waste. As a result of its age, the site does not have an engineered lining system and relies on the underlying low permeability clayey marine sediment / mudstone and continuous operation and maintenance of the leachate pumping system for containment of leachate.

[1] WasteMINZ (October 2022) *Technical Guidelines for Disposal to Land,* Revision 3.

The current tipping face (as of September 2023) is in the northern part of the western sector of the landfill. The remainder of the site has had waste placed historically, to various levels, as described in **Table 2.1**. All of the site is covered by intermediate cover apart from the north and eastern area that has been covered in final cover. The perimeter of the northern and eastern areas of the current landfill area is contained behind an edge bund constructed from compacted soil. There is a perimeter leachate collection trench installed around the northern, western and southern extent of the landfill to intercept leachate seepage prior to it entering Kaikorai Stream. The perimeter leachate drain is a vertical cut-off drain which maintains a permanent drawdown by intercepting seepage from the landfill and transporting it via gravity into pumping sumps from which where it is pumped to the Council Wastewater Treatment Plant (WWTP) south of the landfill.

The highest point of the final cap will be at approximately 31 mRL. The base of the site has a relatively flat grade, with the fill in the current tipping face at 22 to 25 mRL. The majority of the remaining waste fill in the south west of the landfill will have a thickness up to 15 m.

As of the end of 2022, there was approximately 5.19M tonnes of waste in the landfill. As per the Closure Design Report (GHD, 2023), the landfill is likely to be filled by the end of 2029 at which time, the expected cumulative tonnage will be 6.01M tonnes.

2.2 Landfilling 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.

Table 2.1: Summary of landfilling

Filling period	Average fill depth (m)	Description	Capped	LFG extracted
1954 - 1976	6 m	87600 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 the transfer station and other logistical activities associated with the site.	No
1977 - 1992	9 m	119,300 m^2 area in the centre of the site.	This area was capped with intermediate soil cover. Filling over the cover material recommenced in 2002.	Yes, existing wells
1993 - 2001	9 m	72,500 m^2 area in the western part of the site.	This area is capped with intermediate soil cover.	No Extraction is proposed as part of progressive filling in this area.
2002 - 2023	12 m	Filling recommenced in the central part of the site in 2002 and was continuing in late 2020. 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 end of the landfill and the western ringmain was installed in 2022

The landfill has been in operation for more than 65 years. 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. 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 too much moisture can smother bacterial activity if the waste is completely saturated. Historical filling practices also commonly resulted in significant degradation of the waste under aerobic conditions, further reducing the LFG generation potential.

2.3 Landfill gas management

The existing LFG collection system is owned and operated by Council and monitored and managed on a day to day basis by Waste Management NZ Ltd (Waste Management). The current system (as at September 2023) comprises:

- 38 vertical LFG collection wells installed and connected to the network.
- A series of 110 and 225 mm lateral connector pipes that connect to a 335 mm header pipe to convey the LFG to the destruction systems installed at the WWTP.
- The northern subheader (160 mm OD) and western ringmain (250 mm OD) have been installed and connected to convey the LFG to the destruction systems installed at the WWTP.
- A LFG engine that uses LFG gas as a fuel, in conjunction with gas produced from the adjacent WWTP, with its associated blower, power, and alarm systems, to generate electricity which is fed back into the grid. The LFG engine has a 600 kW capacity and operates at a LFG flowrate of approximately 350 m^3/hr.
- A 450 m^3/hr candlestick flare, with its associated blower, power and alarm systems, to destroy the residual LFG that cannot be used by the LFG engine, and as a backup destruction method in instances when the engine is offline.

The existing LFG collection system is shown in Drawing 1008787-200 in **Appendix A**. This has been compiled using information provided by Council.

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 final cap. The system has been progressively expanded since that time. In calendar year 2019, 1.75M m^3 of LFG was collected and destroyed, increasing to 2M m^3 in 2022.

2.4 Waste quantities and composition

Council provided the following waste quantities for the site:

- Tonnage data first recorded in 1964, with known history that filling started in 1954.
- Fill volume and assumed material density from 1965 to 1996.
- Historical record for annual tonnage from weighbridge tonnages from 1997 to 2020.

The data indicates approximately 5.19 M tonnes of waste has been placed into the site since 1954 (as at the end of 2022).

As identified in the Green Island Landfill Closure Design Report (GHD, March 2023), an additional approximately 830,000 tonnes of waste is expected to be placed on site to get the waste fill to the pre-settlement final profile. At the assumed filling rate of 118,334 tonnes per annum[2], Council's revised target date for closure for acceptance of waste is by the end of 2029.

The site has received a mix of municipal waste, commercial and industrial waste, and construction and demolition waste. Two SWAP[3] surveys to assess the composition of the waste entering the site were carried out in 2020[4]. The results of the surveys show that a significant amount of inert material is being brought into the site; inert materials comprised 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 waste (excluding the inert construction materials) is estimated to be 65 to 77%. The main forms of organic waste include food, sludge and wood. When compared to the default waste composition defined in the UEF Regulations, the Green Island Landfill waste contains a higher overall organic content. The sludge content in the waste is the main component that is different. It is significantly higher than the default waste composition, resulting in the higher overall organic content.

In July 2024, the food and green organic bin will be introduced to Dunedin's kerbside services. This will have the effect of diverting organic material from the landfill to the compositing facility. This in turn will reduce the production of landfill gas at the landfill. As the future organic content is hard to accurately predict, the LFG generation modelling has been undertaken conservatively on the basis of historical tonnages of organic material.

2.5 Landfill gas regulatory review

There are three key regulations/ documents that impact how LFG is required to be managed at the site:

- The Climate Change Response Act and requirements of the New Zealand Emissions Trading Scheme (NZ ETS).
- The National Environmental Standards for Air Quality (NES Air Quality).
- The Otago Regional Council – Regional Plan: Air for Otago and the current resource consent for the site for discharges to air.

The Council's obligations under each of these documents, and detail of compliance with these obligations, are described in this section.

2.5.1 New Zealand Emissions Trading Scheme

The Climate Change (Unique Emissions Factors) Amendment Regulations: 2009 requires all operating landfills which currently receive municipal waste, to be liable for their greenhouse gas emissions from 1 January 2013. These liabilities are based on the theoretical methane production from a tonne of waste with a prescribed organic content. They are calculated to account for all methane expected to be generated by the waste and are applied at the time of placement to every tonne of waste that enters the landfill.

The regulations also allow for landfills to reduce their liability by capturing and destroying the LFG and applying for a Unique Emissions Factor (UEF) for their site. The LFG collection and destruction system that is operating is effectively collecting and destroying LFG, therefore there is benefit to Council in applying for a UEF to reduce their liability under the NZ ETS. A UEF based on collection and

[2] As per Design Closure Report (GHD, March 2023) this is based on the annual airspace consumption of 89,000 m^3/year, with the assumed gas-producing waste tonnage of 59,833 tonnes per annum, and the assumed compaction and settlement as outlined in the Closure Report.
[3] SWAP = Solid Waste Analysis Protocol, MfE, 2002.
[4] 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

destruction has been sought for the site each year since the 2019 calendar year, which significantly reduced Council's obligations under the NZ ETS. Ongoing careful management of LFG at the site, as detailed in this plan, will aim to reduce these obligations further for the remainder of the operational life of the site.

2.5.2 NES Air Quality

The NES Air Quality applies to operating landfills that have a total consented capacity of greater than 1M tonnes of waste, and that have already accepted at least 200,000 tonnes of waste. As described in Section 2.4, the site has exceeded this capacity and is anticipated to continue accepting waste until 2029. As such, the site meets the criteria for which compliance with the NES is required. The responsibility for enforcing compliance with the NES Air Quality lies with the ORC.

In order to comply with the NES Air Quality, the site must have a LFG management system for the collection of LFG which aims to ensure that surface emissions do not exceed 5,000 ppm of methane, and the collected LFG must be destroyed either by flaring of the gas, or by utilising it (either as a fuel, or for the generation of electricity). The current system for gas destruction at the site is in compliance with the regulations. The regulations also include specific requirements in relation to the flaring of LFG. Given that flaring is not the primary LFG destruction method, these requirements are not applicable to the site.

2.5.3 Otago Regional Council – Regional Plan: Air for Otago

The landfill holds a consent from Otago Regional Council for the discharge of contaminants to air from the site (Consent No. 94524_V1). The consent was granted in 1995, reissued in 2007, and expires in October 2023. Under this consent, LFG must be collected, and methane and carbon dioxide concentrations must be monitored regularly. The "best practicable option" must be adopted to avoid and/or mitigate any adverse effects on the environment as a result of discharge of contaminants to air.

The current system for the collection and destruction of LFG is considered to be good industry practice, and the expansion of the system as described in this plan is also in-line with good industry practice, thereby allowing Council to comply with the requirements of the air discharge consent.

An application for a new consent to cover ongoing filling until 2029 is currently in progress. The existing consent will remain operable while the application is being processed. Changes to this LFG Masterplan, and how LFG is managed onsite may be required depending on the conditions of the new consent.

2.6 Review of NZ ETS obligations and opportunities

Since 2019, Council has been applying for, and has been granted a UEF for the site based on the collection and destruction efficiency of the LFG management system. This reduction in NZ ETS obligations has resulted in a significant cost saving for Council, and there is scope to reduce the UEF further with careful management of LFG at the site, and investment in the system over the remaining operational years.

2.6.1 Main factors influencing the Unique Emissions Factor

The main factors influencing the UEF, and actions that can be taken to decrease the value are described below. These factors have been taken into account with the development of this LFG Masterplan.

- LFG collection efficiency
  - The coverage and efficiency of the LFG collection system will directly impact on the UEF. This impact can be maximised by:
    - Carrying out filling in small stages and installing LFG collection infrastructure and capping as soon as possible during/after filling in each stage to maximise the amount of LFG able to be captured.
    - Incorporating valves and cross connections into the expansion of the LFG collection system to minimise disruptions to extraction as the network expands or when areas have to be isolated to conduct maintenance.
    - Keep as much of the collection system operational at all times as possible.
- LFG destruction efficiency
  - The current system includes both a LFG engine and a candlestick flare. The regulatory mandated methane destruction efficiency for the LFG engine is 90 %, compared to 50 % for the flare. To maximise the destruction efficiency, Council could:
    - Maximise LFG destruction in the LFG engine, which is largely already taking place as standard operating practice.
    - Use the flare for destruction of any excess LFG where required.
    - Consider upgrading the flare to an enclosed flare if the LFG engine is unable to accommodate the majority of the LFG being collected.
- Methane content
  - The methane concentration of the collected LFG directly impacts on the UEF calculation. Methane concentrations at the LFG engine and flare can be maximised by:
    - Continuing with regular tuning of the LFG collection system to maintain optimal methane concentrations and minimise air ingress.
    - Incorporating valves and cross connections into the expansion of the LFG collection system to minimise disruptions and air ingress as the network expands.
    - Manage gas well construction and filling around wells to minimise air ingress, including adding details like well bore seals to the wells.
- Waste composition
  - If the organic content of the waste entering the site is less than, or significantly different from the default waste composition, incorporating composition into the UEF calculation may reduce the UEF.
  - The default organic composition assumed in the UEF regulations was changed in 2022 from 60.2 % to 42.6 %. Therefore, incorporating composition into the UEF calculation would only be beneficial if it can be demonstrated that the organic composition is less than 42.6 %.
    - Two SWAP surveys were carried out at the site in 2020 (August and December 2020). The outcome of these assessments is described in Section 2.4. The results show that the organic content of the waste (excluding the inert construction materials) is significantly higher than the current default composition. As such, there is unlikely to be value in further assessment of the organic composition unless significant changes occur to the waste streams entering the landfill.
  - The change in default organic composition in 2022 also impacts the LFG generation model used to calculate the UEF. The model calculates a lower LFG generation compared with the previous default composition, which results in an increased collection and destruction efficiency, and a lower UEF than in previous years.

   - DCC is in the process of implementing waste minimisation actions which aim to reduce the organic content of waste as discussed in Section 2.4. This change will only impact the waste received in the last 4-5 years of the life of the landfill (representing **% of the waste placed at the site). As such, it is likely to have minimal impact on the overall volume of LFG generated. A significant change in waste composition may impact the UEF and DCC's surrender obligations. However, this would be subject to the relevant regulations at that time, therefore the scale of impact can not be quantified.
- Presence of historical waste and impact of historical landfilling practices
   - The long history of landfilling at the site, the practices that are likely to have occurred in the past, and the elevated leachate levels within the landfill will have reduced the potential for methane generation from the waste. This is likely to have reduced the overall volume of LFG generated at the site to date by approximately 32 % compared with the default LFG generation model required for the calculation of the UEF. The peak LFG generation rate at closure of the site is also likely to be reduced by approximately 50 m^3/hr.
   - At present, with the exception of waste composition, the NZ ETS does not allow for site specific characteristics to be taken into account. As such the impacts of historical filling practices and elevated leachate levels cannot be taken into account when expected LFG generation for the site is modelled. This results in an overestimation of LFG generation, which limits the potential collection and destruction efficiency that can be achieved. For the Green Island Landfill, this may be impacting the current collection and destruction efficiency by as much as 15 % as discussed in Section 3.

2.6.2 Summary of potential obligations under the NZ ETS

Complying with the obligations under the NZ ETS involves significant cost for DCC. While this is impacted by the cost of NZ credits, which is outside of DCC's control, the information provided above shows how LFG management can also help to reduce these obligations. For the 2022 calendar year, a collection and destruction efficiency of 38.0 % was achieved, resulting in a UEF of 0.564. This is compared to a current default emissions factor (DEF) of 1.023. Careful ongoing management of LFG should enable this value to be reduced further in future.

The DEF, and methodology for calculating the UEF, are subject to the requirements of the UEF regulations. If changes to the regulations are made in future, these will also impact DCC's obligations.

3 Landfill gas generation modelling

3.1 Overview

The LFG generation rate from a particular site depends primarily on waste quantity, deposition rates and composition as well as moisture content and leachate level. Other factors, such as compactive effort, temperature and pH also impact LFG generation, albeit to a lesser extent. The percentage of LFG generation that is collected is referred to as the collection efficiency and varies depending on the design, operation and age of a disposal site.

As discussed in Section 2.2, historical filling practices at the Green Island landfill have resulted in large amounts of the historical waste being unavailable for LFG generation due to elevated leachate levels within the older waste. The historical waste placement data presented in **Table 2.1** has been used along with information regarding leachate levels in each of these areas to more accurately model LFG generation at the site.

LFG generation modelling has been undertaken as part of the UEF applications for the site. The model used for the UEF applications was completed using the input parameters required by the UEF Regulations. These parameters may not be representative of actual conditions at the site; therefore, a new, operational LFG generation model has been developed for the LFG Masterplan which is more reflective of actual site conditions. The model takes into account actual waste composition data (2020 SWAP surveys), local rainfall, as well as the waste placement history, and current elevated leachate levels as discussed below.

3.2 Operational landfill gas generation model inputs

3.2.1 Waste tonnage

The waste tonnage used in the operational LFG generation model represents the expected gas producing waste tonnage, minus waste that is likely to be below the current leachate level.

Of the projected 6M tonnes of waste to be placed by the end of 2029, 3.4M tonnes is expected to be gas producing waste (with the remainder being inert materials). Major contributors to the gas producing waste stream include general refuse, sludge and animal waste, and transfer station waste. The rate of future filling is assumed as per the Closure Design Report (GHD, 2023).

The tonnage of gas producing waste has been reduced further based on the periods of waste placement described in **Table 2.1**, and the leachate levels within each of these areas (as recorded in 2021). Waste that is below the leachate levels has been subtracted from the gas producing tonnage as described in **Table 3.1**. It is noted that Council has the intention of reducing/managing leachate levels in future to assist with slope stability concerns. Lowering the leachate levels will have a positive impact on LFG generation rate.

Table 3.1: Summary of saturated waste

Placement period	Percent of waste that is saturated
1954 – 1976	50 %
1977 – 1992	38 %
1993 – 2001	44 %
2002 – 2020	0 %
2021 - 2026	0 %

3.2.2 Model input parameters

The methane generation potential used in the model (Lo) is based on the results of the 2020 SWAP surveys. The previous iteration of the LFG generation modelling (i.e., as presented in the Final LFG Masterplan, T+T, version 2, completed in May 2021) used the default waste composition as defined in the Climate Change (Unique Emissions Factors) Regulations 2009 as published in January 2018. However, since the update in the Regulations that have been in effect as of 01 January 2023, the default waste composition defined in the Regulations is no longer representative of the site-specific waste composition (refer Section 2.6.12.6.2). Therefore, in the September 2023 version 3 update of the LFG Masterplan, the site-specific waste composition results from the SWAP surveys have been used to calculate Lo. The derivation of the site-specific Lo is included in **Appendix B**. This value could be updated in future models if future SWAPs show that the organic content has changed.

The decay rate constant (k) is based on rainfall for the Dunedin area. The use of the default, higher value of k in the UEF model is required due to the UEF Regulations, however for the operational LFG generation model, using a methane decay rate constant based on local rainfall has been used as it is more accurate for the site. The model inputs are summarised in **Table 3.2**.

The full operational LFG generation model inputs and outputs are provided in **Appendix B**.

Table 3.2: Summary of model inputs

Parameter	Constant values
Lo[1]	79.11
k[2]	0.050

Notes:

1. Lo: methane generation potential (m^3/tonne). The theoretical maximum yield of LFG from a tonne of municipal solid waste.
2. k: methane decay rate constant (1/year). The rate at which the methane generation rate decreases once it reaches the peak rate on waste placement. The higher the value of k, the faster the methane generation rate from each sub-mass decreases over time.

3.3 Model predictions

The operational LFG generation curve is shown graphically in **Figure 3.1**. **Figure 3.2** shows the LFG generation for each period of historical waste placed which have been used to build up the total operational LFG generation model. Key predictions from the models can be summarised as follows:

- LFG generation is modelled to peak in 2030, following the closure and final capping of the site based on the assumption that the consent period is extended and filling up to the updated design final profile is approved.
- At this time, the peak LFG generation rate is estimated to be 903 m^3/hour.
- For the purposes of pipe sizing, it has been estimated that the LFG extraction system will capture 80 % of this peak LFG flow rate (based on the operational LFG model). This assumption is based on the fact that at this stage of the landfill's development:
  - All the gas extraction wells are installed and connected into the LFG extraction system.
  - The landfill final cap is installed.
  - The LFG engine /flare/additional destruction capacity is sized to treat this gas flowrate.

  This flowrate is therefore used as an instantaneous flow to size the LFG collection system pipelines. and should not be confused with the collection efficiency as used in the UEF calculations
- The expected maximum collected LFG, that will be routed through the LFG extraction system pipework, is therefore 722 m^3/hour in 2030.
- It is noted that the inputted waste tonnage has considered the effects of leachate saturation. If leachate levels within the older waste significantly improve across the site, then LFG collection could be increased.

3.4 Model comparison with collection data

Total annual LFG flow rates have been measured at the site since 2019 as part of the UEF applications. Flow is measured by two flowmeters immediately upstream of the engine and the flare. LFG flow to the engine and the flare for the 2022 calendar year is presented in **Figure 3.3.** The graph shows that most of the gas is being directed to the engine, but that the flow to the flare increases when flow to the engine reduces. The average collected LFG flow since 2019 is plotted on **Figure 3.4** in comparison to the modelled LFG collection curves. The maximum measured instantaneous flow recorded is 493 m^3/hr in January 2021. The collected landfill gas volumes are lower than the modelled landfill gas generation rate which is expected for an operational site. This is due to the site not being fully capped while it is operating, the interactions between the engine and the flare, and changes at individual extraction wells as a result of operational activities. The collection efficiency will fluctuate over time throughout the operation of the site; however, it will improve overall as more waste is placed, areas are completed to final profile and permanent LFG extraction pipework is installed and capping is installed.

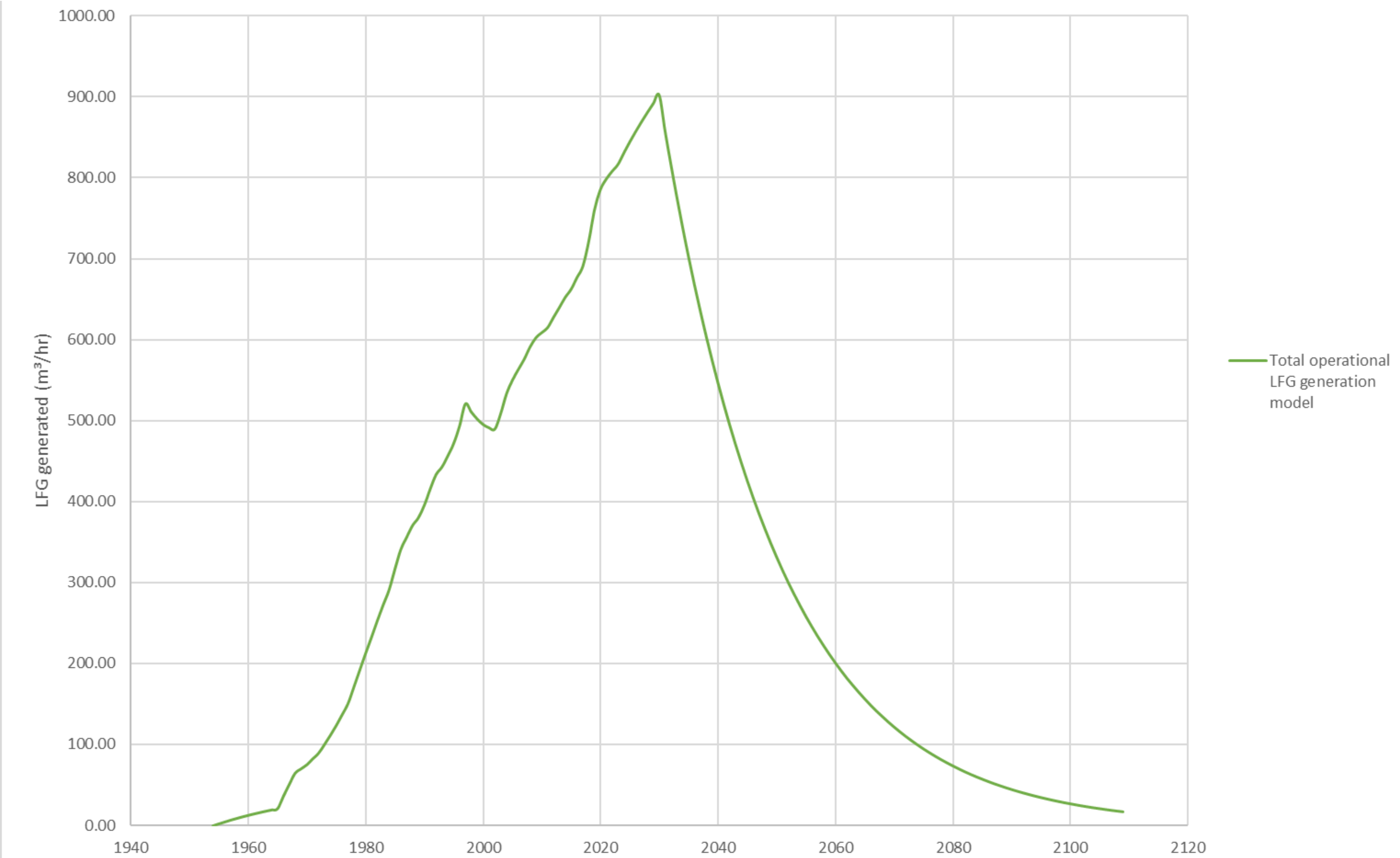

Figure 3.1: LFG generation curves for Green Island Landfill

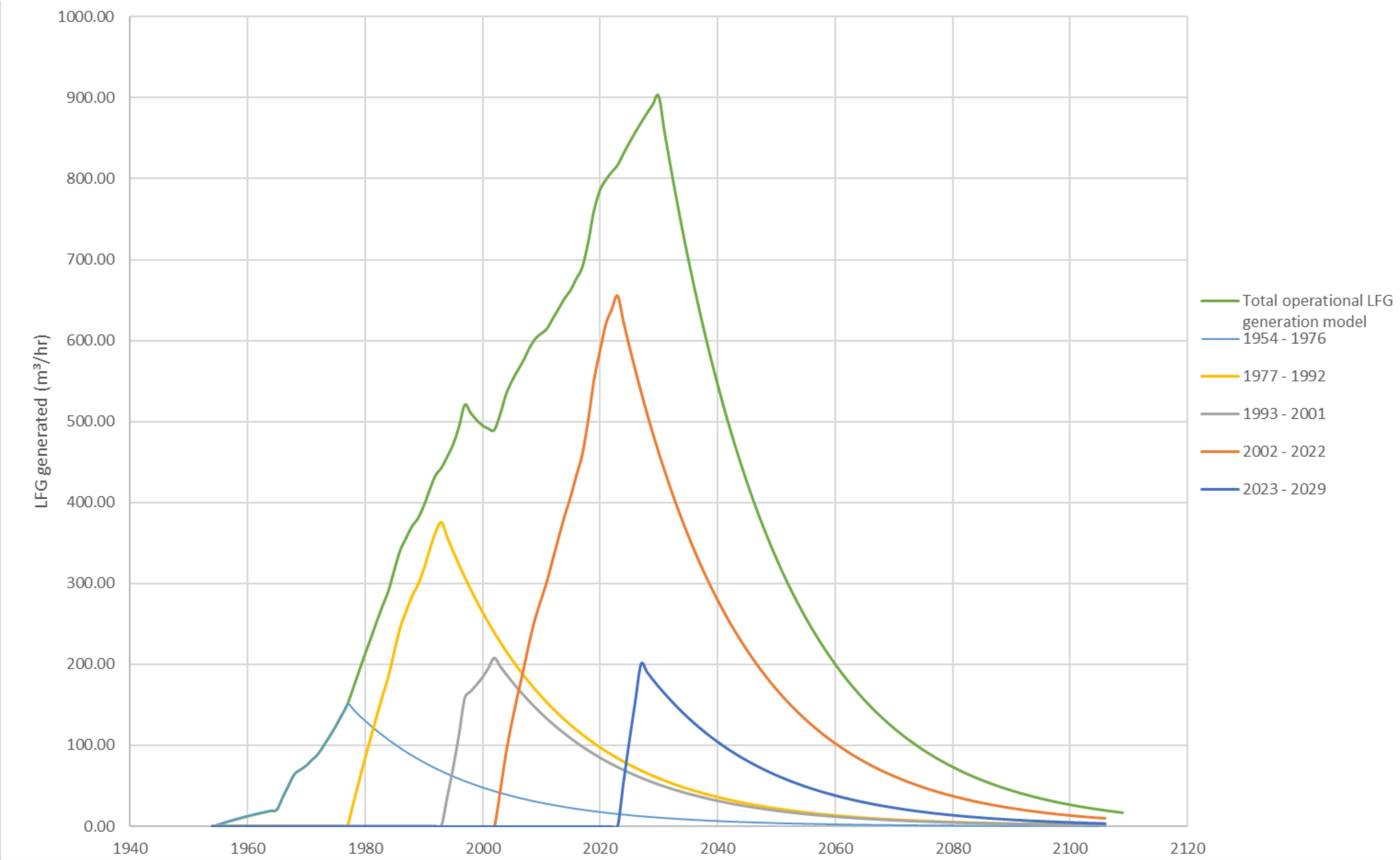

Figure 3.2: LFG generation curves for modelled filling periods at Green Island Landfill

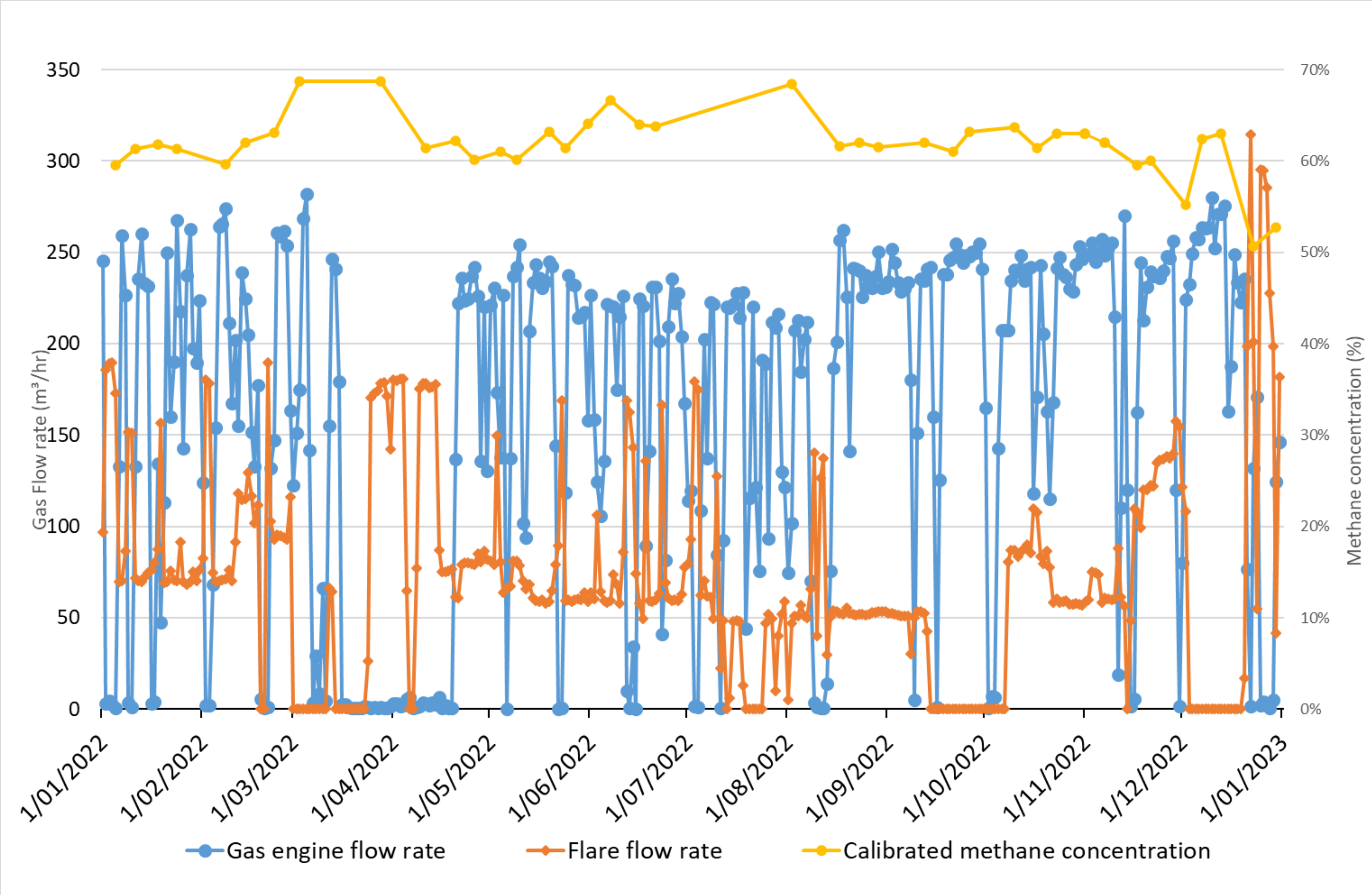

Figure 3.3: Measured LFG flow to the engine and flare in the 2022 calendar year

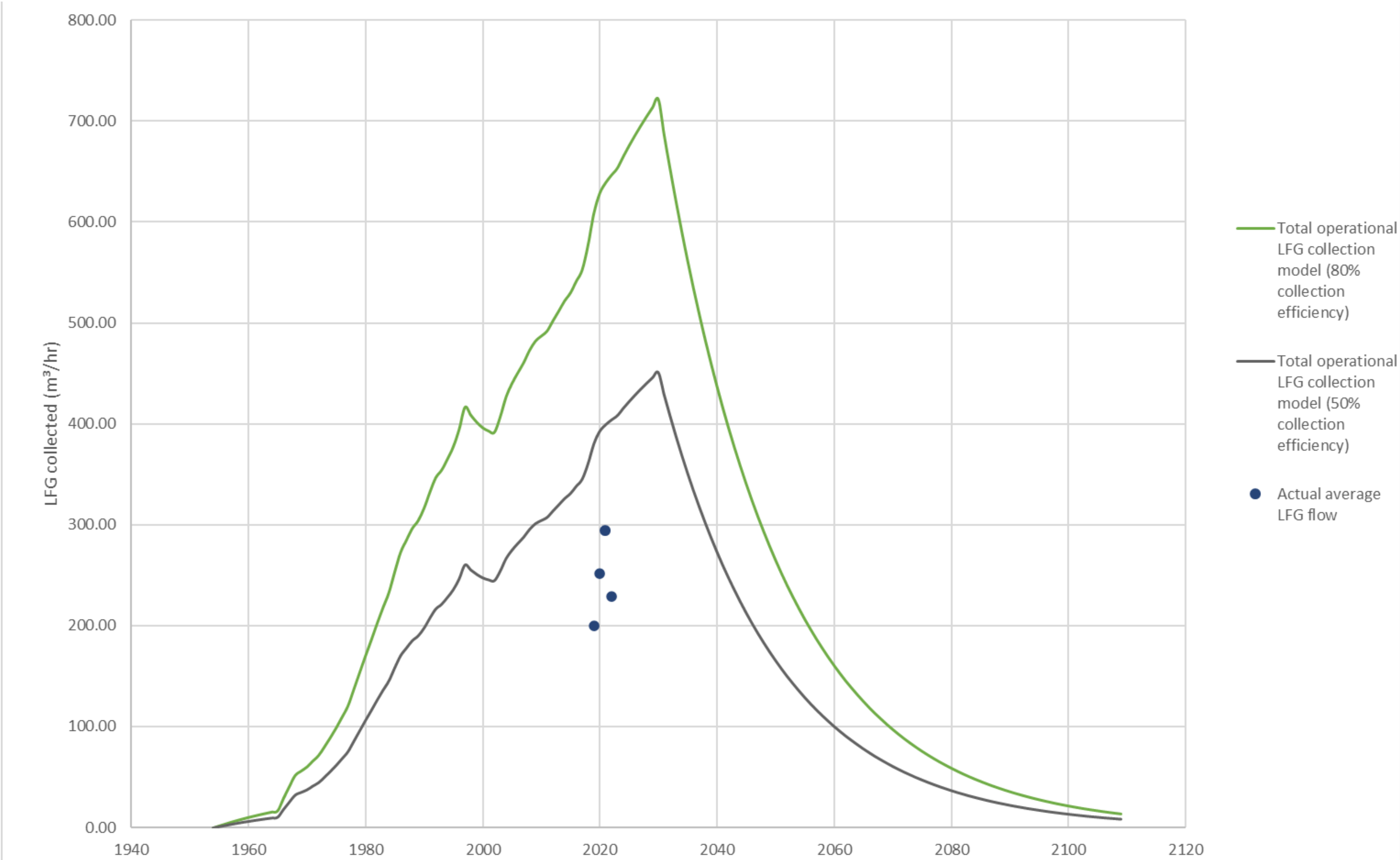

Figure 3.4: LFG generation curves for modelled filling periods at Green Island Landfill

4 Landfill gas extraction system masterplan

The proposed final LFG extraction system that is described in this section has been developed through a process of teleconference meetings, and a site visit conducted on 11 August 2020 with a follow-up meeting to refine the compiled sketches.

The proposed system is described in this section and shown in Drawing 1008787-207 in **Appendix A**.

4.1 Components of a landfill gas management system

The design of a LFG management system must address site-specific conditions. The typical primary components of a LFG management system are shown schematically in **Figure 4.1** and are as follows:

- Vertical and/or horizontal extraction wells, or a combination of these like the Norfolk pine design used by Waste Management.
- Wellheads.
- Connectors and subheader piping.
- Ringmain header piping.
- Condensate management.
- Blower and flare/electricity generator.
- Other utilisation technologies.

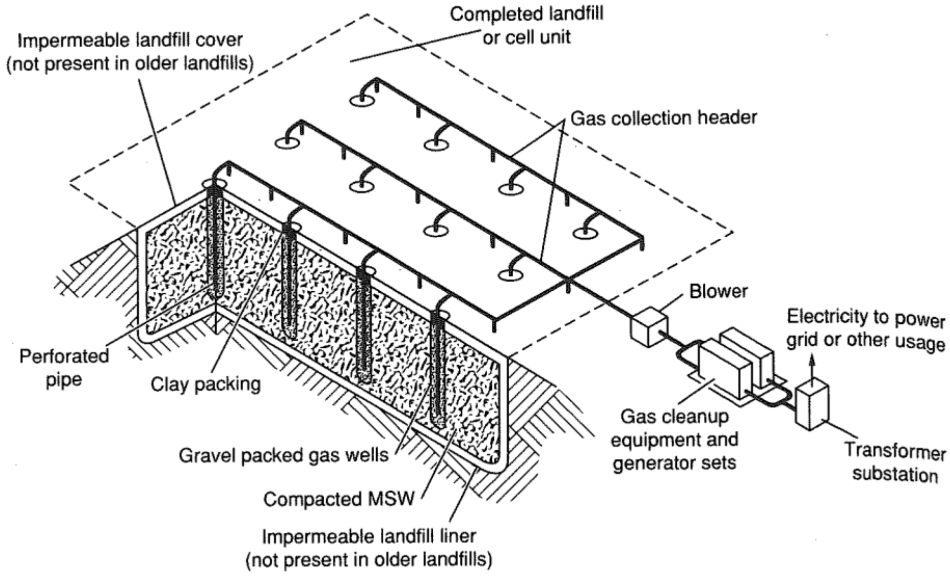

Figure 4.1: Schematic of LFG management system with vertical wells (Tchobanoglous, et.al, 1993).[5]

4.2 Interface with existing system

The Council provided survey data that showed the existing system including:

- Gas well positions.
- Pipe network positions.
- Current site contours.

[5] Tchobanoglous, et al, 1993. Integrated Solid Waste Management: Engineering Principles and Management Issues. Water Science & Technology Library.

Gas wells are currently installed across the whole site with the exception of the western and southern area, where significant additional filling is still required. It is noted that no waste has been placed in these areas for more than 15 years. The wells are spaced at approximately 40 m centres. No additional wells are proposed within the areas where wells have already been installed.

Following the installation of components of the LFG extraction network in 2022, the final extraction network has been updated (refer drawing 1008787-207 in **Appendix A**).

The Council's preference to retain as much of the existing system as possible was considered during the design of the proposed final LFG extraction system. The proposed design considers how the future wellfield expansion would tie into the existing LFG system while optimising LFG collection in as many gas-yielding wells as possible.

The design rationale for the ringmain and header placement is discussed further in Section 4.4 below.

During the construction of the different stages, refer to the T+T staging letter and drawings, the LFG network will continue to operate with the objective of minimising the disruption to the destruction of LFG. Temporary shutdown will be required to allow for the connection works to occur when connecting into existing system. Detailed design for each stage to include connection points/flanges with valve already installed so that future connections would be pre-flanged allowing for bolt on and commissioning and would not require the wellfield to be shut down.

4.3 Landfill gas extraction wells

As of September 2023, there are 38 existing vertical extraction wells installed at the site. The vertical extraction wells are installed at a spacing of approximately 40 m. Further landfill gas extraction wells are proposed to be installed in the southern and western areas.

With the extension of landfilling at the site to the end of 2029, the Closure Design Report states that the depth of waste will be increased in the western area by approximately 8 m (GHD, March 2023). To allow maximum LFG extraction while the LFG system continues to expand, consideration has been given to update the type of extraction wells installed in that area to vertical extendable wells.

In areas where waste placement is ongoing, i.e., the southern area, extendable vertical extraction wells will be installed to increase the extraction coverage. An extendable vertical well slip casing is shown in **Figure 4.2** and a typical detail is shown in **Figure 4.3**. Given that the southern area has historical waste placement, these can be installed now, by augering in the starter well, and immediately brought online and fed into the extraction system. They can be extended as the waste depth increases by pulling up the steel slip casing section, extending the well casing and filling the space between the steel slip casing and the well casing with drainage aggregate. The operational challenge with these wells is that there is an approximately 40 m spacing between the extraction wells that restricts operational access around the wells. This makes the wells prone to damage from the waste delivery trucks and equipment used for waste spreading and compaction.

Figure 4.2: Extendable vertical well

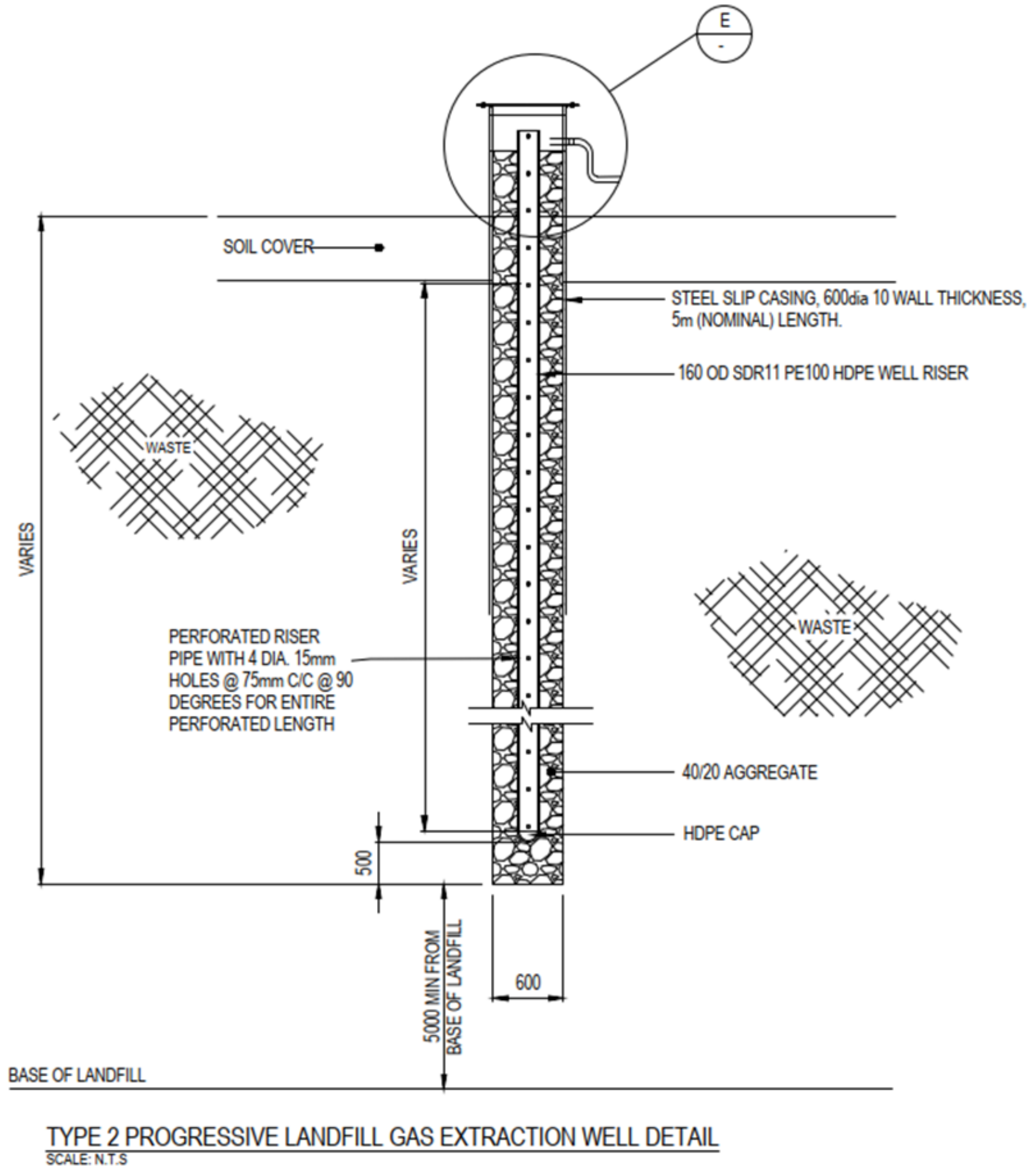

Figure 4.3: Extendable vertical well typical detail

4.3.1 Horizontal extraction wells

Horizontal extraction wells were an alternative option considered for collecting LFG. Horizontal wells are formed by excavating a trench into the working platform of a landfill cell. LFG is collected via a stone drainage backfill and perforated collection pipes.

The trench is typically installed in a large, wide cell and sloped to allow leachate to drain to the lower part of the trench while gas is extracted from the opposite, higher end. The sloped trench minimises leachate flooding the wells, which could result in a reduction, or total failure of gas flow from the well. The leachate at the lower end of a well can be removed by constructing a stone leachate sump to infiltrate the seepage back into the waste body.

Horizontal extraction wells work well in sites where there is a large, wide cell where there is a relatively uniform waste thickness as this allows access to waste. This is not the case at the site due to the sporadic historical filling of the southern area, and the inclined revised cap surface resulting in varied waste depth. Therefore, horizontal wells are not recommended for the site.

4.4 Header lines and ringmain

The LFG extraction system will ultimately comprise a primary ringmain header, and a number of subheaders and connectors that connect the gas wells to the ringmain, see final Stage 6 layout in Drawing 1008787-207 in **Appendix A**. There will also be valves throughout the network to allow for redundancy and flexibility to continuously collect LFG during shut-down maintenance periods. The Masterplan has been designed to maximise LFG collection with the following key features:

- Gas line 1: The existing gas line 1 (355 mm diameter) between the existing Y-junction with Gas line 2 and the LFG engine/flare will remain in place and form the south western portion of the permanent ringmain. Gas line 1 is connected to gas line 2 at its start and continues to the flare at the WWTP.
- Gas line 2: The existing gas line 2 will form a section of the new eastern permanent ringmain. Gas line 2 is connected to gas line 1 on the south, and the splits into the new eastern ringmain, and subheader 2 to the north.
- Western ringmain: A new pipeline has been constructed to form the ringmain header along the western perimeter of the landfill. The western ringmain will extend the existing network to the southern area of the site and collect LFG from the gas wells in the northern area of the landfill. It forms a closed loop ringmain that allows for redundancy in LFG collection in instances where the eastern ringmain is out of service.
- Eastern ringmain: A new pipeline is proposed to close the ringmain across the centre of the site. It closes the ringmain loop as it connects to the western ringmain on the west, and gas line 2 on the east. It will collect gas from the central gas wells (GW9, GW16, GW15, GW14), and form a cross-connection that links GW16 to GW29 for increased LFG collection redundancy in the event of an out-of-service branch.
- Eastern Subheader: The existing eastern branch will remain and collect LFG from the gas wells in the eastern capped area of the landfill (GW1, GW2, GW3, GW4, GW5, GW6, GW7, GW10, GW11, GW13). This branch will form a subheader which will be connected to gas line 2 on the east, and the western ringmain on the west.
- Northern subheader: A new pipeline was installed in the northern section of the landfill in 2022 to connect the existing gas wells (GW18, GW19, GW20, GW21, GW22, GW23, GW24) to the network. It has connected the western ringmain on the west, and the eastern subheader on the east.
- Cross headers (north, centre, south) – these three (3) cross headers are connected along the western ringmain and join across to either gas line 2 or the eastern ringmain. They allow connection of gas wells that are not along the ringmains

The staging plan gives consideration to merge the filling plan and the pipe installation phases; new pipes and wells to be installed when the waste is at final level before the final capping layer is installed. It is assumed that the pipelines will be buried in the interim capping layer. Consideration has also been given to use temporary connector pipes to optimise LFG collection in specific stages. The staging plan will be confirmed in detail during the detailed design stage.

4.5 Condensate management

The majority of the well connectors have been designed to allow gravity drainage of condensate into the subheader/header pipelines to prevent condensate forming a blockage to the flow from a well. In instances where well connectors could not be designed in this way (i.e., GW4, GW3, GW2, GW1, GW17, GW18, GW19, GW20, and GW22, GW23), the well will be designed as a condensate sump to allow condensate to flow back into the well instead of blocking the connector pipes. Typical details to be included in the detailed design of each stage of works to be undertaken.

As per discussions with Council, the LFG extraction pipelines have been designed with a minimum slope of 2 % to minimise the risk of potential U-traps forming in the pipeline, and surging / interruption of flow due to differential settlement of the waste. This is less than the industry norm of 3 %, however, given the site's flat topography, achieving more fall than this would require multiple condensate sumps. To compensate, pipe sizing should be increased to the next standard size up during detailed design phase. Due to the site topography, some sections of the network will experience contra-flow where LFG is extracted in the uphill direction while condensate flows downhill. Condensate knockouts should be installed at low points throughout the network to drain condensate and prevent it blocking the extraction pipes.

The exact type of condensate knockout should be confirmed at the detailed design stage, and consideration should be given to connecting the knockouts directly to the leachate drainage network, draining the condensate back into the waste, or draining to the perimeter collection drain to be pumped to the WWTP.

4.6 Implications of landfill gas generation modelling on system design

The operational landfill generation model has shown the effects of excluding waste that has been in place for many decades and waste that is saturated due to elevated leachate levels. The well balancing records were reviewed in 2021 which highlight that the existing LFG extraction wellfield has significant variabilities in the quantity and quality of LFG extracted from the individual wells[6]. These variabilities are due to various reasons, including:

- Gas extraction wells of different ages (some back to 2008/09).
  - The older the waste, the less available carbon there is to be degraded and converted through anaerobic degradation to methane and carbon dioxide. The waste in the eastern part of the site, which has been covered with final capping, would be in this decreasing phase of LFG production.
- Gas extraction wells installed in either intermediate, or final capped areas of the landfill.
  - More LFG is likely to be lost through surface emissions in intermediate capped areas, whereas final capped areas should be better at containing LFG so that it can be drawn to the gas wells. The waste placed in the northern part of the landfill, which is also the newest waste to be placed, is currently covered with intermediate cap only, which will reduce the amount of LFG that can be extracted by the system.
- Gas extraction wells installed in areas with limited depth of waste i.e., areas still to be filled to final height.
  - The shallower the depth of waste surrounding a well, the less biodegradable carbon there is to be broken down and converted to LFG. In extremely thin areas of the site the waste may not even become anaerobic, and it will thus not generate LFG. This may be impacting the southern and western areas of the landfill which currently have a thin layer of waste covered by intermediate cover.

The design flow calculations are likely to therefore be conservative in some areas, and potentially slightly understated or underestimated in other areas. The built-in redundancy described in Section 4.5 will however be sufficient to compensate for these variations.

The maximum peak LFG that can be generated as per the operational model is 902 m^3/hr.

[6] Trends and relationships described in this section are based on data up until August 2020.

4.7 Landfill gas destruction

The LFG collected is currently destroyed on site by:

- A LFG engine: LFG is used as fuel to generate electricity. The LFG engine also receives gas from the adjacent WWTP.
- A candlestick flare.

Based on the LFG generation modelling, the maximum possible collected LFG at the site will be approximately 722 m^3/hr in 2030(one year after the site stops receiving waste. This flow rate is based on collection of 80 % of the modelled maximum peak LFG generation rate stated in section 4.6. The capacity of the existing LFG engine is approximately 350 m^3/hr, and the capacity of the existing candlestick flare is approximately 450 m^3/hr. Together, these methods of LFG destruction are therefore theoretically of sufficient capacity for the projected LFG collection in 2030.

As of September 2023, there has been discussion of replacing the existing back up flare with a new enclosed flare. To allow for maximum flexibility in the LFG extraction system (i.e., if the engine is offline for a period of time), an enclosed flare with a capacity of 1000 N m^3/hr is recommended. Enclosed flares typically have a turn down ratio between 1:7 and 1:10, allowing the flare to operate as low as 100 to 150 N m^3/hr.

No testing of the destruction efficiency of either the engine or the flare has been carried out. Therefore, under the UEF Regulations, default destruction efficiencies of 90 % and 50 % are assumed for the existing engine and flare respectively.

With the increased LFG to be collected at the landfill, and that being generated at the WWTP, other destruction or utilisation options could be considered for the site in the future, in addition to the upgrade of the existing flare. This could include installation of additional electricity generators. Options include increasing the number of LFG engines, upgrading to a larger LFG engine or installing modular microturbines, depending on the volume of LFG flow available. Other direct uses of the gas, as a heating source for a nearby business or commercial facility, could also be explored.

If and/or when changing the LFG treatment and destruction methods, consideration should be given to:

- The volume of LFG collected: different destruction methods have a different ranges of LFG volume and methane concentration in which they can operate. For example, a flare can typically cope with a wide range of flow including flow as low as 10 % at a 1 to 10 turndown, and a lower methane concentration than LFG engines.
- The stability of LFG flow: LFG collection may fluctuate depending on the season, weather, or status of the well field. Different destruction methods have a range of flexibility to cope with fluctuations.
- The extent to which the various destruction alternatives will reduce future ETS obligations and result in cost savings to offset implementation costs.

5 Conclusion

LFG management is a crucial part of modern landfill operations as it controls off-site migration of methane, odour, and hazardous volatilized components. It also serves to control greenhouse gas emissions and enables compliance with regulations. There is also an opportunity to recover energy in the process.

This LFG Masterplan allows management of the site in accordance with the key objectives identified in the WasteMINZ Disposal to Land Guidelines. It serves as a guide in the site's development into the west and southern areas of the landfill. This Masterplan outlines the model for LFG generation and collection which estimates the potential volume of LFG that is available for extraction from the waste. It also outlines the plan in which LFG collection can be maximised, while keeping as much of the existing LFG extraction system in place as possible.

Lastly the Masterplan reviews destruction capacity and possible alternatives to increase this capacity as the LFG extraction system is expanded.

The LFG management system that is in place at the site is considered to be consistent with current good practice, and will allow for the site to continue to be managed to minimise the effects on the environment.

The LFG Masterplan has been developed based on our understanding of the future development and filling of the landfill and on the assumption that the current consented period will be extended to allow for filling to the end of 2029 (depending on actual incoming waste tonnage and status of consenting), as described in the resource consent application which is currenting being processed. It should be reviewed periodically, including as part of any significant changes in the design or filling plan for the site.

6 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.

Tonkin & Taylor Ltd

Report prepared by:	Authorised for Tonkin & Taylor Ltd by:
....	....
Alex de Guzman	Jonathan Shamrock
Environmental Engineer	Project Director

Reviewed by: Jo Ferry – Principal Environmental Consultant

ALDG
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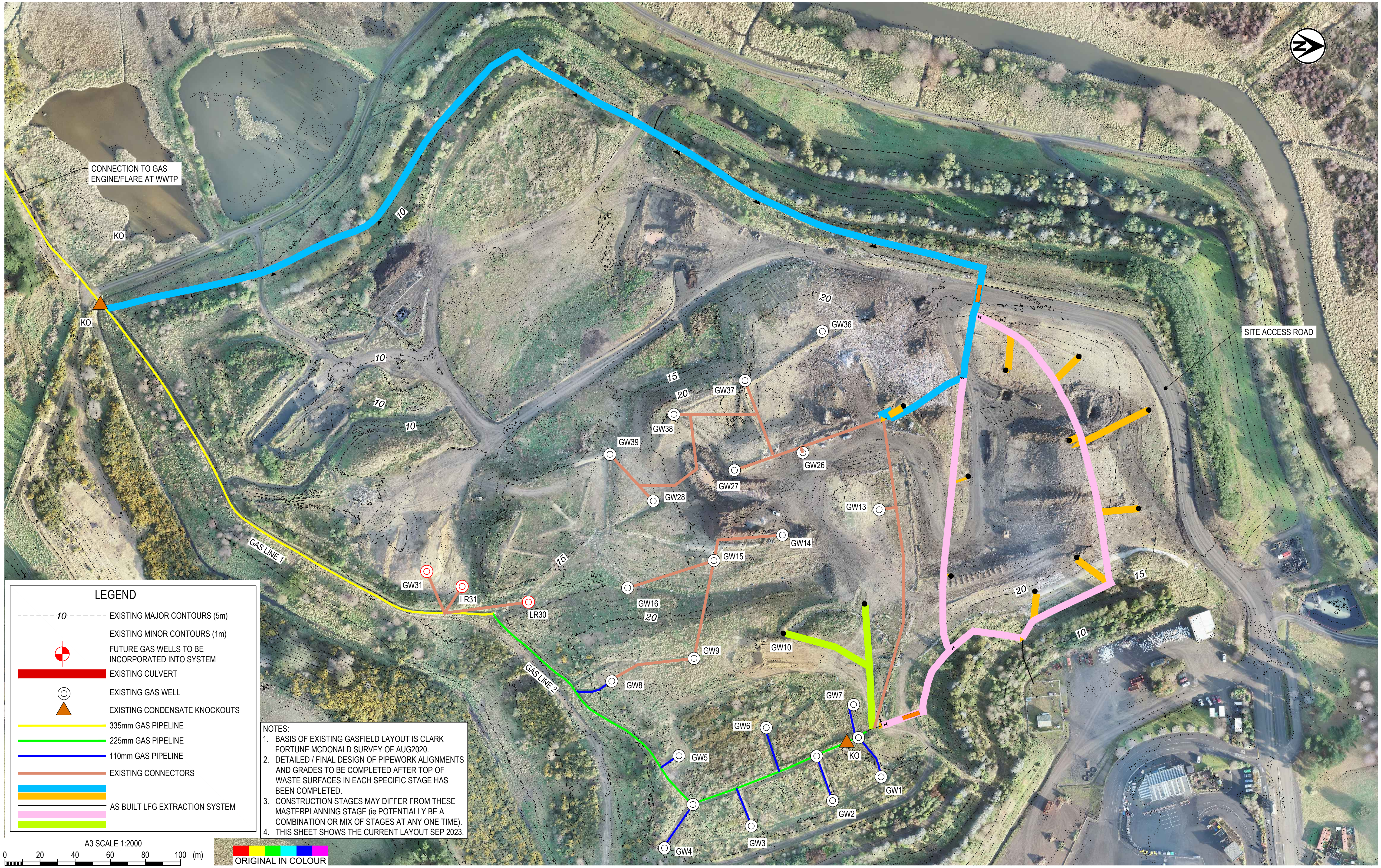
Appendix A: Drawings

C:\12dS\data\ALBTCAD\Green Island Expansion_215\CAD\DWG\1008787-200.dwg 2023-Sep-13 4:43:14 pm Plotted By: EMMA SONG



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

A3 SCALE 1:2000

0 20 40 60 80 100 (m)

ORIGINAL IN COLOUR

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.

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REV	DESCRIPTION	CAD	CHK	DATE
1	CLIENT REVIEW	EMSO		
2	REPORT ISSUE	EMSO		
3	UPDATE FOR CONSENT EXTENSION APPLICATION	EMSO		

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

DRAWING STATUS: REPORT ISSUE

NOT FOR CONSTRUCTION

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

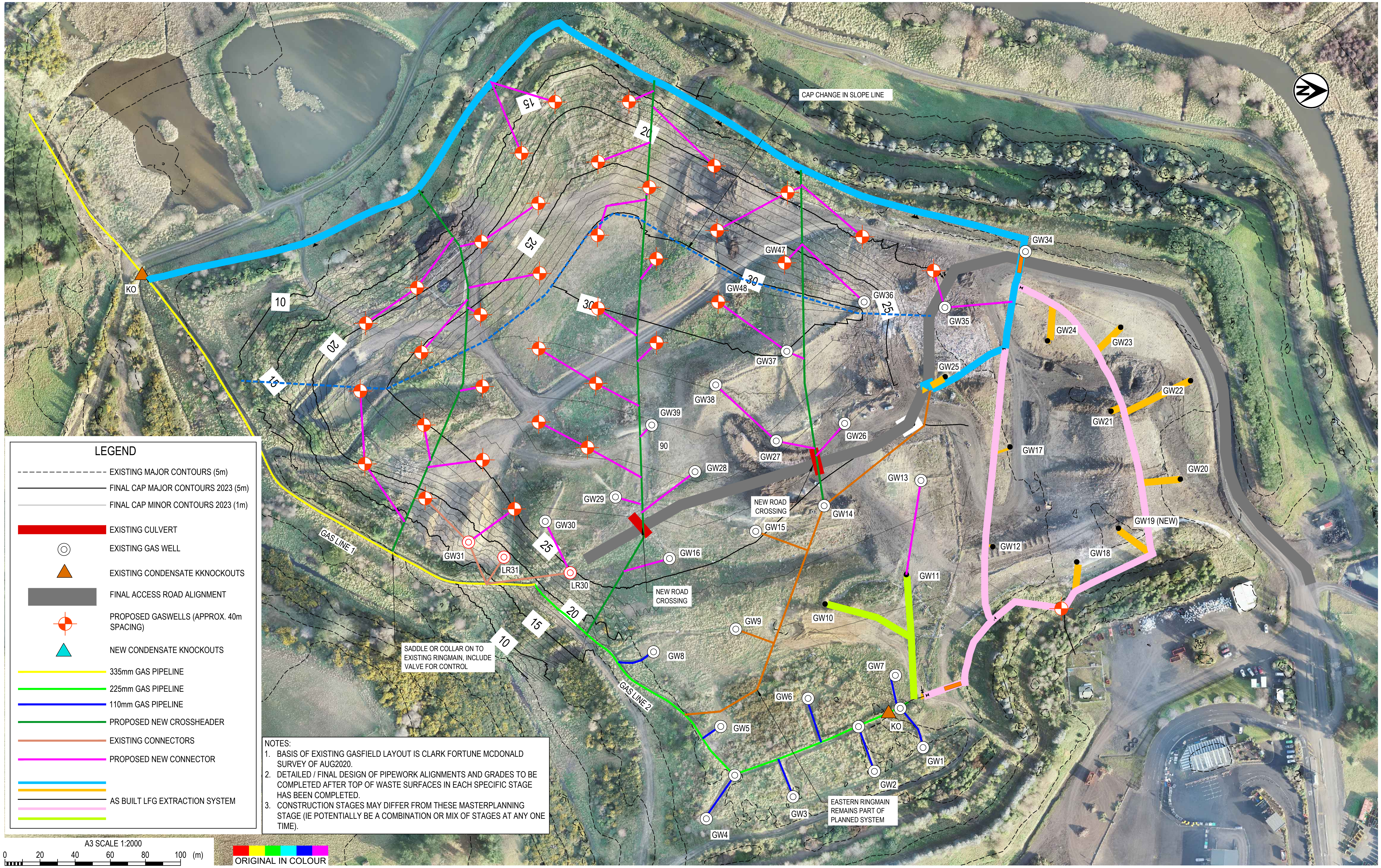
CLIENT: DUNEDIN CITY COUNCIL

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 3

C:\12dS\data\ALBTCAD\Green Island Expansion_215\CAD\DWG\1008787-207.dwg 2023-Sep-13 4:42:45 pm Plotted By: EMMA SONG



LEGEND

- EXISTING MAJOR CONTOURS (5m)
- FINAL CAP MAJOR CONTOURS 2023 (5m)
- FINAL CAP MINOR CONTOURS 2023 (1m)
- EXISTING CULVERT
- EXISTING GAS WELL
- EXISTING CONDENSATE KKNOCKOUTS
- FINAL ACCESS ROAD ALIGNMENT
- PROPOSED GASWELLS (APPROX. 40m SPACING)
- NEW CONDENSATE KNOCKOUTS
- 335mm GAS PIPELINE
- 225mm GAS PIPELINE
- 110mm GAS PIPELINE
- PROPOSED NEW CROSSHEADER
- EXISTING CONNECTORS
- PROPOSED NEW CONNECTOR
- 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).

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		

DESIGNED	JOSH	Sep.23
DRAWN	EMSO	Sep.23
DESIGN CHECKED		
DRAWING CHECKED		
APPROVED		DATE

NOT FOR CONSTRUCTION

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 FINAL LFG EXTRACTION SYSTEM
SCALE (A3): 1:2000 DWG No. 1008787-207 REV 3

Appendix B: Landfill gas model inputs and output

Green Island Landfill: Waste tonnage projection

Prepared	A. de Guzman	19/04/2021
Updated:	A. de Guzman	4/09/2023
Reviewed:	J. Ferry	11/09/2023

Notes / Assumptions:

1. The tonnage used is the inert adjusted waste tonnage. This has been estimated for the period 1954-1996 based on available information.
This has not been averaged as with the UEF application model as it is not required by the Regulations.

2. The projected gas-producing waste is as assumed in the Green Island Closure Design Report (GHD, March 2023).

3. The projected total tonnage after 2022 is calculated as per airspace consumed calculated in the Green Island Closure Design Report (GHD, March 2023):
Waste is compacted to 0.8 tonnes/m³, Soils are compacted to 1.6 tonnes/m³, 10 % of soils is lost to the voids in the waste, waste settles 10 % during waste placement, and a further 15% post-placement.

Tonnage period	Percentage of waste saturated by leachate
1954 - 1976	50%
1977 - 1992	38%
1993 - 2001	44%
2002 - 2022	0%
2023 - 2029	0%

Year	Tonnage data (tonnes)			Operational waste tonnages (tonnes)					
	Projected total tonnage	Projected non-inert waste	Waste tonnage used in UEF Application	Projected gas producing waste	1954 - 1976	1977 - 1992	1993 - 2001	2002 - 2022	2023 - 2029
1954	7293.09	5396.89	40145.23	2698.44	2698.44	0.00	0.00	0.00	0.00
1955	7293.09	5396.89	40145.23	2698.44	2698.44	0.00	0.00	0.00	0.00
1956	7293.09	5396.89	40145.23	2698.44	2698.44	0.00	0.00	0.00	0.00
1957	7293.09	5396.89	40145.23	2698.44	2698.44	0.00	0.00	0.00	0.00
1958	7293.09	5396.89	40145.23	2698.44	2698.44	0.00	0.00	0.00	0.00
1959	7293.09	5396.89	40145.23	2698.44	2698.44	0.00	0.00	0.00	0.00
1960	7293.09	5396.89	40145.23	2698.44	2698.44	0.00	0.00	0.00	0.00
1961	7293.09	5396.89	40145.23	2698.44	2698.44	0.00	0.00	0.00	0.00
1962	7293.09	5396.89	40145.23	2698.44	2698.44	0.00	0.00	0.00	0.00
1963	7293.09	5396.89	40145.23	2698.44	2698.44	0.00	0.00	0.00	0.00
1964	7293.09	5396.89	40145.23	2698.44	2698.44	0.00	0.00	0.00	0.00
1965	49060.00	36304.40	40145.23	18152.20	18152.20	0.00	0.00	0.00	0.00
1966	49060.00	36304.40	40145.23	18152.20	18152.20	0.00	0.00	0.00	0.00
1967	49060.00	36304.40	40145.23	18152.20	18152.20	0.00	0.00	0.00	0.00
1968	25630.00	18966.20	40145.23	9483.10	9483.10	0.00	0.00	0.00	0.00
1969	25630.00	18966.20	40145.23	9483.10	9483.10	0.00	0.00	0.00	0.00
1970	33000.00	24420.00	40145.23	12210.00	12210.00	0.00	0.00	0.00	0.00
1971	33000.00	24420.00	40145.23	12210.00	12210.00	0.00	0.00	0.00	0.00
1972	38500.00	33225.50	40145.23	16612.75	16612.75	0.00	0.00	0.00	0.00
1973	41800.00	36073.40	40145.23	18036.70	18036.70	0.00	0.00	0.00	0.00
1974	45100.00	38921.30	40145.23	19460.65	19460.65	0.00	0.00	0.00	0.00
1975	49500.00	42718.50	40145.23	21359.25	21359.25	0.00	0.00	0.00	0.00
1976	52800.00	45566.40	40145.23	22783.20	22783.20	0.00	0.00	0.00	0.00
1977	57200.00	49363.60	40145.23	30605.43	0.00	30605.43	0.00	0.00	0.00
1978	60500.00	52211.50	40145.23	32371.13	0.00	32371.13	0.00	0.00	0.00
1979	62700.00	54110.10	40145.23	33548.26	0.00	33548.26	0.00	0.00	0.00
1980	62700.00	54110.10	40145.23	33548.26	0.00	33548.26	0.00	0.00	0.00
1981	66000.00	56958.00	40145.23	35313.96	0.00	35313.96	0.00	0.00	0.00
1982	66000.00	56958.00	40145.23	35313.96	0.00	35313.96	0.00	0.00	0.00
1983	66000.00	56958.00	40145.23	35313.96	0.00	35313.96	0.00	0.00	0.00

Year	Tonnage data (tonnes)			Operational waste tonnages (tonnes)					
	Projected total tonnage	Projected non-inert waste	Waste tonnage used in UEF Application	Projected gas producing waste	1954 - 1976	1977 - 1992	1993 - 2001	2002 - 2022	2023 - 2029
1984	82500.00	71197.50	40145.23	44142.45	0.00	44142.45	0.00	0.00	0.00
1985	82500.00	71197.50	40145.23	44142.45	0.00	44142.45	0.00	0.00	0.00
1986	66000.00	56958.00	40145.23	35313.96	0.00	35313.96	0.00	0.00	0.00
1987	66000.00	56958.00	40145.23	35313.96	0.00	35313.96	0.00	0.00	0.00
1988	66000.00	49500.00	40145.23	30690.00	0.00	30690.00	0.00	0.00	0.00
1989	66000.00	60324.00	40145.23	37400.88	0.00	37400.88	0.00	0.00	0.00
1990	77000.00	70378.00	40145.23	43634.36	0.00	43634.36	0.00	0.00	0.00
1991	74800.00	68367.20	40145.23	42387.66	0.00	42387.66	0.00	0.00	0.00
1992	65665.00	54501.95	40145.23	33791.21	0.00	33791.21	0.00	0.00	0.00
1993	84300.00	69969.00	40145.23	39182.64	0.00	0.00	39182.64	0.00	0.00
1994	89724.00	74470.92	40145.23	41703.72	0.00	0.00	41703.72	0.00	0.00
1995	106224.00	88165.92	40145.23	49372.92	0.00	0.00	49372.92	0.00	0.00
1996	122929.00	102031.07	40145.23	57137.40	0.00	0.00	57137.40	0.00	0.00
1997	142206.00	30701.00	30701.00	17192.56	0.00	0.00	17192.56	0.00	0.00
1998	127924.00	32293.00	32293.00	18084.08	0.00	0.00	18084.08	0.00	0.00
1999	165003.00	35026.00	35026.00	19614.56	0.00	0.00	19614.56	0.00	0.00
2000	123537.00	40004.00	40004.00	22402.24	0.00	0.00	22402.24	0.00	0.00
2001	123635.00	43767.00	43767.00	24509.52	0.00	0.00	24509.52	0.00	0.00
2002	96245.00	47553.00	47553.00	47553.00	0.00	0.00	0.00	47553.00	0.00
2003	88880.00	54805.00	54805.00	54805.00	0.00	0.00	0.00	54805.00	0.00
2004	96581.18	47156.00	47156.00	47156.00	0.00	0.00	0.00	47156.00	0.00
2005	94738.00	44727.00	44727.00	44727.00	0.00	0.00	0.00	44727.00	0.00
2006	111689.00	44424.00	44424.00	44424.00	0.00	0.00	0.00	44424.00	0.00
2007	149655.28	47976.03	47976.03	47976.03	0.00	0.00	0.00	47976.03	0.00
2008	94460.44	44580.00	44580.00	44580.00	0.00	0.00	0.00	44580.00	0.00
2009	105051.06	39662.30	39662.30	39662.30	0.00	0.00	0.00	39662.30	0.00
2010	86574.21	39962.24	39962.24	39962.24	0.00	0.00	0.00	39962.24	0.00
2011	129053.98	47154.67	47154.67	47154.67	0.00	0.00	0.00	47154.67	0.00
2012	169989.19	47538.42	47538.42	47538.42	0.00	0.00	0.00	47538.42	0.00
2013	182211.77	48449.06	48449.06	48449.06	0.00	0.00	0.00	48449.06	0.00
2014	100275.78	46333.36	46333.36	46333.36	0.00	0.00	0.00	46333.36	0.00
2015	88350.78	51856.12	51856.12	51856.12	0.00	0.00	0.00	51856.12	0.00
2016	84338.94	52130.48	52130.48	52130.48	0.00	0.00	0.00	52130.48	0.00
2017	121220.74	71393.74	71393.74	71393.74	0.00	0.00	0.00	71393.74	0.00
2018	169338.35	82600.01	82600.01	82600.01	0.00	0.00	0.00	82600.01	0.00
2019	127601.57	68692.74	68692.74	68692.74	0.00	0.00	0.00	68692.74	0.00
2020	126111.14	56972.27	56972.27	56972.27	0.00	0.00	0.00	56972.27	0.00
2021	101004.84	53811.66	53811.66	53811.66	0.00	0.00	0.00	53811.66	0.00
2022	116324.67	53207.63	53207.63	53207.63	0.00	0.00	0.00	53207.63	0.00
2023	118333.56	59833.00	NA	59833.00	0.00	0.00	0.00	0.00	59833.00
2024	118333.56	59833.00	NA	59833.00	0.00	0.00	0.00	0.00	59833.00
2025	118333.56	59833.00	NA	59833.00	0.00	0.00	0.00	0.00	59833.00
2026	118333.56	59833.00	NA	59833.00	0.00	0.00	0.00	0.00	59833.00
2027	118333.56	59833.00	NA	59833.00	0.00	0.00	0.00	0.00	59833.00
2028	118333.56	59833.00	NA	59833.00	0.00	0.00	0.00	0.00	59833.00
2029	118333.56	59833.00	NA	59833.00	0.00	0.00	0.00	0.00	59833.00

Green Island Landfill - Inputs to gas generation model

Prepared by:	ALSA	21/10/2020
Checked by:	JMC	22/10/2020

	Garden	Nappy	Food	Paper	Sludge	Wood	Textile
	GW	NSW	OPW	PW	SSW	TMW	TXW
Overall organic composition of all waste	12.1%	1.7%	18.9%	9.3%	9.4%	11.7%	3.9%

First order decay parameters
As per regulations Schedule 3

Methane generation potential - Lo (m^3 CH_4/tonne)	100	120	75	200	25	215	120	79.11	Site specific Lo

01 SCHOLL CANYON PARAMETERS

In the Scholl Canyon model there are two parameters that determine generation rate and its decay with time from a unit weight of waste. These are

L_o = the total volume of landfill gas that a unit weight of waste will produce

k = the decay rate constant

Once these constants have been estimated, the rate of waste placement and the time in the landfill life cycle determine the estimated gas emission rate.

Reference

DEPARTMENT OF THE ARMY U.S. Army Corps of Engineers CEMP-RT Washington, DC 20314-1000 ETL 1110-1-160 Technical Letter No. 1110-1-160 17 April 1995 "Engineering and Design LANDFILL OFF-GAS COLLECTION AND TREATMENT SYSTEMS" pp A-42

Pierce J, LaFountain L, Huitec R (2005), "Landfill gas generation & modelling manual of practice", The Solid waste Association of North America (SWANA), SWANA's Landfill Gas Management Technical Divivion / Landfill Gas Generation and Modeling Committee.

k Generation rate constant

The gas generation decay rate constant, k, estimates how rapidly the methane production rate falls after the waste has been placed. The method assumes the rate is at its maximum upon placement. The value of k is strongly influenced by:

- temperature,
- moisture content,
- availability of nutrients, and
- pH.

CH_4 generation increases as the moisture content increases up to a level of 60% to 80%, at which the generation rate does not increase . Values of k obtained from literature, laboratory simulator results, and back-calculated from measured gas generation rates range from 0.003/yr to 0.21/yr .

$$\frac{0.03}{yr} \le k \le \frac{0.21}{yr}$$

Typical value of k in a landfill with no impermeable cap $k := 0.08yr^{-1}$

Typical value of k in a landfill with a permanent cap $k := 0.04yr^{-1}$

These values can be modified and optimised by leachate recirculation.This may be desirable where the gas is to be used in landfill gas to energy project.

The SWANA report postulates an exponential best fit curve for k values versus annual rainfall (in inches) based on data recorded in 2003 & 2004

$$k(r) := 0.016 \cdot e^{0.040\left(r \cdot in^{-1}\right)} \qquad k(726.2mm) = 0.05$$

Typical values of parameters

Location	Condition	k (1/year)	Lo (m^3/tonne)
Theoretical maximum (balanced stoichiometric equations)			230 to 270
Range in international literature		0.03 to 0.21	
USA EPA default AP-42	Dry climate[1]	0.02	100
USA EPA default AP-42	Wet climate	0.04	100
USA EPA default NSPS/EG	Dry climate[1]	0.02	170
USA EPA default NSPS/EG	Wet climate	0.05	170
Typical New Zealand landfills		0.036 to 0.15	100 to 230

Notes 1 Dry climate <25 inches of rainfall per year

17 SCHOLL CANYON MODEL MULTIPLE WASTE PROFILE

The generation of landfill gas is estimated by the Scholl Canyon model, which is a first order decay model. The calculation procedures permits the modelling of:

- multiple waste/time input profiles
- single gas production and decay per unit weight (L_o & k)

References

DEPARTMENT OF THE ARMY U.S. Army Corps of Engineers CEMP-RT Washington, DC 20314-1000 ETL 1110-1-160 Technical Letter No. 1110-1-160 17 April 1995 "Engineering and Design LANDFILL OFF-GAS COLLECTION AND TREATMENT SYSTEMS"

Parameters

Waste parameters

Potential CH_4 generation capacity of the waste (SWAP 2020) $L_o := 79.11 m^3 \cdot tonne^{-1}$

CH_4 generation decay rate constant $k := 0.05 \cdot yr^{-1}$

Time since initial waste placement, yrs. $Time := 70yr$

Time to reach anaerobic conditions, yrs. $lag := 0.5yr$

Landfill waste input

$Date := \left(Waste^{\langle 0 \rangle}\right) \cdot yr$

$Anwaste_{A1} := Waste^{\langle 1 \rangle} \cdot tonne$

Waste := (Date, Tonnes)

	0	1
0	1954	2698.44
1	1955	2698.44
2	1956	2698.44
3	1957	2698.44
4	1958	2698.44
5	1959	2698.44
6	1960	2698.44
7	1961	2698.44
8	1962	2698.44
9	1963	2698.44
10	1964	2698.44
11	1965	18152.2
12	1966	18152.2
13	1967	18152.2
14	1968	9483.1
15	1969	9483.1
16	1970	12210
17	1971	12210
18	1972	16612.75
19	1973	18036.7

20	1974	19460.65
21	1975	21359.25
22	1976	22783.2
23	1977	30605.43
24	1978	32371.13
25	1979	33548.26
26	1980	33548.26
27	1981	35313.96
28	1982	35313.96
29	1983	35313.96
30	1984	44142.45
31	1985	44142.45
32	1986	35313.96
33	1987	35313.96
34	1988	30690
35	1989	37400.88
36	1990	43634.36
37	1991	42387.66
38	1992	33791.21
39	1993	39182.64
40	1994	41703.72
41	1995	49372.92
42	1996	57137.4
43	1997	17192.56
44	1998	18084.08
45	1999	19614.56
46	2000	22402.24
47	2001	24509.52
48	2002	47553
49	2003	54805
50	2004	47156
51	2005	44727
52	2006	44424
53	2007	47976.03
54	2008	44580
55	2009	39662.3
56	2010	39962.24
57	2011	47154.67
58	2012	47538.42
59	2013	48449.06
60	2014	46333.36
61	2015	51856.12
62	2016	52130.48
63	2017	71393.74

64	2018	82600.01
65	2019	68692.74
66	2020	56972.27
67	2021	53811.66
68	2022	53207.63
69	2023	59833
70	2024	59833
71	2025	59833
72	2026	59833
73	2027	59833
74	2028	59833
75	2029	59833

Start date for anlysis $Start := Date_0$ $Start = 1954 \cdot yr$

Incoming waste $Incom_A := 76$ years

Closure date $Close_A := Start + (Incom_A - 1) \cdot yr$ $Close_A = 2029 \cdot yr$

Final date for analysis $Final := Close_A + 80yr$ $Final = 2109 \cdot yr$

Scholl Canyon Equation

Estimated landfill gas flow rate

$Q(Time, Anwaste, Incom) :=$

$q \leftarrow 0 \cdot m^3 \cdot hr^{-1}$

Number of increments in a year

$inc \leftarrow 20$

$\text{for } i \in 0..(Incom - 1)$

$\quad \text{for } j \in 0..inc - 1$

Time from the day of waste placement

$\qquad Day_{i \cdot inc+j} \leftarrow Date_i + j \cdot \frac{365}{inc} \cdot day$

If the waste has not been placed it does not contribute.

$\qquad waste_{i \cdot inc+j} \leftarrow \frac{Anwaste_i}{inc}$

Value of k is dependent upon capping from time of placement

$\text{for } i \in 0..(Incom \cdot inc - 1)$

$\quad ti \leftarrow Time - Day_i$

This assumes that 50% of the landfill gas is CH_4.

$\quad q \leftarrow q + 0 \cdot m^3 \cdot hr^{-1} \text{ if } ti \le 0 \cdot day$

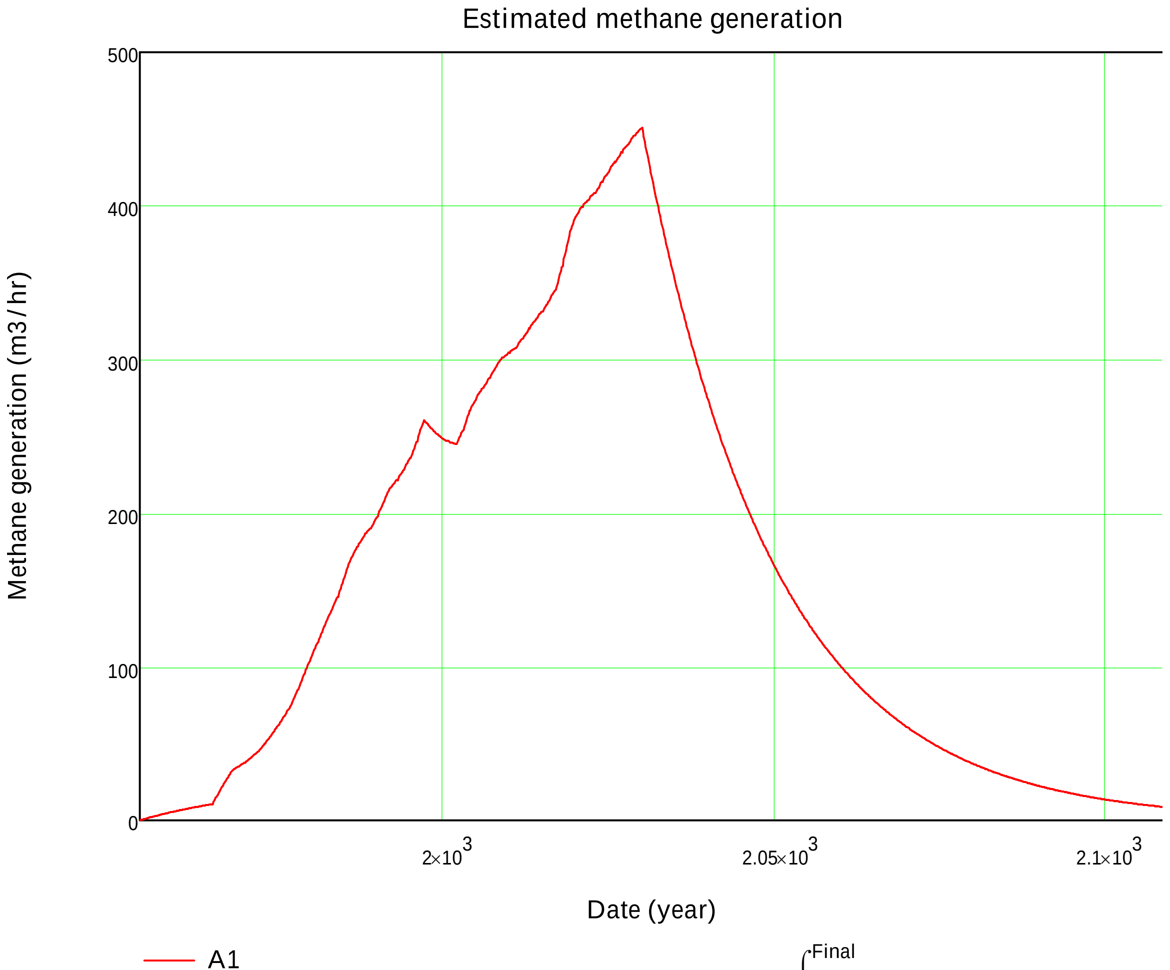
$\quad \text{otherwise}$

$\qquad \Delta q \leftarrow 2 \cdot k \cdot L_o \cdot waste_i \cdot e^{-k \cdot (ti - lag)}$

$\qquad q \leftarrow q + \Delta q$

q

Results



Volume of methane generated

$$TotalCH4(Anwaste, Incom) := \int_{Start}^{Final} Q(t, Anwaste, Incom)\, dt$$

$$TotalCH4(Anwaste_{A1}, Incom_A) = 4.199 \times 10^8\ m^3$$

Assessment of residual methane generation

Residual methane volume

$$ResidualCH4(t_1, Anwaste, Incom) := \int_{t_1}^{Final} Q(t, Anwaste, Incom)\, dt$$

Residual %age

$$Residual\%age(t_1, Anwaste, Incom) := \frac{ResidualCH4(t_1, Anwaste, Incom)}{TotalCH4(Anwaste, Incom)}$$

Assume 20 years post closure

$t_A := Close_A + 20yr$

$$ResidualCH4(t_A, Anwaste_{A1}, Incom_A) = 5.812 \times 10^7\ m^3$$

$$Residual\%age(t_A, Anwaste_{A1}, Incom_A) = 13.839 \cdot \%$$

Assume 60 years post closure

$t_A := Close_A + 50yr$

$ResidualCH4(t_A, Anwaste_{A1}, Incom_A) = 5.812 \times 10^7 m^3$

$Residual\%age(t_A, Anwaste_{A1}, Incom_A) = 2.525 \cdot \%$

Landfill gas generation- Scholl Canyon Model

Estimated LFG produced after landfill closure

$Q(2030yr, Anwaste_{.A1}, Incom_{.A}) = 7.907 \times 10^6 \cdot m^3 yr^{-1}$

Operational LFG generation model output: 1954 - 2026

Prepared 20/04/2021 ALDG
Updated 04/09/2023 ALDG
Reviewed 11/09/23 JMC

Notes:

1. Output from Mathcad LFG generation model.

2. The tonnage used is the inert adjusted waste tonnage. This has been estimated for the period 1954-1996 based on available information. This has not been averaged as with the UEF application model as it is not required by the Regulations.

3. All waste tonnages reported here represent the portion of waste that is gas producing, and has been reduced to account for leachate saturation as discussed in the waste tonnage projection spreadsheet.

4. Model inputs are the SWAP specific Lo (79.11 m³/tonne), and rainfall-related k (0.05 /year)

5. Collection efficiency 80% 50%

6. Methane composition in LFG 50%

Year	Projected tonnage	Modelled LFG generation		Modelled LFG colleciton 80%	Modelled LFG colleciton 50%
	tonnes	m³/year	m³/hr	m³/hr	m³/hr
1954	2698.44	0.00	0.00	0.00	0.00
1955	2698.44	21320.00	2.43	1.95	1.22
1956	2698.44	41610.00	4.75	3.80	2.38
1957	2698.44	60900.00	6.95	5.56	3.48
1958	2698.44	79250.00	9.05	7.24	4.52
1959	2698.44	96710.00	11.04	8.83	5.52
1960	2698.44	113300.00	12.93	10.35	6.47
1961	2698.44	129100.00	14.74	11.79	7.37
1962	2698.44	144100.00	16.45	13.16	8.22
1963	2698.44	158400.00	18.08	14.47	9.04
1964	2698.44	172000.00	19.63	15.71	9.82
1965	18152.20	185000.00	21.12	16.89	10.56
1966	18152.20	319400.00	36.46	29.17	18.23
1967	18152.20	447200.00	51.05	40.84	25.53
1968	9483.10	568900.00	64.94	51.95	32.47
1969	9483.10	616000.00	70.32	56.26	35.16
1970	12210.00	660900.00	75.45	60.36	37.72
1971	12210.00	725200.00	82.79	66.23	41.39
1972	16612.75	786300.00	89.76	71.81	44.88
1973	18036.70	879200.00	100.37	80.29	50.18
1974	19460.65	978900.00	111.75	89.40	55.87
1975	21359.25	1085000.00	123.86	99.09	61.93
1976	22783.20	1201000.00	137.10	109.68	68.55
1977	30605.43	1322000.00	150.91	120.73	75.46
1978	32371.13	1500000.00	171.23	136.99	85.62
1979	33548.26	1682000.00	192.01	153.61	96.00
1980	33548.26	1865000.00	212.90	170.32	106.45
1981	35313.96	2039000.00	232.76	186.21	116.38
1982	35313.96	2219000.00	253.31	202.65	126.66
1983	35313.96	2390000.00	272.83	218.26	136.42
1984	44142.45	2552000.00	291.32	233.06	145.66
1985	44142.45	2777000.00	317.01	253.61	158.50
1986	35313.96	2990000.00	341.32	273.06	170.66
1987	35313.96	3123000.00	356.51	285.21	178.25
1988	30690.00	3250000.00	371.00	296.80	185.50
1989	37400.88	3334000.00	380.59	304.47	190.30
1990	43634.36	3467000.00	395.78	316.62	197.89
1991	42387.66	3643000.00	415.87	332.69	207.93
1992	33791.21	3800000.00	433.79	347.03	216.89
1993	39182.64	3882000.00	443.15	354.52	221.58
1994	41703.72	4002000.00	456.85	365.48	228.42
1995	49372.92	4136000.00	472.15	377.72	236.07
1996	57137.40	4325000.00	493.72	394.98	246.86
1997	17192.56	4565000.00	521.12	416.89	260.56
1998	18084.08	4478000.00	511.19	408.95	255.59
1999	19614.56	4403000.00	502.63	402.10	251.31
2000	22402.24	4343000.00	495.78	396.62	247.89
2001	24509.52	4308000.00	491.78	393.42	245.89

Year	Projected tonnage	Modelled LFG generation		Modelled LFG colleciton 80%	Modelled LFG colleciton 50%
	tonnes	m³/year	m³/hr	m³/hr	m³/hr
2002	47553.00	4292000.00	489.95	391.96	244.98
2003	54805.00	4458000.00	508.90	407.12	254.45
2004	47156.00	4674000.00	533.56	426.85	266.78
2005	44727.00	4819000.00	550.11	440.09	275.06
2006	44424.00	4937000.00	563.58	450.87	281.79
2007	47976.03	5047000.00	576.14	460.91	288.07
2008	44580.00	5180000.00	591.32	473.06	295.66
2009	39662.30	5280000.00	602.74	482.19	301.37
2010	39962.24	5336000.00	609.13	487.31	304.57
2011	47154.67	5391000.00	615.41	492.33	307.71
2012	47538.42	5501000.00	627.97	502.37	313.98
2013	48449.06	5608000.00	640.18	512.15	320.09
2014	46333.36	5718000.00	652.74	522.19	326.37
2015	51856.12	5805000.00	662.67	530.14	331.34
2016	52130.48	5932000.00	677.17	541.74	338.58
2017	71393.74	6054000.00	691.10	552.88	345.55
2018	82600.01	6323000.00	721.80	577.44	360.90
2019	68692.74	6667000.00	761.07	608.86	380.54
2020	56972.27	6885000.00	785.96	628.77	392.98
2021	53811.66	6999000.00	798.97	639.18	399.49
2022	53207.63	7083000.00	808.56	646.85	404.28
2023	59833.00	7158000.00	817.12	653.70	408.56
2024	59833.00	7282000.00	831.28	665.02	415.64
2025	59833.00	7400000.00	844.75	675.80	422.37
2026	59833.00	7511000.00	857.42	685.94	428.71
2027	59833.00	7618000.00	869.63	695.71	434.82
2028	59833.00	7719000.00	881.16	704.93	440.58
2029	59833.00	7815000.00	892.12	713.70	446.06
2030		7907000.00	902.63	722.10	451.31
2031		7521000.00	858.56	686.85	429.28
2032		7155000.00	816.78	653.42	408.39
2033		6806000.00	776.94	621.55	388.47
2034		6474000.00	739.04	591.23	369.52
2035		6158000.00	702.97	562.37	351.48
2036		5858000.00	668.72	534.98	334.36
2037		5572000.00	636.07	508.86	318.04
2038		5300000.00	605.02	484.02	302.51
2039		5042000.00	575.57	460.46	287.79
2040		4796000.00	547.49	437.99	273.74
2041		4562000.00	520.78	416.62	260.39
2042		4340000.00	495.43	396.35	247.72
2043		4128000.00	471.23	376.99	235.62
2044		3927000.00	448.29	358.63	224.14
2045		3735000.00	426.37	341.10	213.18
2046		3553000.00	405.59	324.47	202.80
2047		3380000.00	385.84	308.68	192.92
2048		3215000.00	367.01	293.61	183.50
2049		3058000.00	349.09	279.27	174.54
2050		2909000.00	332.08	265.66	166.04
2051		2767000.00	315.87	252.69	157.93
2052		2632000.00	300.46	240.37	150.23
2053		2504000.00	285.84	228.68	142.92
2054		2382000.00	271.92	217.53	135.96
2055		2265000.00	258.56	206.85	129.28
2056		2155000.00	246.00	196.80	123.00
2057		2050000.00	234.02	187.21	117.01
2058		1950000.00	222.60	178.08	111.30
2059		1855000.00	211.76	169.41	105.88
2060		1764000.00	201.37	161.10	100.68
2061		1678000.00	191.55	153.24	95.78
2062		1596000.00	182.19	145.75	91.10
2063		1519000.00	173.40	138.72	86.70

Year	Projected tonnage	Modelled LFG generation		Modelled LFG colleciton 80%	Modelled LFG colleciton 50%
	tonnes	m³/year	m³/hr	m³/hr	m³/hr
2064		1445000.00	164.95	131.96	82.48
2065		1374000.00	156.85	125.48	78.42
2066		1307000.00	149.20	119.36	74.60
2067		1243000.00	141.89	113.52	70.95
2068		1183000.00	135.05	108.04	67.52
2069		1125000.00	128.42	102.74	64.21
2070		1070000.00	122.15	97.72	61.07
2071		1018000.00	116.21	92.97	58.11
2072		968300.00	110.54	88.43	55.27
2073		921100.00	105.15	84.12	52.57
2074		876100.00	100.01	80.01	50.01
2075		833400.00	95.14	76.11	47.57
2076		792800.00	90.50	72.40	45.25
2077		754100.00	86.08	68.87	43.04
2078		717300.00	81.88	65.51	40.94
2079		682300.00	77.89	62.31	38.94
2080		649100.00	74.10	59.28	37.05
2081		617400.00	70.48	56.38	35.24
2082		587300.00	67.04	53.63	33.52
2083		558600.00	63.77	51.01	31.88
2084		531400.00	60.66	48.53	30.33
2085		505500.00	57.71	46.16	28.85
2086		480800.00	54.89	43.91	27.44
2087		457400.00	52.21	41.77	26.11
2088		435100.00	49.67	39.74	24.83
2089		413900.00	47.25	37.80	23.62
2090		393700.00	44.94	35.95	22.47
2091		374500.00	42.75	34.20	21.38
2092		356200.00	40.66	32.53	20.33
2093		338800.00	38.68	30.94	19.34
2094		322300.00	36.79	29.43	18.40
2095		306600.00	35.00	28.00	17.50
2096		291600.00	33.29	26.63	16.64
2097		277400.00	31.67	25.33	15.83
2098		263900.00	30.13	24.10	15.06
2099		251000.00	28.65	22.92	14.33
2100		238800.00	27.26	21.81	13.63
2101		227100.00	25.92	20.74	12.96
2102		216100.00	24.67	19.74	12.33
2103		205500.00	23.46	18.77	11.73
2104		195500.00	22.32	17.85	11.16
2105		186000.00	21.23	16.99	10.62
2106		176900.00	20.19	16.16	10.10
2107		168300.00	19.21	15.37	9.61
2108		160100.00	18.28	14.62	9.14
2109		152200.00	17.37	13.90	8.69

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