CLIMATE & CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

PRE-FEASIBILITY STUDY TO ASSESS THE POTENTIAL LFG RECOVERY AT THE CHEESEMANBURG LANDFILL

City of Monrovia, Liberia

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Table of Contents

List of Figures:

List of Tables:

List of Appendices:

EXECUTIVE SUMMARY

The pre-feasibility study to assess the potential LFG recovery at the Cheesemanburg Landfill located in the vicinity of the City of Monrovia, Liberia was performed as part of direct technical assistance being provided by the Waste Initiative of the Climate and Clean Air Coalition (CCAC). The main objective of this study is to develop a study to assess the potential landfill gas recovery and utilization from the Cheesemanburg landfill. The study included the review of landfill design of the future Cheesemanburg landfill and expected waste quantities to estimate the potential landfill gas recovery over its lifetime. In addition, it includes the preparation of a landfill gas collection and recovery system conceptual design and a budgetary cost estimate.

Site Assessment

The site assessment presents an analysis of the documentation gathered through publicly available information and data provided by various project stakeholders and the review of the landfill design provided within the Cheesemanburg landfill environmental and social impact assessment (ESIA).

Cheesemanburg landfill will be located approximately 25 kilometers north of the Monrovia city center in the town of Cheesemanburg. Currently, the final design is being revised per indications by the Liberia EPA. The access road and some clearing of the site was observed during the site visit, but actual construction is not expected until the revised design is approved by Liberia EPA.

The landfill is expected to start operations in early 2026 with a life span of approximately 20 years. The site property is approximately 40 hectares from which 24.2 hectares have been assigned for waste placement.

Cheesemanburg Landfill will be classified as a managed landfill per IPCC criteria as it is expected that this landfill will be designed, constructed, managed and operated using the best international management practices for landfills. Leachate, groundwater, stormwater and landfill gas (LFG) will be managed and monitored as a modern engineered landfill throughout the active operations of the landfill and provided with post closure care.

Preparation of Landfill Gas Assessment Report

The LFG assessment presents LFG generation and recovery projections that can be collected for the implementation of an LFG utilization project. LFG generation projections were developed based on information gathered including waste types, waste quantities, dates of filling, projected filling plans, climate, waste filling practices and the future disposal plans. The following table presents the LFG model results from 2026-2045.

LFG Model Results

Year	LFG Generation (m^3/hr)	LFG Recovery (m^3/hr)	Maximum Power Plant Capacity (MW)	Methane Emissions Reduction Estimates (tonnes/CO_2eq/yr)
2026	0	0	0.0	0
2027	342	0	0.0	0
2028	601	0	0.0	0
2029	804	0	0.0	0
2030	971	0	0.0	0
2031	1,113	579	1.0	38,101
2032	1,238	644	1.1	42,401
2033	1,353	704	1.2	46,334
2034	1,461	760	1.3	50,035
2035	1,565	814	1.3	53,592
2036	1,666	867	1.4	57,067
2037	1,767	919	1.5	60,504
2038	1,867	971	1.6	63,934
2039	1,967	1,023	1.7	67,378
2040	2,069	1,076	1.8	70,854
2041	2,172	1,129	1.9	74,375
2042	2,276	1,184	2.0	77,951
2043	2,382	1,239	2.0	81,591
2044	2,491	1,295	2.1	85,302
2045	2,602	1,353	2.2	89,092

Note: Projected LFG recovery rates are in m^3/hr, adjusted to 50% methane.

Liberia's revised nationally determined contributions (NDCs) published in July 2021, have committed to reduce GHG emissions from waste sector by 7.6% below business-as-usual levels by 2030, and it is expected that this commitment will continue after 2030. If the flaring and/or a utilization project is implemented, it can potentially provide a reduction of approximately 1,000,000 tonnes CO_2eq/yr from 2031-2045.

GCCS Conceptual Plan

Since the Cheesemanburg landfill will be in operations for 20 years, it is expected that the GCCS is installed once there is enough LFG for a project utilization. These means that the GCCS will be installed while the landfill operates for waste disposal. Therefore, the development of the GCCS has been conceptualized in four phases. Each phase is expected to occurred approximately every 5 years starting in 2030. The following table presents the estimated budgetary cost for all four phases of the project.

Summary of GCCS Capital Cost

Area of Work	Total
Initial Phase I* - Installed in 2030	$990,000
Phase II – Installed in 2035	290,000
Phase III – Installed in 2040	250,000
Phase IV – Installed in 2045 upon closure of the landfill	460,000

Note: * Includes blower/flare station for the full project, miscellaneous cost and 10% contingency.

LFG Utilization Assessment

The Cheesemanburg landfill is located in an area with no industrial activity in the near vicinity. Therefore, the best available option for the use of the LFG will be electricity generation. In conversation held during the site visit in March 2024, the Liberia Electricity Corporation (LEC) express its interest on the potential energy generated by this project.

Based on the LFG recovery projections, with collection efficiency of 52%, by 2031, there will be enough gas to support a 1-MW landfill gas to energy project from 2031 through 2045, assuming that the gas collection and control system (GCCS) is expanded as the landfill continues growing through its life span. Further research will be needed for this option to determine the project interconnection point with the public power network.

Recommendations

Recommendations that will be key on the implementation of the project are presented below:

- Use this assessment as a tool to seek for potential financing and contract arrangements.
- Full project engineering design will be necessary prior to implementation.
- Operate the landfill using best management practices, maintain access roads, provide a designated disposal area at all times. Provide proper compaction of the waste, provide daily soil cover to prevent vectors and increase on leachate generation, provide leachate, stormwater and LFG management, provide intermediate cover in areas where waste will not be places in several months.
- Provide technical training to landfill managers and operators landfill manager and operations practices.
- Incentivize industry to developed closer to the landfill so they can be potential end-users of the LFG.
- Evaluate if existing power lines are able to take the potential energy generated by a utilization project.

PRE-FEASIBILITY STUDY TO ASSESS THE POTENTIAL LFG RECOVERY AT THE CHEESEMANBURG LANDFILL

INTRODUCTION

The pre-feasibility study to assess the potential LFG recovery and utilization at the existing Cheesemanburg Landfill located in the vicinity of the City of Monrovia is being performed as part of direct technical assistance provided by the Waste Initiative of the Climate and Clean Air Coalition (CCAC).

The main objective of this study is to develop a study to assess the potential landfill gas recovery and utilization from the Cheesemanburg landfill. The study included the review of the landfill design of the future Cheesemanburg landfill and expected waste quantities to estimate the potential landfill gas recovery over its lifetime. In addition, it includes the preparation of a landfill gas collection and recovery system conceptual design and a budgetary cost estimate.

SITE ASSESSMENT

The site assessment included the review of documentation provided by Monrovia City Corporation (MCC) and other project stakeholders, information publicly available and technical aspects related to current site conditions, landfill operations, stormwater, leachate and landfill gas management reviewed during the site visit performed the week of March 25, 2024. The information listed below was reviewed as part of the site assessment:

1. Waste Disposal History from 2011 thru 2023, MCC
2. Waste Characterization Study, page 57, from Greater Monrovia Solid Waste Management Baseline, Cities Alliance 2022.
3. Two versions of the Environmental Impact Assessment Cheesemanburg Landfill, May 2017 and December 2022 by Earthtime, provided by EPA.
4. Cheesemanburg Landfill Urban Sanitation (CLUS) Project Appraisal Document, World Bank, June 28, 2017.
5. Cheesemanburg Landfill Urban Sanitation (CLUS) Project Procurement Plan, February 15, 2024.
6. Project Design Document Form for the Landfill Gas Project (CDM PDD) - Version 03 2006.
7. Greater Monrovia Solid Waste Management Baseline, Cities Alliance Study 2021.
8. Liberia’s Revised Nationally Determined Contribution (NDC), July 2021.

The site visit performed on the week of March 25th, 2024, included interviews with city officials from the Environmental Protection Agency (EPA), Monrovia City Corporation (MCC), Paynesville City Corporation (PCC), and stakeholders such as Evergreen, Cities Alliance, Greenlight, and Liberia Electricity Corporation (LEC), and a visit to Cheesemanburg landfill site to observe current conditions and operations. Lenn Gomah from Liberia EPA was present during all the interviews and the site visit.

Background Information

The City of Monrovia (Monrovia) is the capital of Liberia located on Cape Mesurado on the Atlantic coast. Figure 1 presents the location of the city and the future site for the landfill.

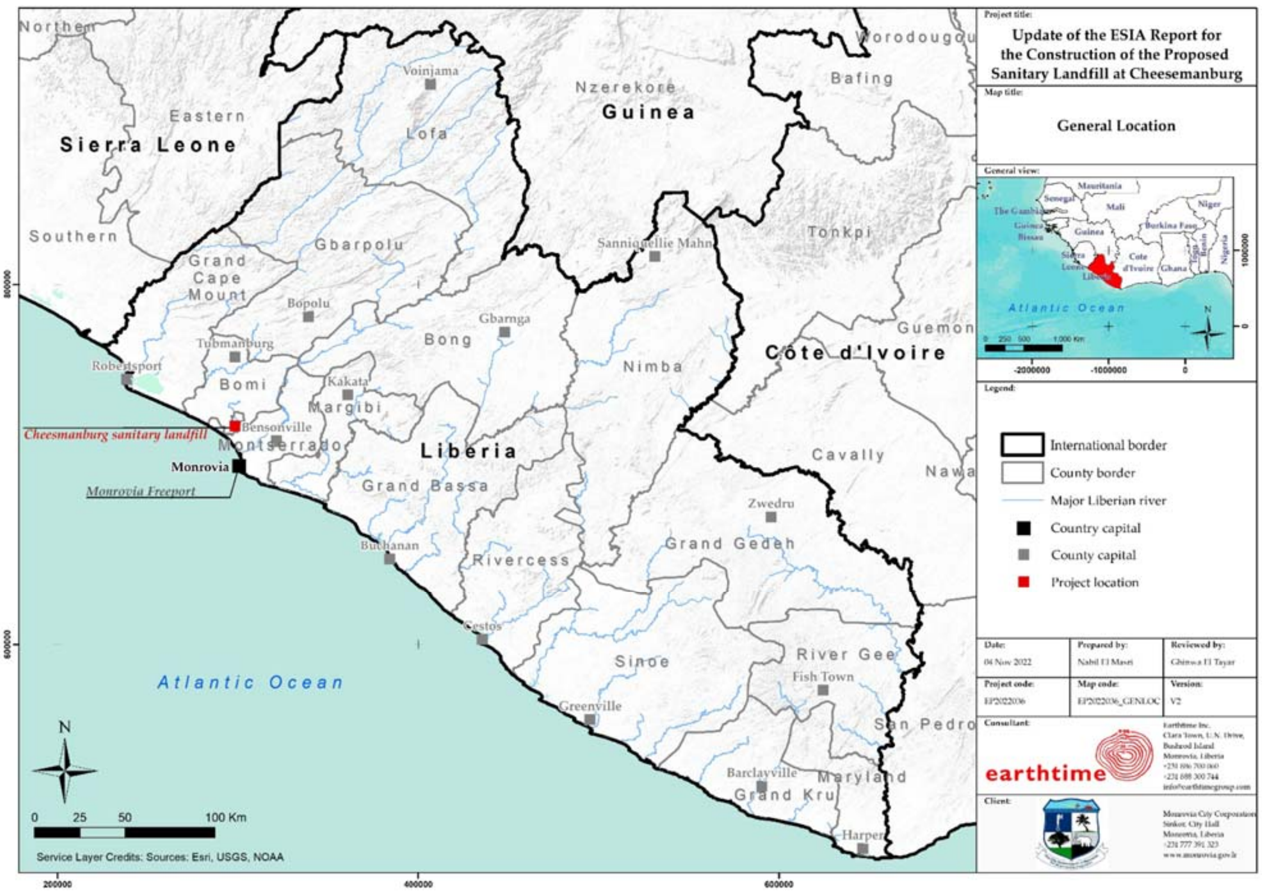


Figure 1. City of Monrovia Location

Its metro area includes Montserrado and Margibi counties and was home to 2,225,911 inhabitants as of the 2022 census. As the nation's primate city, Monrovia is the country's economic, financial and cultural center; its economy is primarily centered on its harbor and its role as the seat of Liberian government.

Municipal solid waste management in Monrovia is the responsibility of Monrovia City Corporation (MCC). MCC has one active municipal solid waste disposal sites Whein Town Landfill and two transfer stations: Fiamah and Stockton Creek. Whein Town Landfill is expected to closed late 2025.

The new Cheesemanburg landfill is in the design stage. Liberia EPA has provided some comments on the design and these comments are being incorporated. At the time of the site visit, the access road and some clearing of vegetation to prepare for construction has been completed.

Figure 2 presents the location of the future Cheesemanburg landfill and Whein Town landfill and the two transfer stations.

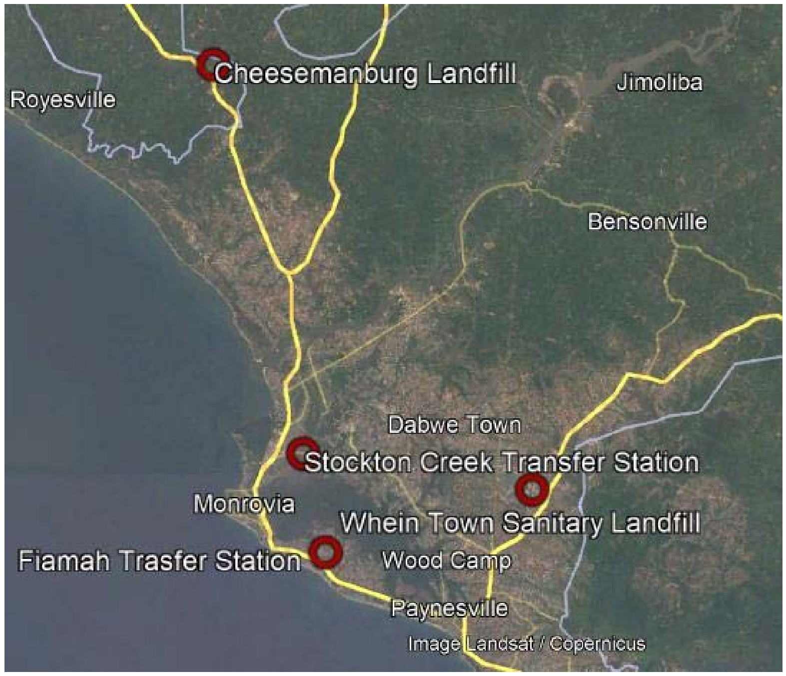


Figure 2. Waste Disposal Sites and Transfer Station Locations

Site Description

Figure 3 presents the location of the Cheesemanburg landfill site located approximately 0.5 km west of the Monrovia-Kakata Highway. The Project site is located at elevation ranging between at elevation between 40 and 62 meters (m) mean sea level (msl).

Figure 3. Proposed Landfill Site Location

The following ancillary facilities will be constructed at the site:

- A perimeter fence
- Two entrance gates
- Guard rooms
- A control office
- A weighbridge
- Administrative buildings
- Workers' facility, which will include lockers, showers and toilets for workers
- Parking area
- Vehicle washing station
- Workshop, which will be used for truck and machinery repair, and will include an equipment storage room for tools and spare parts
- Generators
- Fuel tanks
- Fire protection room

Geology and Hydrology

Geologically, the site is located the Melanocratic Gneiss Formation (gnm) which includes varying proportions of dark-colored hypersthene-diopside-hornblende-plagioclase-biotite gneiss with varying amounts of pyroxenes, hornblende amphibolites (with and without pyroxenes), granitic gneiss (with and without pyroxenes), and sillimanite-hypersthene-garnet-two mica gneiss; only very acid rocks, which are subordinate, are light colored. The site is located close to a major fault zone.

In 2019, a hydrogeological assessment consisting of four boreholes was performed at the project site (See Figure 4). Four boreholes were drilled on site to a maximum total depth of 30 m below ground level (mBG) and penetrating the metamorphic rock at a maximum depth of 12 m. The bed rock is mainly covered with a layer of soil that can reach up to 20 m in depth and is divided into three main layers:

- A topsoil – Laterite layer consisting of reddish-brown clayey sand with a thickness between 0.5 and 2 m.
- A reddish brown clayey and silty fine sand layer ranging in thickness between 10 and 20 m.
- A grayish brown coarse sand layer ranging in thickness between 0 and 10 m. This layer not continuous all over the site and acts as an intermediate between the metamorphic rock and the topsoil.

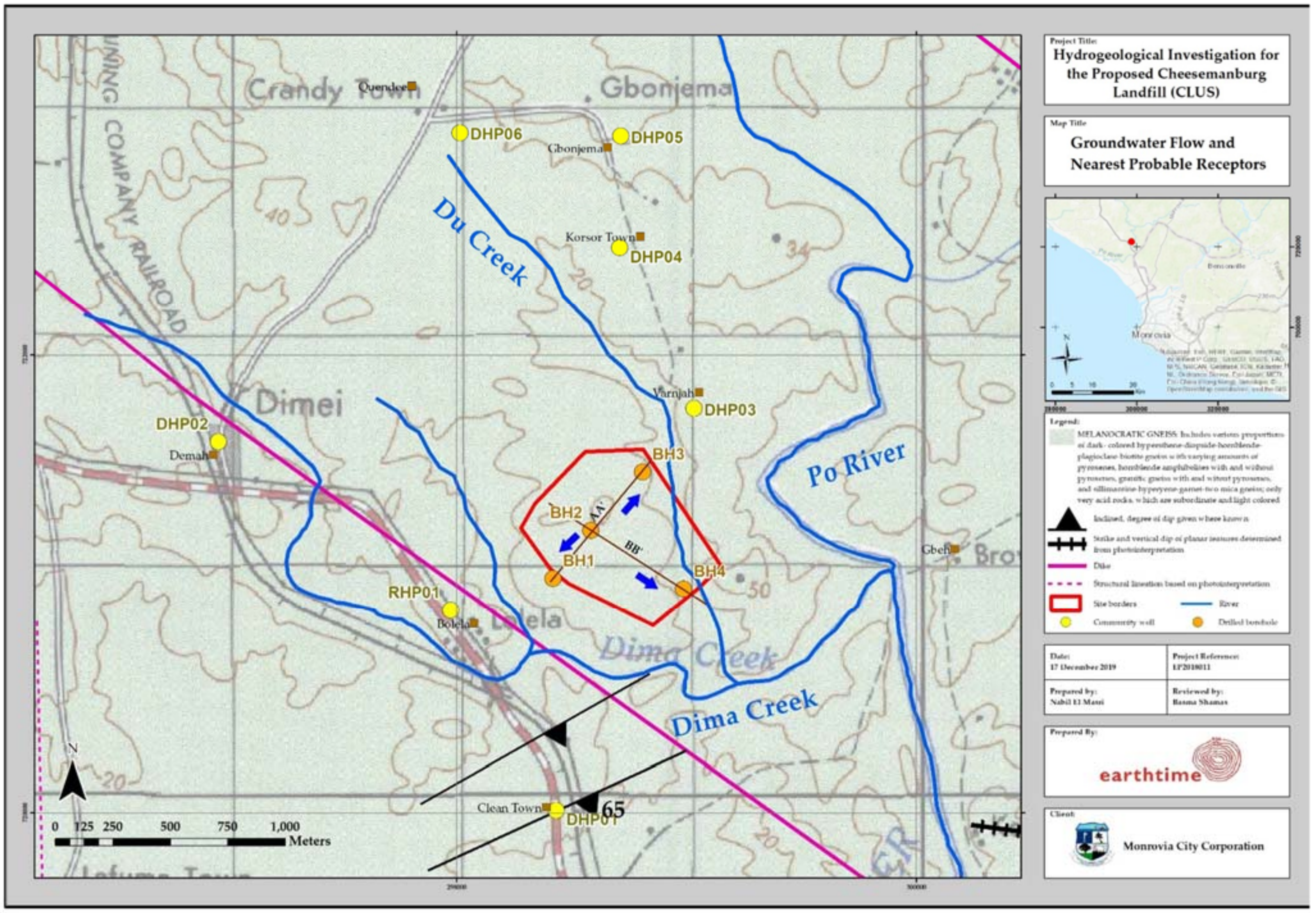


Figure 4. Site Hydrogeological Assessment

Surface water bodies in the vicinity of the proposed site include the Du Creek in the eastern perimeter, the Dima Creek in the western perimeter, and a third unnamed creek on the western perimeter which are all tributaries of the Po River. The Du Creek crosses the eastern boundary of the site from north to south. Three wetland areas were identified around the site on its north-western (the largest), north-eastern, and south-eastern sides (See Figure 5 and Figure 6).

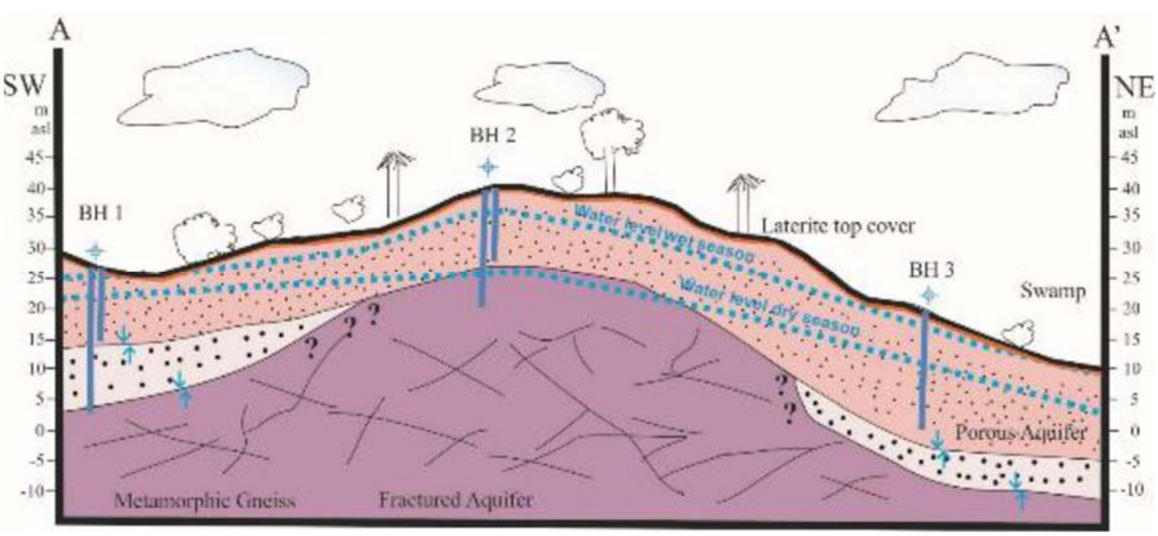


Figure 5. Site Geological Profile South-North

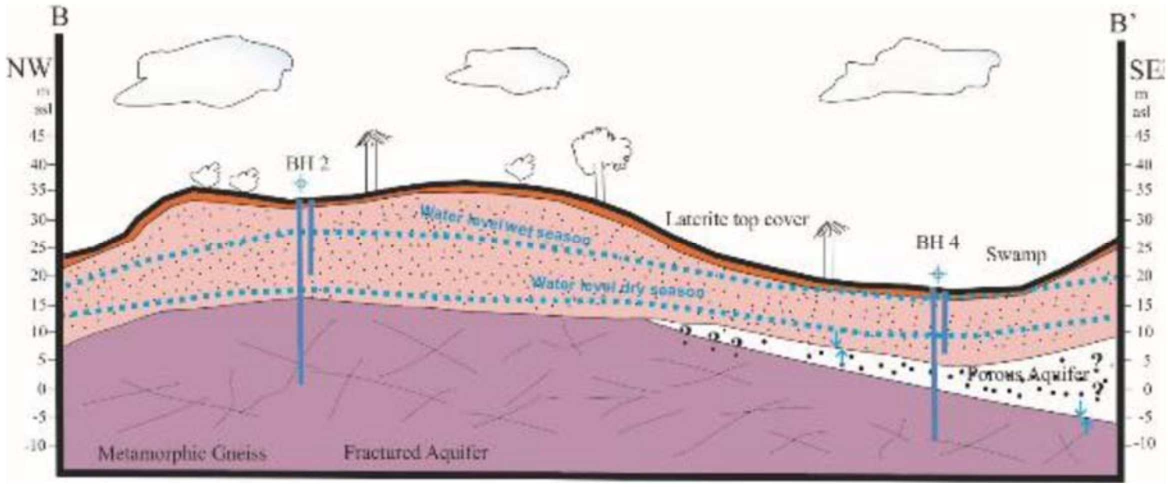


Figure 6. Site Geological Profile West-East

Groundwater

The general groundwater level varies from dry season (5 to 15 m) to rainy season (0 - 5 m). Its flow direction on site was found to be mainly away from the central high areas in the center of the proposed landfill site towards the lowlands on either side. During the hydrogeological assessment the following two aquifers were identified:

- A shallow aquifer consisting of the upper soil layer of clayey and silty sand.
- An intermediate aquifer consisting of the coarse sand layer and the upper part of the metamorphic rock.

Landfill Design Information

The document provided with the most relevant data regarding the design and operation of the future Cheesemanburg landfill is the Environmental and Social Impact Assessment (ESIA) prepared by Earthtime in May 2022. This ESIA covers the construction, operation, and decommissioning phases of the Cheesemanburg Sanitary Landfill (CSL) and its ancillary facilities.

The landfill site has a total area of approximately 400,000 m^2 (100 acres). The landfill will be developed in four phases. The waste limits for the four phases will cover a total area of approximately 242,400 m^2 (see Figure 7). The site will include a leachate treatment system, a landfill gas collection and flaring system, a stockpiling area, an area for future sorting and compositing, and ancillary facilities. Sideslopes have been proposed to be set at 1V:3.5H with a maximum waste height of 35 m. A drawing with the proposed landfill design is provided in Appendix I.

The site expected capacity is approximately 20 years with a disposal rate of 150,000 tons/year and an expected annual disposal increase of 2.5% serving the cities of Monrovia and Paynesville, and their surrounding towns and boroughs. It is expected that each phase will provide approximately landfill airspace for 5 years.

Figure 7. Landfill Development Plan

Table 1 presents the proposed landfill development plant assuming different daily disposal waste rates. Based on the disposal rates reported at the Whein Town landfill, the most realistic scenario for Cheesemanburg will be the one using 150,000 ton/year disposal rate.

Table 1. Proposed Landfill Development Plan

Cell	Design capacity		Number of years of service* for an average MSW disposal rate of:			
	Area (m2)	Volume of waste and intermediate soil cover (m3)	275 tonnes/day (≈100,000 tonnes/year 1)	340 tonnes/day (≈125,000 tonnes/year 1)	410 tonnes/day (≈ 150,000 tonnes/year 1)	550 tonnes/day (≈200,000 tonnes/year 1)
Cell 1-a	27,400	240,000	2.0	1.6	1.3	1.0
Cell 1-b	23,500	400,000	5.0	4.0	3.5	2.6
Cell 2	50,500	1,060,000	12.0	10.0	8.5	6.5
Cell 3	64,000	1,500,000	20.0	17.0	15.0	11.0
Cell 4	77,000	1,500,000	27.0	23.0	20.0	16.0
Total	242,400	4,700,000				

Assuming a 2.5% yearly growth rate

Bottom Liner System

The proposed bottom liner system for the landfill is composed of the following elements and is shown in Figure 8 (from bottom to top):

- A 0.10 m sand layer.
- A geosynthetic clay liner (GCL).
- A 2.0 mm high-density polyethylene resin (HDPE) geomembrane, textured on both sides.
- An 800 g/m^2 protection geotextile, which is non-woven polypropylene UV-stabilized.
- A 0.30 m drainage and protection layer with low calcium carbonate content, made up of gravel.

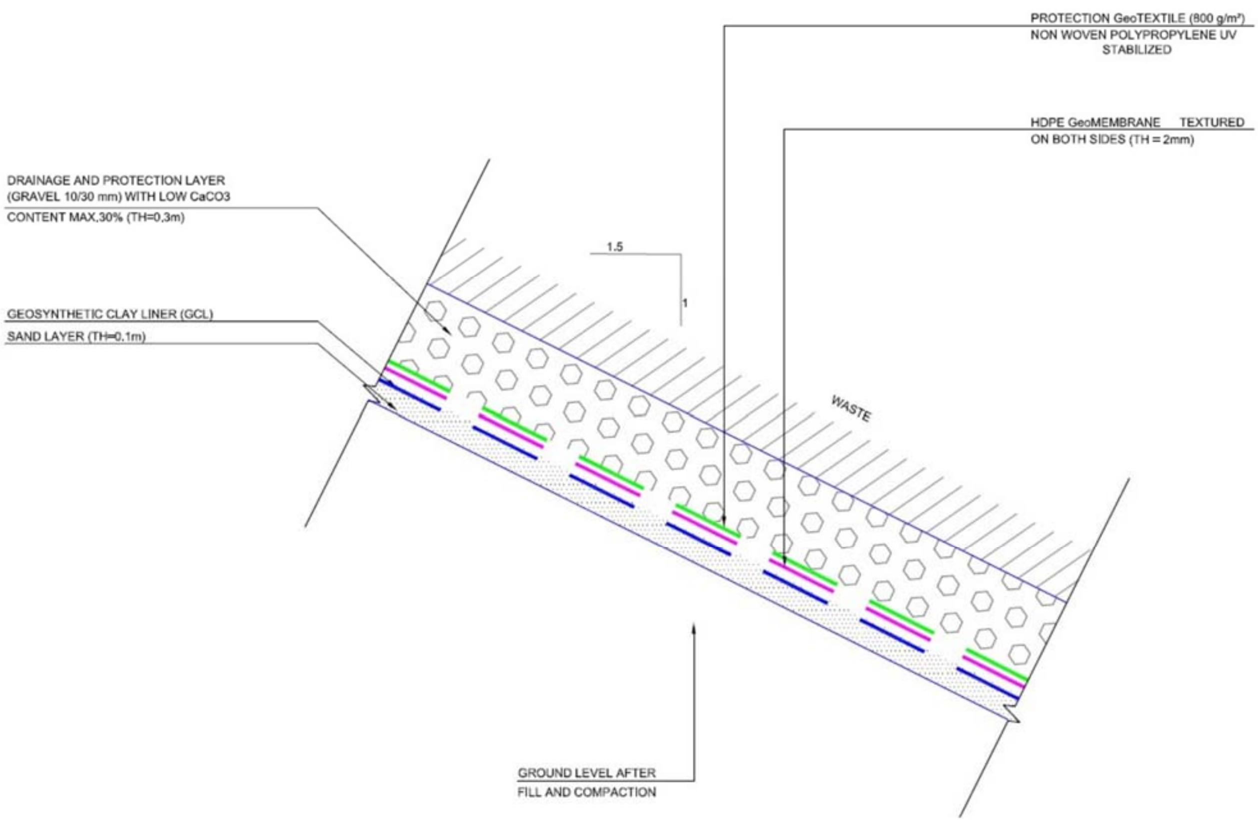


Figure 8. Proposed Liner System

Leachate Collection System

The leachate collection system will consist of perforated HDPE pipes installed in trenches and surrounded by geotextile and basalt aggregate, (See Figure 9). Leachate from each cell will flow (west to east) by gravity. Then leachate will flow by gravity to a 1,000 mm collection pipe along the eastern side of the landfill. The 1,000 mm collection pipe will transport the leachate by gravity to the leachate ponds. Leachate will pumped form the leachate ponds to the leachate treatment system.

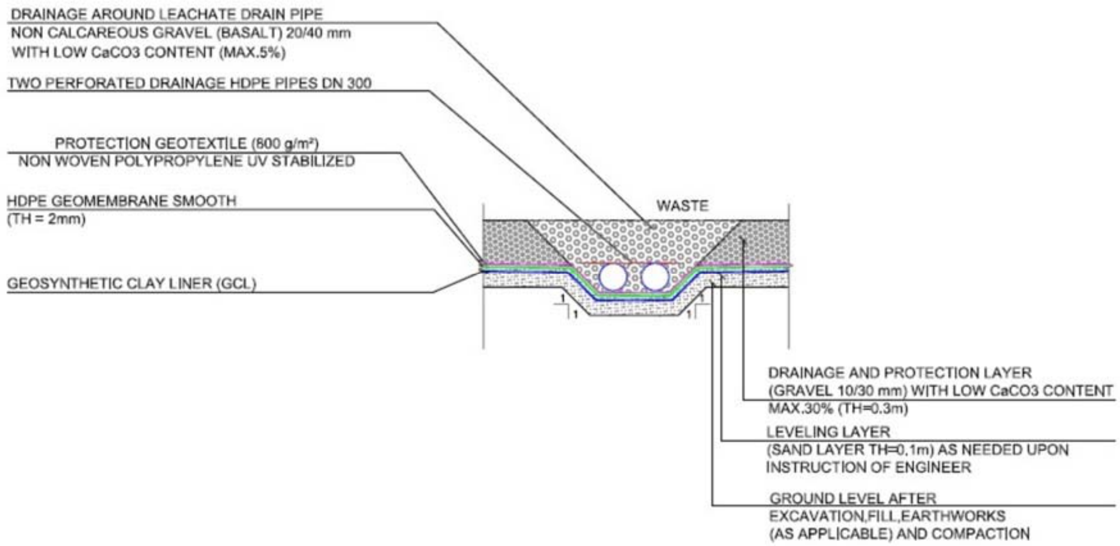


Figure 9. Proposed Leachate Collection System

Leachate Treatment

The leachate treatment process will consist of biological treatment by aeration, with possible physico-chemical treatment if needed to achieve acceptable effluent quality. The leachate treatment process aims at removing organics and ammonia, and is summarized below:

- Leachate will flow by gravity to two settling and balancing ponds of 4,500 m^3 capacity each, where solids will be allowed to settle and be filtered.
- Leachate will be pumped into a tank where sodium hydroxide will be added, and nitrification and denitrification will take place.
- Leachate will be aerated in two concrete aeration tanks of 1,000 m^3 capacity each, where aerobic conditions will be provided for oxidation.
- Leachate will then go through two clarification tanks of 500 m^3 capacity each.
- Finally, leachate will be chlorinated.
- Sludge will be removed from the settling and balancing ponds, the aeration tanks and the clarification tanks, and be recirculated into the landfill.

Leachate will be treated to meet environmental discharge guidelines set by the EPA. The treated effluent will be discharged into the Du Creek on a daily basis.

Stormwater Management

Stormwater falling on the roads will be connected to a reinforced concrete side channel, which will directly discharge in the nearest water body. Stormwater falling on the waste disposal areas will be collected in a reinforced concrete channel on the periphery of the site and will flow by gravity to the southeastern corner of the site, where it will go through a sedimentation pond before it is discharged in the Du Creek.

Landfill Gas Management

A series of wells will be installed across the site. The wells will be used as passive vents to release pressure from landfill gas initially, and later as active vents. The vents will be connected to a network system which will lead to a flare, located in the southeastern corner of the site, near the leachate ponds, as shown in Figure 7.

Final Cover System

Final cover will be installed on areas of the landfill that have reached their final, preplanned elevation. The final cover will consist of the following layers, from bottom to top (see Figure 10):

- A 0.30 m grading layer
- A 250 g/m^2 protection geotextile, which is non-woven polypropylene UV-stabilized
- A 2.0 mm high-density HDPE geomembrane, textured on both sides
- A HDPE geonet
- An 800 g/m^2 protection geotextile, which is non-woven polypropylene UV-stabilized
- A 0.50 m layer of agricultural soil

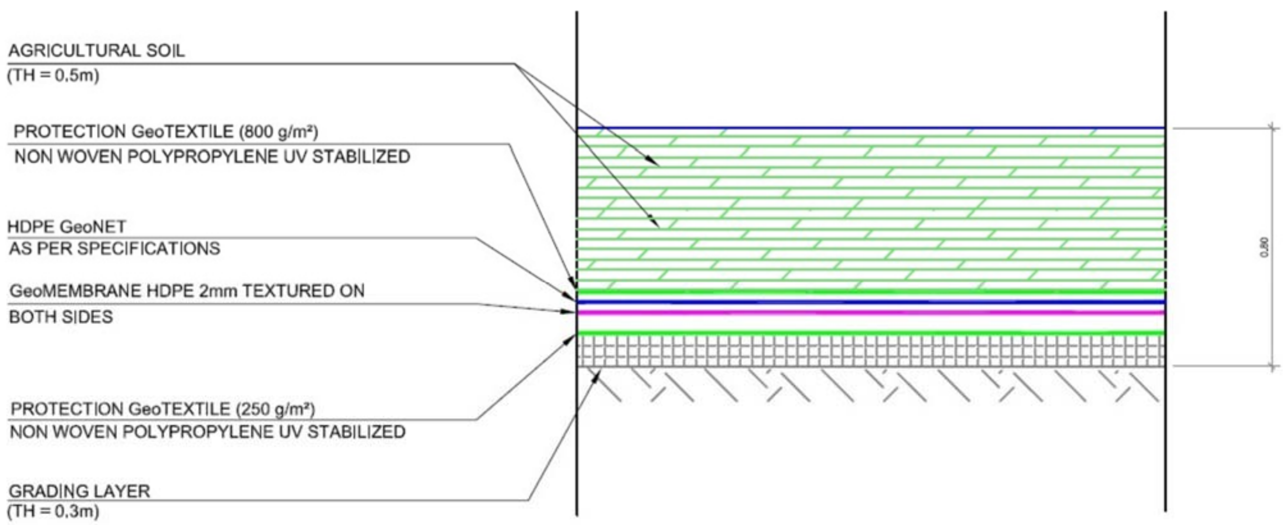


Figure 10. Proposed Final Cover System

Appendix I presents the design drawings and details included in the ESIA.

Relevant Data

Waste Data

Table 2 presents the waste disposal data from three sources found during our online record research and data provided by MCC:

- Environmental and Social Impact Assessment (ESIA),

- Project Design Document for the clean development mechanism landfill gas project (PDD), and
- MCC provided waste disposal data recorded on the weighbridge from 2011 through 2023.

Based on waste disposal records from 2011 through 2023 provided by MCC, the average daily waste disposal rate was calculated to be approximate 340 metric tons per day (tonnes/day). It is important to note that in the average waste disposal rate has been changing between 240 to 460 tonnes/day. These annual average changes could be cause by waste collection coverage changes around the metropolitan area as waste collection is the responsibility of each town within the metropolitan area.

During transport from the hotel to Whein Town landfill and from Whein Town to Cheesemanburg landfill it was observed that multiple illegal dumping areas were present along the main roads. This is an indication of waste collection coverage not being 100%. Therefore, the waste that can be disposed at the landfill could be potentially greater.

Table 2. Waste Disposal History

Years	EIA	PDD	MCC
	Annual Quantity of waste Generated. (tonnes/year)		
Jun-Dec 2008	36,500	36,500	
2009	109,500	109,500	
2010	124,100	124,100	
2011	138,700	138,700	26,930
2012	152,935	152,935	83,796
2013	156,950	156,950	94,868
2014	167,900	167,900	86,921
2015	175,200	175,200	167,365
2016	186,150	186,150	127,042
2017			85,494
2018			126,730
2019			122,358
2020			128,644
2021			123,123
2022			122,824
2023			97,469

Data from MCC can be considered more reliable since this data is based on data recorded at the weighbridge. Therefore, this data set will be used to estimate potential disposal waste projections at the Cheesemanburg landfill.

Waste Characterization Data

Four municipal solid waste characterization data sets were found in different documents as follows:

- The World Bank Technical Paper No 426, Solid Waste Landfalls in Middle and Low Income Countries in 2004,
- Project Design Document Form for the Landfill Gas Project (CDM PDD) - Version 03 2006
- Environmental Impact Assessment, Table 4-2: Waste Composition in Monrovia. Source: Solid Waste Management Plan. In 2008,
- Greater Monrovia Solid Waste Management Baseline, Cities Alliance Study 2021, and Waste composition in greater Monrovia as derived from Pasco in 2012.

Table 3 below provides the data from the different sources. The documents from 2004, 2006 and 2008 have identical data and the 2012 document data is very similar with a few differences. In addition, as a reference, West Africa data from the IPCC Guidelines for National Greenhouse Gas Inventories is included on this table. This data with some adjustments will be used on the modeling of landfill gas generation and recovery projections.

Table 3. Waste Characterization Data

Waste Fraction	2004	2006	2008	2012	West Africa*
Paper & Cardboard	10.0	10.0	10.0	7.00	7.5
Glass, Ceramics	1.2	1.0	1.0	1.00	1.3
Metals	2.0	2.0	2.0	1.00	2.7
Plastics	13.0	13.0	13.0	11.00	6.4
Leather, Rubber	0.2				
Wood, Bones, Straw	4.6	5.0	5.0	12.0	0.0
Textiles	6.0	6.0	6.0	5.00	1.9
Vegetable/Putrescible	43.0	43.0	43.0	43.00	53.7
Other Combustible Waste				2.00	
Miscellaneous Items	20.0	20.0	20.0	18.00	26.5
Total	100.0	100.0	100.0	100.0	100.0
* Data from 2019 IPCC Guidelines for National Greenhouse Gas Inventories.					

Climate

Monrovia has a tropical monsoon climate. It is the wettest capital city in the world, with annual rainfall averaging 3,582 mm (141 in). It has a wet (May-October) and a dry season (November – April), but even the dry season precipitation is present. Temperatures are fairly constant throughout the year, averaging around 25.7 °C. The only slight difference are the high temperatures as they are around 28.1 °C in the winter and near 24.7 °C. Table Table 4 below presents the climate data from the Roberts International Airport Station located about 50 km east of the Monrovia city center.

Table 4. Climate Data for City of Monrovia

Month	Mean Daily Minimum Temperature (°C)	Mean Daily Maximum Temperature (°C)	Mean Total Rainfall (mm)	Mean Number of Rain Days
Jan	24.1	29.3	92	14
Feb	24.6	29.3	113	16
Mar	24.9	29.4	167	19
Apr	24.9	29.4	219	19
May	24.4	28.9	329	21
Jun	23.7	27.6	497	21
Jul	23.4	26.6	428	20
Aug	23.3	26.3	504	20
Sep	23.3	27	539	21
Oct	23.5	28.1	368	22
Nov	23.7	28.8	207	21
Dec	24.0	29.0	119	18
Avg/Total	24.0	28.3	3,582	232

Note: Climate data for Roberts International Airport, more than 50 km east of Monrovia, Liberia

Solid Waste Regulations

A review of environmental regulations and policies potentially applicable to te project was performed to determine any potential requirements regarding the closure of the final waste disposal site and development of te landfill gas project. The following Table 5. Relevant Environmental RegulationsTable 5 presents federal and local regulations and policies found during our research:

Table 5. Relevant Environmental Regulations

ID	Regulation
Law 26/11/2002	The Environment Protection Agency (EPA) Act. The Act provides the Agency with the authority of government for the protection and management of the environment in Liberia. It requires that an Environmental Impact Assessment (EIA) be carried out for all activities and projects likely to have an adverse impact on the environment.
Law 26/11/2002	The National Environmental Policy Act. It defines policies, goals, objectives, and principles of sustainable development and improvement of the physical environment, quality of life of the people and ensures coordination between economic development and growth with sustainable management of natural resources.
Law 04/29/2004	Environmental Protection and Management Law establishes a legal framework for the sustainable development, management and protection of the environment by the Environment Protection Agency in partnership with regulatory Ministries and organizations
Law 2009	Liberia Waste Management & Standards Regulations provides standards for general waste management activities including licensing of solid waste disposal facilities

Table 5. Relevant Environmental Regulations

ID	Regulation
Law 2019	Public Health Law of Liberia as Revised provides with respect to a wide array of matters concerning public health, including, among other things, animal diseases, communicable diseases, (veterinary) drugs, environmental sanitation, hygiene in food establishments, control of parasites and mosquitoes, placing on the market of food, freshwater pollution and drinking water.
City Ordinance No. 1; and 7	Enhancement of Cleanliness of The City, Ordinance Requiring Residents/Businesses Within the Limits of The Monrovia City Corporation to Pay a Monthly Garbage Collection and Disposal Fees to The Corporation.

Regulations regarding solid waste disposal facilities was not found, nor the interviewed officers from EPA, MCC or PCC were aware of any federal or local regulations. From the relevant regulations found, the following could impact the landfill:

1. Law 2009, Liberia Waste Management and Standard Regulations which provides standards to license solid waste disposal facilities.

2. The City ordinances 1 establishes the following relevant requirements and fees:

   - Solid waste can only be disposed at sites designated by MCC, between 5 pm and 6 am, with fines of $100 dollars for each offence.
   - Littering is prohibited within the city limits with fines from $10 to $25 dollars.
   - The use of dump sites and undeveloped property is strictly prohibited with fines from $5 to $10 dollars.

3. The City ordinance 7 established the monthly fee for waste collection and disposal for residents, commercial establishments, government offices and healthcare institutions from $5 up to $150 dollars.

Additionally, Liberia's revised nationally determined contributions (NDCs) published in July 2021, have committed to reduce GHG emissions from waste sector by 7.6% below business-as-usual levels by 2030. Among the activities proposed to meet this goal are:

- Reduce emissions by 25.63 Gg CO_2e per year by supporting the implementation of a landfill gas recovery system on When Town Landfill by 2022.
- Reduce emissions by 25.63 Gg CO_2e per year by supporting the implementation of a landfill gas recovery system on Cheeseman burg Landfill by 2025.
- Reduce emissions by 0.84 Gg CO_2e per year by supporting the development of small-scale composting of market waste with a production of 500 t/year each; by 2025.

LFG RECOVERY POTENTIAL

The LFG recovery assessment contains a forecast of LFG generation and recovery projections for Cheesemanburg landfill. LFG generation projections were developed based on information gathered during the site assessment activities including waste types, waste quantities, dates of filling, projected filling plans, climate, waste filling practices and the future disposal plans. In addition, observations made during the site visit the week of March 25, 2024 regarding current site conditions, waste disposal practices, and site operations and the Whein Town landfill were also considered.

As proposed in the implementation plan, the LFG generation and recovery projections were prepared using the Colombia LFG Model developed by The United States Environmental Protection Agency (USEPA) under the Global Methane Initiative (GMI). The Colombia LFG Model is a simplified model developed based on the first order decay model from USEPA's LandGEM and the Intergovernmental Panel on Climate Change (IPCC) model to evaluate landfills in Colombia. This model will provide adequate results for Liberia by using a climate region in Colombia similar to Monrovia and inputting Monrovia waste characterization and site-specific waste disposal data.

LFG Model

The model estimates the LFG generation rate in a given year using the following first-order exponential equation which was modified from the U.S. EPA's Landfill Gas Emissions Model (LandGEM) version 3.02 (EPA, 2005). The model also, incorporates the methane correction factor (MCF)and fire correction factor used on the IPCC Model and a fire adjustment factor (F), with revised input assumptions to reflect local climate and conditions at disposal sites.

$$Q_{LFG} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} 2kL_0 \left[\frac{M_i}{10}\right] (e^{-kt_{ij}}) (MCF) (F)$$

Where: Q_{LFG} = maximum expected LFG generation flow rate (m^3/yr)
i = 1 year time increment
n = (year of the calculation) – (initial year of waste acceptance)
j = 0.1year time increment
k = methane generation rate (1/yr)
L_O = potential methane generation capacity (m^3/Mg)
M_i = mass of solid waste disposed in the i^{th} year (Mg)
t_{ij} = age of the j^{th} section of waste mass Mi disposed in the i^{th} year (decimal years)
MCF = methane correction factor
F = fire adjustment factor.

The above equation is used to estimate LFG generation for a given year from cumulative waste disposed up through that year. Total LFG generation is equal to two times the calculated methane generation (the model assumes methane content on the biogas is 50%). The exponential decay function assumes that LFG generation is at its peak following a time lag representing the period prior to methane generation. The model assumes a six-month time lag between placement of waste and LFG generation. For each unit of waste, after six months the model assumes that LFG generation decreases exponentially as the organic fraction of waste is consumed. The year of maximum LFG generation normally occurs in the closure year or the year following closure (depending on the disposal rate in the final years).

The model estimates LFG generation and recovery in cubic meters per hour (m^3/hr) and cubic feet per minute (cfm). It also estimates the energy content of generated and recovered LFG in million British thermal units per hour (mmBtu/hr), the system collection efficiency, the maximum power plant capacity that could be fueled by the recovered LFG (MW), and the emission reductions in tonnes of CO_2 equivalent (CERs) achieved by the collection and combustion of the LFG.

Model Limitations and Disclaimer

This report was prepared in accordance with the care and skill generally exercised by LFG professionals, under similar circumstances, in this or similar sites around the world. No warranty, expressed or implied, is made as to the professional opinions presented herein, nor in the accuracy of the data provided for this analysis. Changes in the landfill property use and conditions such as variations in rainfall, water levels, waste disposal rates, landfill operations, final cover systems, or other factors may affect future gas recovery at the proposed Site. The quantity or quality of available LFG is not guaranteed.

LFG Model Assumptions

Climate

Since Colombia has locations with a similar tropical climate, the model can be used for the evaluation of LFG generation and recovery projections by using a region in Colombia with similar annual rainfall as Monrovia. The Colombia model has five climate categories based on the average annual precipitation for the different regions in Colombia:

- Dry (<500 mm/yr annual rainfall).
- Moderately dry (500-999 mm/yr annual rainfall).
- Moderately wet (1,000-1,499 mm/yr annual rainfall).
- Wet (1,500-1,999 mm/yr annual rainfall).
- Very wet (>2,000 mm/yr annual rainfall).

Monrovia has an annual rainfall of 3,582 mm (141 in) which falls in the very wet category (>2,000 mm/yr) of the Colombia Model and is similar to the Colombia amazon region. Therefore, the Amazonia Region will be used.

Waste Characterization Data

The rate and volume of LFG produced in a solid waste disposal site depends on the characteristics of the waste (moisture content, composition, and age) and a number of environmental factors, including the presence of oxygen in the waste mass, waste moisture, pH and temperature. The more organic waste present in a landfill, the more LFG is produced by methane-generating bacteria during decomposition. Rates of waste decay and LFG generation vary significantly with waste age and organic waste types, so that recently buried waste containing a high percentage of food waste would be much more productive than older waste with only slowly decaying materials remaining after the food waste has been consumed.

During the site assessment four municipal solid waste characterization studies were found in different documents available online. All waste characterization sources provided very similar results with minimal variations. Since the waste characterization for Pasco study of 2012 is the most recent one, it was used for this assessment. This waste characterization was modified to fit the model waste characterization inputs as shown in Table 6:

Table 6. Modified Waste Characterization Data

Waste Category	Monrovia
Food Waste	43.0%
Paper and Cardboard	7.0%
Garden Waste (Green Waste)	0.0%
Wood Waste	6.0%
Rubber, Leather, Bones, Straw	6.0%
Textiles	5.0%
Toilet Paper	0.0%
Other Organics	2.0%
Diapers (assume 20% organics / 80% inorganics)	0.0%
Metals	1.0%
Construction and Demolition Waste	0.0%
Glass and Ceramics	1.0%
Plastics	11.0%
Other Inorganic Waste	18.0%
TOTAL	100.0%

Source: Waste composition in greater Monrovia as derived from Pasco in 2012

Based on the available waste composition data, the estimated organic content of disposed wastes is approximately 70%. For LFG modeling purposes, the organic waste is divided into four categories based on the estimated rate of waste decay and LFG generation:

- Fast decay organic waste, including food waste, other organics, 20% of diapers.

- Moderate fast decay organic waste, including garden waste (green waste), toilet paper.
- Moderate slow decay organic waste, including paper and cardboard, textiles.
- Slow decay organic waste, including wood, rubber, leather, bones, straw.

Values of the methane generation rate constant (k) and potential methane generation capacity (L_0) are assigned for each waste category.

Model Methane Generation Rate (k) Values

The methane generation rate constant (k), determines the rate of generation of methane from refuse in the landfill. The units for k are in year-1. The value of k is a function of the following factors: (1) refuse moisture content, (2) availability of nutrients for methane-generating bacteria, (3) pH, and (4) temperature. Moisture conditions inside a landfill typically are not well known and are estimated based on average annual precipitation. Therefore, k values are assigned by the model based on waste types and the annual rainfall which is used to characterize moisture conditions at a site.

For the k values assigned by the model were the following:

- Fast decay organic waste: 0.400
- Moderate fast decay organic waste: 0.170
- Moderate slow decay organic waste: 0.070
- Slow decay organic waste: 0.035

Model Potential Methane Generation Capacity (L_0) Values

Waste composition data is used to estimate the potential methane generation capacity of refuse (L_0). L_0 describes the total amount of methane gas potentially produced by a ton of refuse as it decays and depends almost exclusively on the composition of waste. Separate L_0 values were calculated by the Model for the different waste categories:

- Fast decay organic waste, 17 m^3/Mg.
- Moderate fast decay organic waste, 22 m^3/Mg.
- Moderate slow decay organic waste, 39 m^3/Mg.
- Slow decay organic waste, 48 m^3/Mg.

LFG Model Assumptions

Methane Correction Factor

The IPCC recommends accounting for aerobic conditions in solid waste disposal sites by applying a “methane correction factor” (MCF). The MCF varies depending on waste depth and landfill type, as defined by site management practices. At managed, sanitary landfills, all waste decay is assumed to be anaerobic (MCF of 1). At landfills or dumps with conditions less conducive to anaerobic decay, the MCF will be lower to reflect the extent of aerobic conditions at these sites.

MCF values vary from 0.4 (60% reduction in LFG generation for very shallow dumpsites) to 1.0 (no reduction for managed landfills). Table 7 summarizes the MCF adjustments applied by the model based on information on waste depths and site management practices.

Table 7: Methane Correction Factor (MCF)

Site Management	Depth <5m	Depth ≥5m
Unmanaged Disposal Site	0.4	0.8
Managed Landfill	0.8	1.0
Semi-Aerobic Landfill	0.4	0.5
Unknown	0.4	0.8

For this assessment the Cheesemanburg landfill will be considered a managed landfill with depth over 5 m with a MCF of 1.0. To reach these criteria, managers and operator will need to have technical training on best management practices regarding waste disposal, compaction, leachate, stormwater and LFG management as well as environmental monitoring.

Some sources for technical training:

ISWA -SWIS Winter School (https://swis.uta.edu/)- 2 full weeks of training at the University of Texas, Arlington.
Solid Waste Association of North America (www.swana.org):

- Manager of Landfill Operations
- Landfill Gas Systems Operations and Maintenance

Annual Waste Disposal Rates

Based on the three sources of waste disposal data gathered during the site assessment activities, it was concluded that the annual waste disposal rates vary from year to year and the reasons for this variation are unclear. One potential reason is that waste collection coverage might be not constant from year to year. It was also observed that the largest waste collection rate was in 2015, 167,365 tons, and the average annual rate from 2018 thru 2022 is approximately 125,000 tons/year. There is a 34% difference between the maximum and the average annual disposal rate.

Table 8 presents the waste disposal projections from 2026 thru 2045 based on waste data from Whein Town Landfill and a 3.5% population increase (source: https://worldpopulationreview.com/cities/liberia/monrovia, United Nations population estimates and projections).

Table 8. Model Waste Disposal–Cheesemanburg Landfill

Year	Annual Waste Disposal (tonnes/year)	Accumulated Waste (tonnes)
2026	139,258	139,258
2027	144,020	283,278
2028	148,950	432,228
2029	154,040	586,268
2030	159,310	745,578
2031	164,760	910,338
2032	170,390	1,080,728
2033	176,220	1,256,948
2034	182,250	1,439,198
2035	188,480	1,627,678
2036	194,930	1,822,608
2037	201,600	2,024,208
2038	208,490	2,232,698
2039	215,620	2,448,318
2040	222,990	2,671,308
2041	230,620	2,901,928
2042	238,510	3,140,438
2043	246,670	3,387,108
2044	255,110	3,642,218
2045	263,830	3,906,048

Collection Efficiency

Collection efficiency is a measure of the ability of the gas collection system to capture generated LFG. It is a function of both system design and system operations and maintenance. Collection efficiency is a percentage value that is applied to the LFG generation projection produced by the model to estimate the amount of LFG that is or can be recovered. Although rates of LFG recovery can be measured, rates of generation in a site cannot be measured, hence the need for a model to estimate generation, reason for existence of considerable uncertainty regarding actual collection efficiencies achieved at landfills.

The LFG model automatically calculates collection efficiency based on the following factors:

- Site management practices – properly managed landfills will have characteristics such: cover soils, waste compaction and leveling, control of waste placement, control of scavenging, control of fires, leachate management systems which allow for the achievement of higher collection efficiencies than unmanaged dumpsites.
- Collection system coverage – collection efficiency is directly related to the extent of wellfield coverage of the waste disposal areas.
- Waste depth – shallow landfills require shallow wells which are less efficient because they are more prone to air infiltration.

- Cover type and extent – collection efficiencies will be highest at landfills with a low permeable soil cover over all areas with waste, which limits the release of LFG into the atmosphere, air infiltration into the gas system, and rainfall infiltration into the waste.
- Site bottom liner – landfills with clay or synthetic bottom liners will have lower rates of LFG migration into surrounding soils, resulting in higher collection efficiencies.
- Waste compaction – uncompacted waste will have higher air infiltration and lower gas quality, and thus lower collection efficiency.
- Size of the active disposal ("tipping") area – unmanaged disposal sites with large tipping areas will tend to have lower collection efficiencies than managed sites where the disposal is directed to specific tipping areas.
- Leachate management – high leachate levels can dramatically limit collection efficiencies, particularly at landfills with high rainfall, poor drainage, and limited soil cover.

Table 9 provides the collection efficiency calculations made by the model based on the inputs provided on the "Inputs" spreadsheet. The column on table 9 named Discount provides the basis to determine the proposed collection efficiency for Cheesemanburg landfill.

Table 9. Model Collection Efficiency Calculations - Cheesemanburg Landfill

	Collection Efficiency Calculations	Discount
Account for site management practices	100%	No 15% discount since site will he operated as a managed landfill
Account for waste depth	100%	No discount because waste depth is >10 m
Account for wellfield coverage of waste area	70%	Tt is assumed the GCCS will cover 70% of the site in parallel the other 30% will be set for waste disposal
Account for cover type and extent	61%	Since the site will be in operation in 2031 when the GCCS starts operation, it is assumed that the site will have intermediate cover. Reduce collection efficiency by 80%
Account for liner type and extent	61%	No discount as is assumed waste disposal was done over a liner system
Account for waste compaction	61%	No 3% discount as it is assumed compaction will be performed properly
Account for focused tip area	61%	No 5% discount as it is assumed that there will be a dedicated tip area throughout the life of the landfill
Account for leachate	52%	To be conservative 15% discount assuming that leachate seeps and pounding on the waste area will be an issue as rainfall in the area is constant through the year.
Calculated Collection Efficiency:	52%	

Collection efficiency will increase once the landfill reaches closure and the GCCS is installed its las phase.

LFG Model Results

LFG generation and recovery projections are presented in greater detail in Appendix 3 LFG Model results including:

- Annual disposal estimates and "waste-in-place" values.
- Projected LFG generation rates through 2055.
- Maximum power plant capacity.
- Methane emissions reduction estimates.
- The k values used for the fast, moderately fast, moderately slow and slow decay waste organic fractions.
- The L_0 values calculated for the fast, moderately fast, moderately slow, and slow decay organic waste fractions.
- Proposed collection efficiency (in %) and LFG recovery rates (in m^3/hr and ft^3/min).
- Methane Emissions Reduction Estimates (in tonnes CH_4/yr and tonnes/CO2eq/yr).

The maximum power plant capacity assumes a gross heat rate of 10,800 Btus per kW-hr (hhv), while the emission reductions do not account for electricity generation or project emissions and are calculated using a methane density (at standard temperature and pressure) of 0.0007168 Mg/m^3.

LFG Model Results

Table 10 below presents a summary of the model results for Cheesemanburg Landfill from 2026–2052. LFG generation and recovery are projected to continue declining after 2045, once Cheesemanburg Landfill is officially closed.

Table 10. LFG Model Results

Year	LFG Generation (m^3/hr)	LFG Recovery (m^3/hr)	Maximum Power Plant Capacity (MW)	Methane Emissions Reduction Estimates (tonnes/CO_2eq/yr)
2026	0	0	0.0	0
2027	342	0	0.0	0
2028	601	0	0.0	0
2029	804	0	0.0	0
2030	971	0	0.0	0
2031	1,113	579	1.0	38,101
2032	1,238	644	1.1	42,401
2033	1,353	704	1.2	46,334
2034	1,461	760	1.3	50,035
2035	1,565	814	1.3	53,592
2036	1,666	867	1.4	57,067

Table 10. LFG Model Results

Year	LFG Generation (m^3/hr)	LFG Recovery (m^3/hr)	Maximum Power Plant Capacity (MW)	Methane Emissions Reduction Estimates (tonnes/CO_2eq/yr)
2037	1,767	919	1.5	60,504
2038	1,867	971	1.6	63,934
2039	1,967	1,023	1.7	67,378
2040	2,069	1,076	1.8	70,854
2041	2,172	1,129	1.9	74,375
2042	2,276	1,184	2.0	77,951
2043	2,382	1,239	2.0	81,591
2044	2,491	1,295	2.1	85,302
2045	2,602	1,353	2.2	89,092
2046	2,715	1,412	2.3	92,966
2047	2,161	1,124	1.9	74,004
2048	1,772	922	1.5	60,689
2049	1,495	777	1.3	51,193
2050	1,293	673	1.1	44,290
2051	1,143	595	1.0	39,156
2052	1,029	535	0.9	35,235

Note: Projected LFG recovery rates are in m3/hr adjusted to 50% methane.

Figure 11, presents the model results in graphic form for Cheesemanburg landfill from 2008 through 2045.

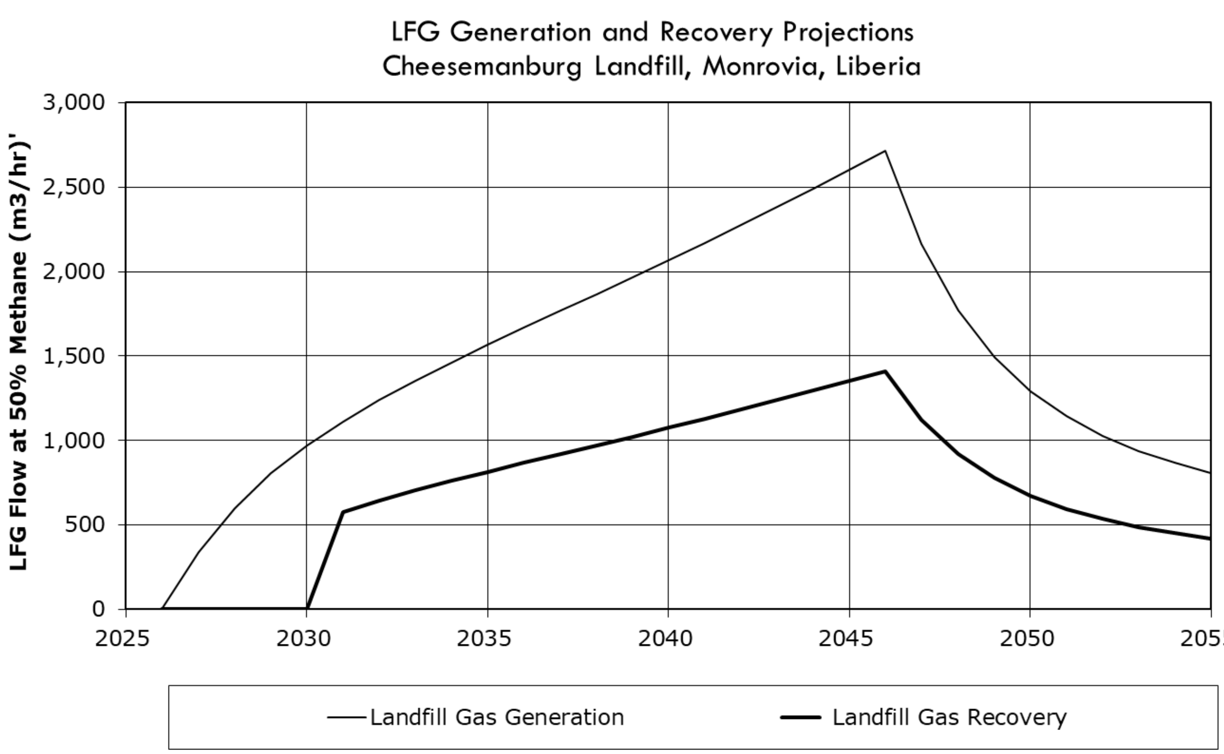


Figure 11. Cheesemanburg Landfill Model Results

The maximum LFG recovery rate of approximately 1,400 m^3/hr (considering a 52% collection efficiency) will be reached in 2046, one year after the closure of Cheesemanburg Landfill. After 2046 LFG recovery rate will decrease rapidly. If this LFG is flared or given a beneficial use it can contribute to the reduction of approximately 1 million tonnes of CO_2Eq from 2031 through 2046 (Detailed LFG model results are presented in Appendix 2).

LFG COLLECTION AND CONTROL PLAN

The conceptual plan for landfill gas collection and control (GCCS) was prepared based on information contained in the ESIA, because design drawings were not available during the assessment. This plan was prepared using industry standards, and best management practices, but most be considered conceptual not for construction and will have to be reviewed upon availability of a landfill designed drawings.

The LFG recovery projections presented in a previous section of this document were used to prepare a conceptual design for the GCCS (included in Appendix 3). The main components for the GCCS are as follows:

- **Well Field Design and Layout.** 19 vertical extraction wells were determined to be adequate to cover all waste disposal areas.

- **Extraction Well Design.** The borehole should be at least 60 cm diameter. It should be backfilled with 30 cm of gravel (form the design well depth) before inserting the casing pipe. The slotted or perforated sections of pipe followed by the solid sections until the pipe is raised above the ground surface. The pipe should be centered in the borehole, and gravel added around the outside until it has reached the depth shown on the plans covering all the slotted pipe length. Soil backfill and a bentonite plug are then added, until the fill extends to the surface. The borehole should be slightly overfilled and compacted to help minimize settlement of the well area which could result in collecting water around the well.

- **Well Casing.** The well pipe should be constructed of 150 mm diameter SDR-11 HDPE pipe. This material has proven to exhibit excellent compatibility with landfill materials so that it would resist corrosion and good chemical resistance. It provides enough flexibility that the well would have less of a chance of being broken during landfill settlement. HDPE also performs adequately under the temperatures generated within landfills. The gravel or crushed rock layer would consist of non-calcareous material.

- **Wellhead.** The wellhead design must allow for system monitoring and control. Sampling ports must allow for the measurement of differential pressure for the calculation of gas flow values from each individual well. The wellhead must contain a valve which allows variable rates of vacuum to be applied to the system. Sampling ports must be strategically located so that LFG quality from the well can be measured. A permanent temperature probe must be placed on the well to measure LFG temperatures. A flexible hose connects the well to the header to allow differential settlement between the well and header.

- **Header and Lateral Piping.** The layout of a route for the header line and laterals to connect each of the gas wells into the system and convey the collected gas to a central location for destruction must be properly design prior to construction. Typical design criteria for header and lateral pipe design are provided below:

  - Header Slope. All proposed header pipes outside the waste limits should be designed to have a slope of not less than 0.5% in natural ground toward each condensate/leachate sump. In addition, a minimum of 3% slope in header pipe inside the waste limits since it is expected some differential settlement around the landfill area.

  - Header Pipe Sizing. The velocity of the gas should be approximately 12.0 m/sec when gas flow is concurrent with condensate flow. If gas flow is countercurrent to condensate flow, the velocity should be approximately 6.0 m/sec. Flow conditions within any segment of header line should not consistently exceed the velocity limitations.

  - The header and lateral pipe construction typically consist of the use of HDPE pipe. HDPE pipe is ideal due to its compatibility with LFG and waste, its flexibility (if settlement occurs), its long-term stability, and its excellent chemical resistance. The pipe would be fusion-welded and placed above ground (except at condensate sumps, traps and road crossings). Steel rebar or some other method should be used to keep the pipe from "snaking" due to expansion and contraction associated with temperature changes. All pipes should be pressure-tested and any leaks repaired before the pipe is put into service. At all road crossings, the pipe should be protected by a section of corrugated metal pipe or other suitable material. Typically, the protective casing is two pipe sizes larger than the gas line.

- **Isolation Valves.** Control valves are located throughout the collection header network. The valves can manually shut off the applied vacuum to a particular section of header pipe. This allows portions of the well field to be isolated for monitoring and maintenance purposes.

- **Condensate Sumps.** LFG condensate is produced during the collection and transportation of LFG. The condensate must be removed at engineered low points in the GCCS header piping, or it would eventually fill up the header lines and impede gas flow. The header collection system alignment is designed to use the vertical relief provided by the landfill contours for gravity flow of condensate. The conceptual design includes three condensate sumps at strategic points in the header pipe. An additional sump (for a total of three) is included at what would be the low point in the entire system, off the waste area at blower/flare station. An option to explore would be to discharge condensate from the sumps into the leachate main that runs parallel to the GCCS header pipe, which would transport leachate to the leachate storage tanks prior to treatment. This could be less expensive than using a dedicated condensate pipe.

- **Blower and Flare Station:** the blower and flare station main components are as follows:

  - Blower Equipment. The GCCS must be designed to handle the maximum expected gas flow rate from the entire area of the proposed engineered landfill that warrants control, over the intended use period of the GCCS equipment. Since the blower equipment is responsible for providing the vacuum that actually extracts the gas from the wellfield and moves it through the system, the sizing of the blower is crucial. Typically, equipment with two or more redundant blowers is required. For the final design, the appropriate size and number of blowers for the final system configuration will need to be determined.

  - Control Device. The control device can be an open or enclosed flare, Typically, design of the control device is for the maximum LFG generation. The conceptual design assumes an enclosed flare which is more expensive but also provides the means to monitor for destruction efficiency which is a requirement for a carbon credit certification project.

  - Monitoring System. The control device must be equipped to adequately address all desired testing, monitoring, reporting and recordkeeping needs. These needs typically include flow and temperature monitoring for all enclosed combustion devices, an auto-dialer when the system goes down, and LFG quality monitoring equipment for energy generation.

Since the Cheesemanburg landfill will be in operations for 20 years, it is expected that gas collection and control system will be installed upon enough LFG for a project utilization. These means that the GCCS will be installed while the landfill operates for waste disposal. Therefore, the development of the GCCS has been conceptualized for a four phases project.

Table 11 presents a summary of the quantities needed to for each of the main elements for each of the GCCS development phases.

Table 11. Summary of GCCS Main Elements

Element	Amounts
Phase I	
Vertical extraction well	16
Header and lateral piping (m)	1000
Condensate sump	1
Isolation valve	2
Blower	1-350 m^3/hr

Table 11. Summary of GCCS Main Elements

Element	Amounts
Flare	1-350 m^3/hr
Monitoring system	1
Phase II	
Vertical extraction well	16
Header and lateral piping (m)	1350
Condensate sump	0
Isolation valve	2
Phase III	
Vertical extraction well	15
Header and lateral piping (m)	650
Condensate sump	2
Isolation valve	2
Phase IV	
Vertical extraction well	32
Header and lateral piping (m)	1850
Condensate sump	0
Isolation valve	0

GCCS Cost Estimate

Table 12 presents a summary of the project cost for the four phases of the GCCS. Project cost was estimated based on the conceptual design plan described in previous sections, and the conceptual GCCS design provided on Appendix C. The unit prices used were developed from similar projects developed by USA and abroad. In Addition, A more detail capital cost estimate is presented in Appendix 4.

Table 12. Summary of GCCS Capital Cost

Area of Work	Total
Initial Phase I*	$1,067,000
Phase II	350,000
Phase III	300,000
Phase IV	570,000

Note: * Includes Phase I, miscellaneous and 10% contingency

Appendix 4 includes a more detail table for the GCCS capital cost estimates. This budgetary capital cost includes cost up to flaring the LFG, does not include the cost related to the LFG utilization project.

LFG UTILIZATION ASSESSMENT

LFG has been used for multiple purposes in previous projects around the world. These projects can be categorized in three major categories:

- **Medium Heat Content Projects.** LFG extracted from the landfill is converted to electricity using internal combustion engines, turbines or microturbines for autogeneration or interconnected to the public electrical network.

- **High Heat Content Projects.** LFG is cleaned to produce the equivalent of natural gas, compressed natural gas (CNG) or liquefied natural gas (LNG).

- **Direct Used Projects.** LFG is used as a direct source of fuel in nearby industry to feed boilers, ovens or other equipment with fuel needs.

Unfortunately, no industry that could use the LFG for a direct used project in their facilities is located in the vicinity of the landfill at the time of evaluation. But it is important to reevaluate this aspect in the next 5 years to see if anything has changed.

The Liberia Electricity Corporation (LEC) has expressed great interest in the potential landfill gas to energy (LFGE) project as LEC is in need to increase their generation capacity. they also expressed that the price of electricity is set by the Liberia Electricity Regulatory Commission (LERC) and can vary from $0.10 and $0.25 US dollars, which are values to be considered further on the evaluation of a potential LFGE project.

Model results estimate that by 2031 there will be enough energy available for a 1-MW project of electricity. The landfill will support this project size for until 2050. The investment cost for an LFGE project is approximately USD 2.5 million/MW, plus an additional cost for interconnection. For a 1-MW project the cost will be approximately USD $2,500,000 plus the cost of interconnection to the grid. Interconnection point to the grid will need to be evaluated by the Liberia Electricity Company.

APPENDIX 1

LANDFILL DESIGN DRAWINGS AND DETAILS

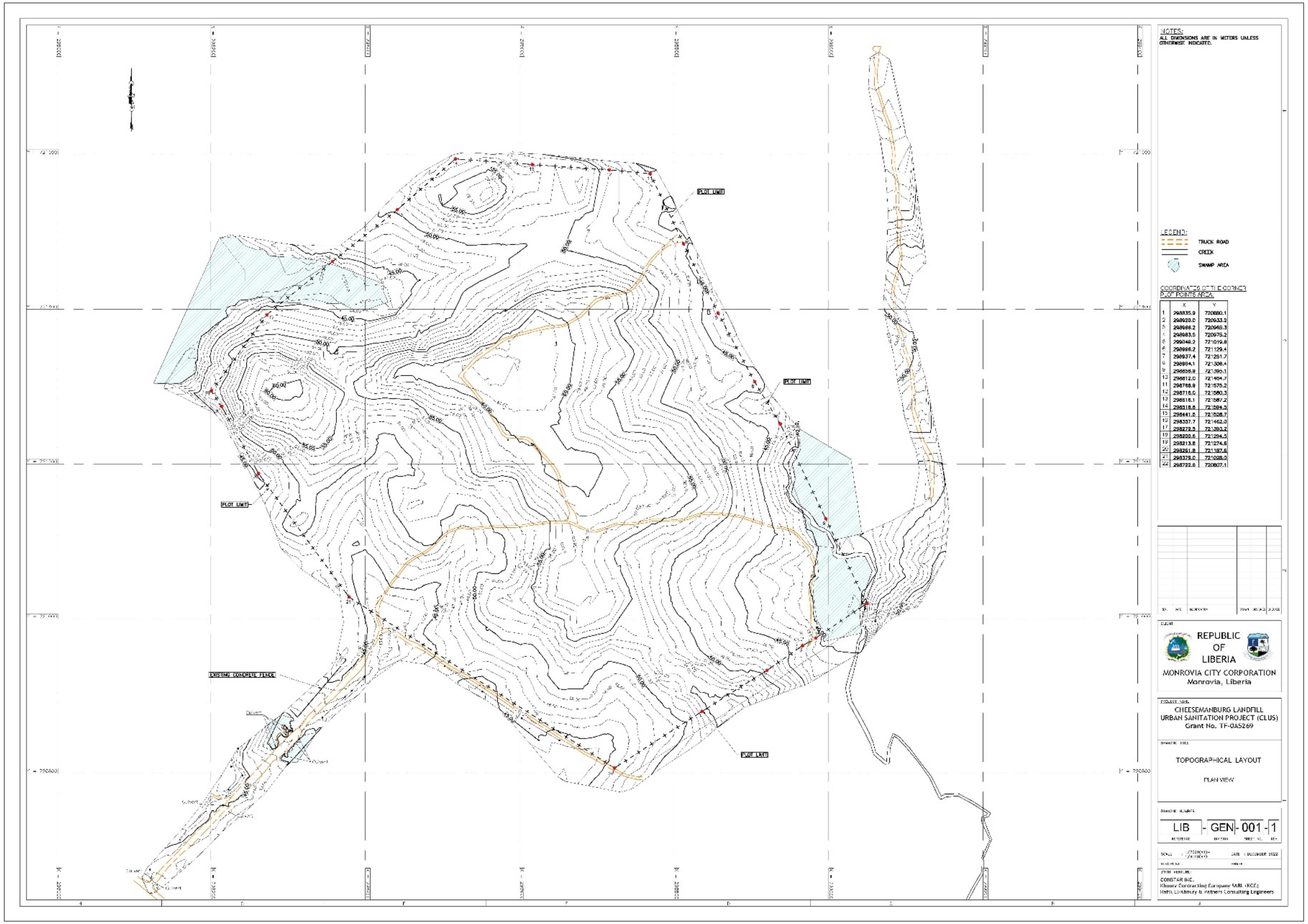


Figure 6-2 Topographic layout of the site (provided by Constar JV, 2022)

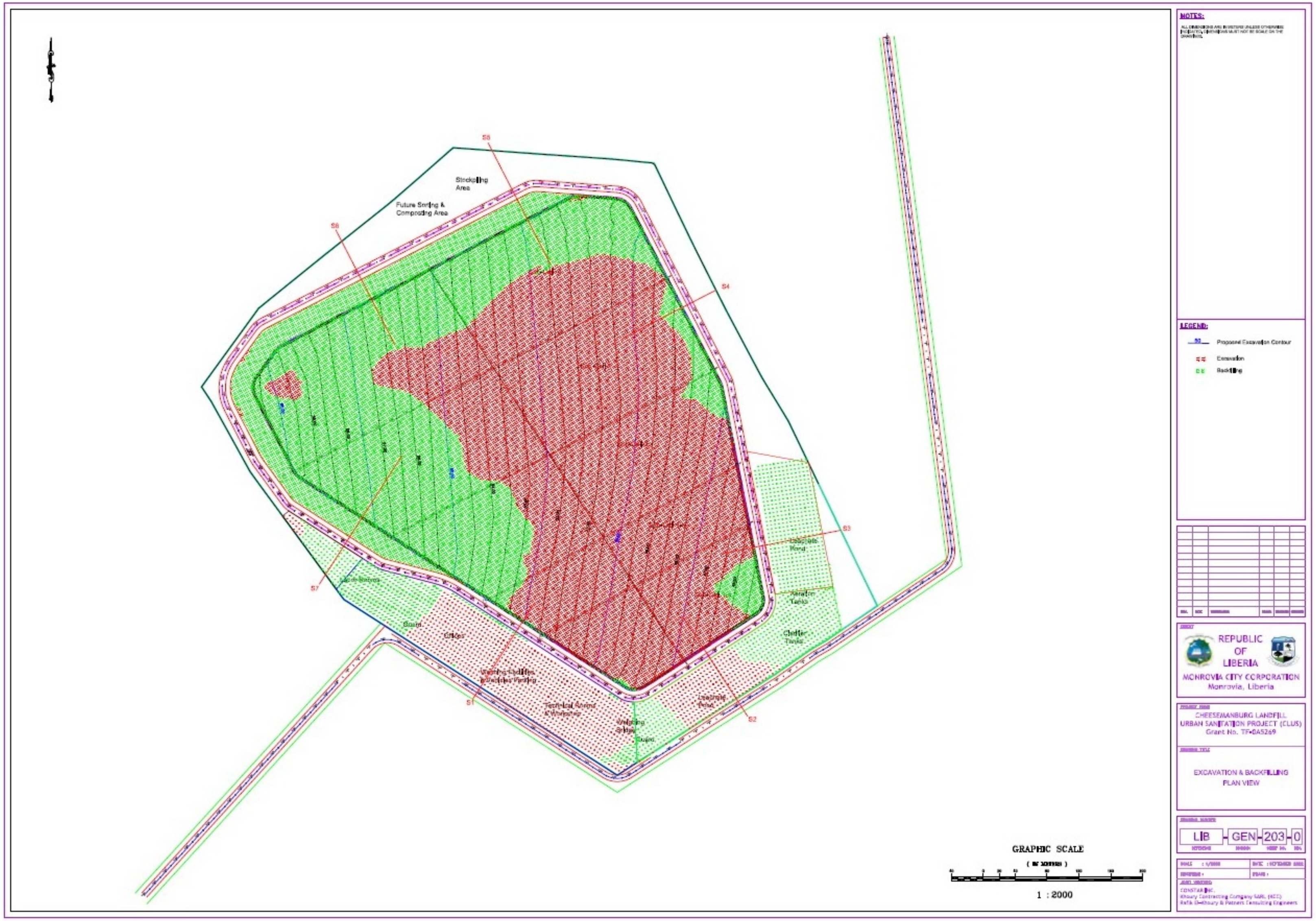


Figure 3-9 Excavation and backfilling (Constar JV, 2022a)

Figure 3-7 Project design (provided by Constar JV, 2022)

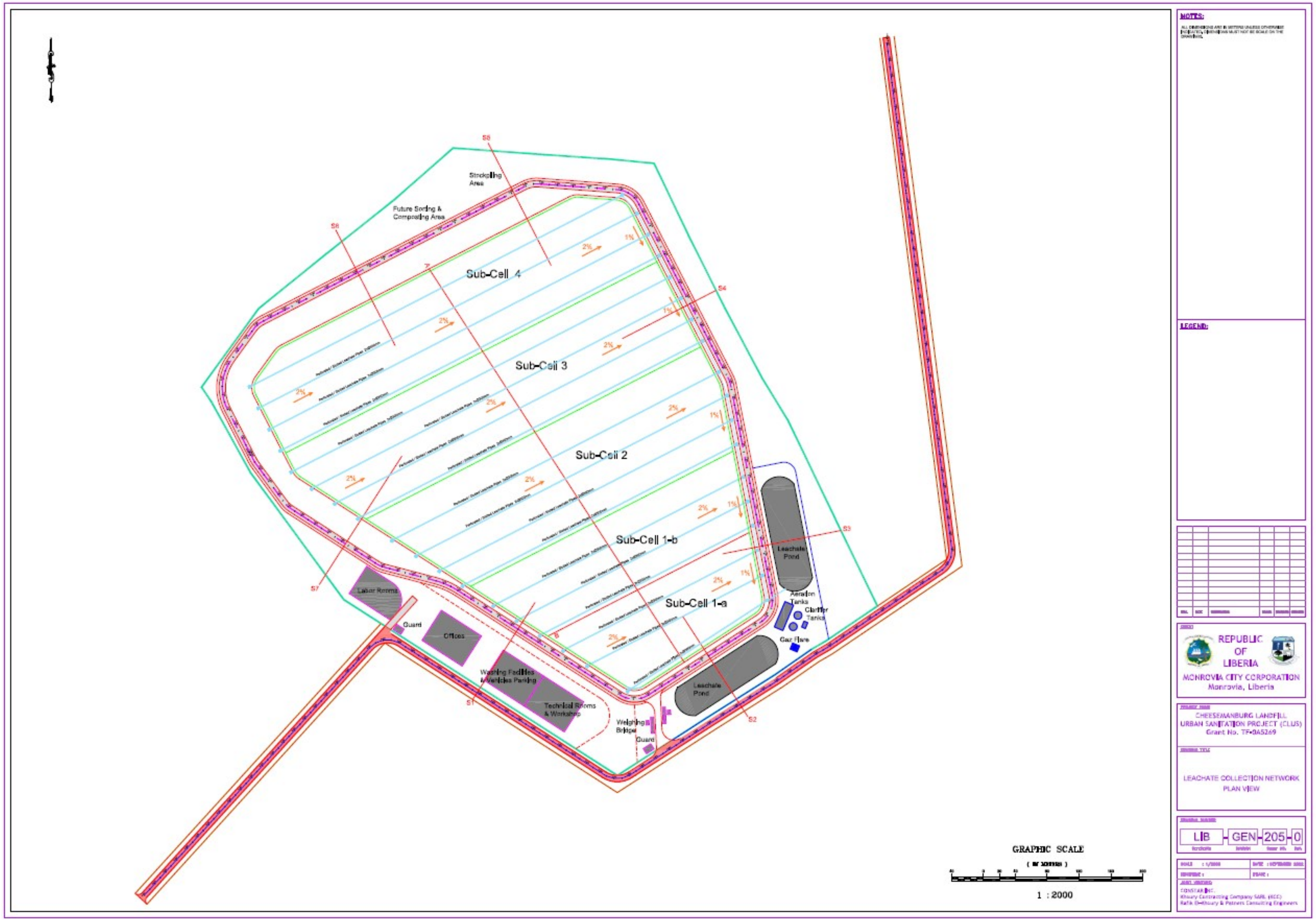


Figure 3-14 Leachate collection network (Constar JV, 2022a)

Figure 3-17 Landfill gas collection system (provided by Constar JV, 2022)

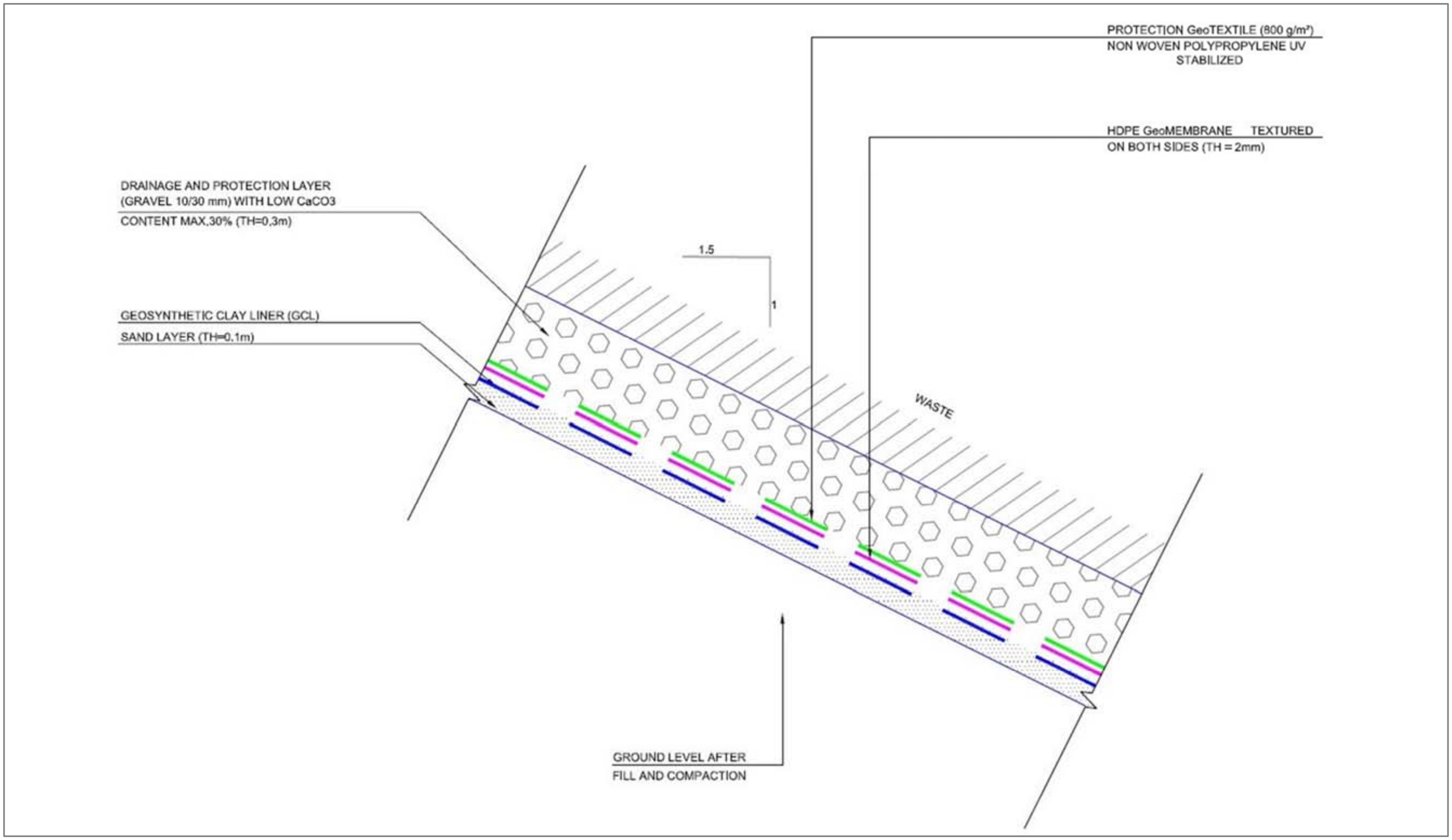


Figure 3-11 Base of landfill layout (Constar JV, 2022a)

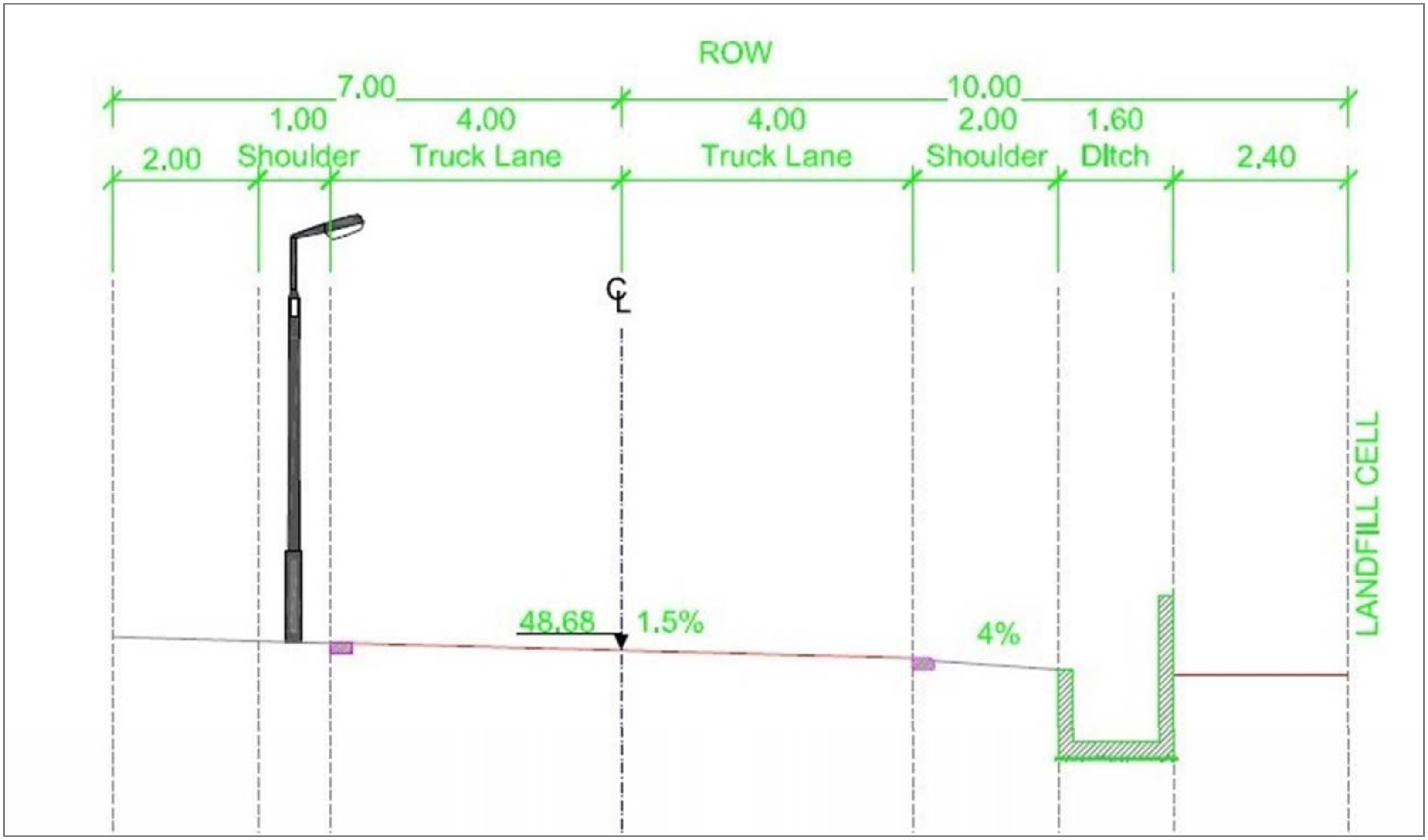


Figure 3-12 Typical cross-section of Peripheral Service Road (Constar JV, 2022a)

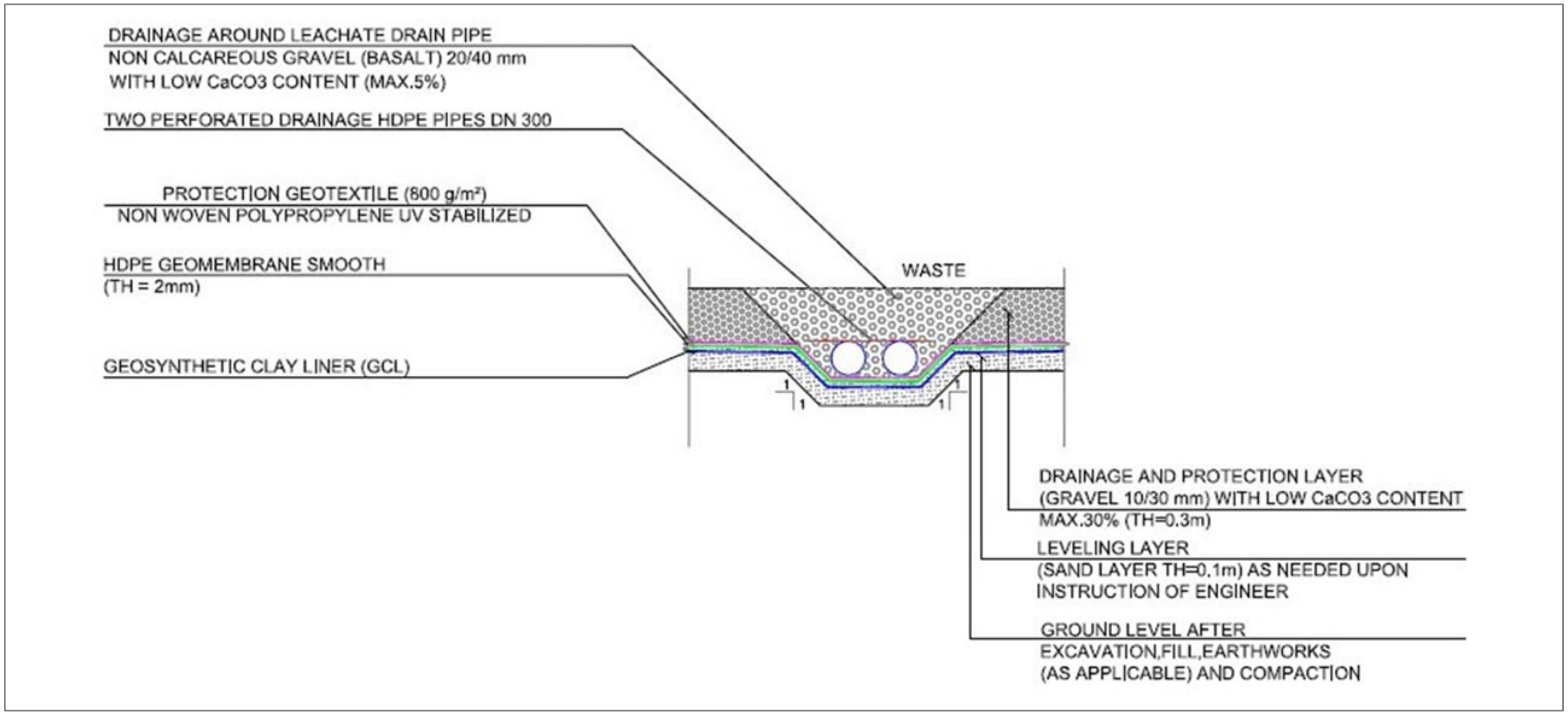


Figure 3-13 Typical section at main leachate connection pipe (Constar JV, 2022a)

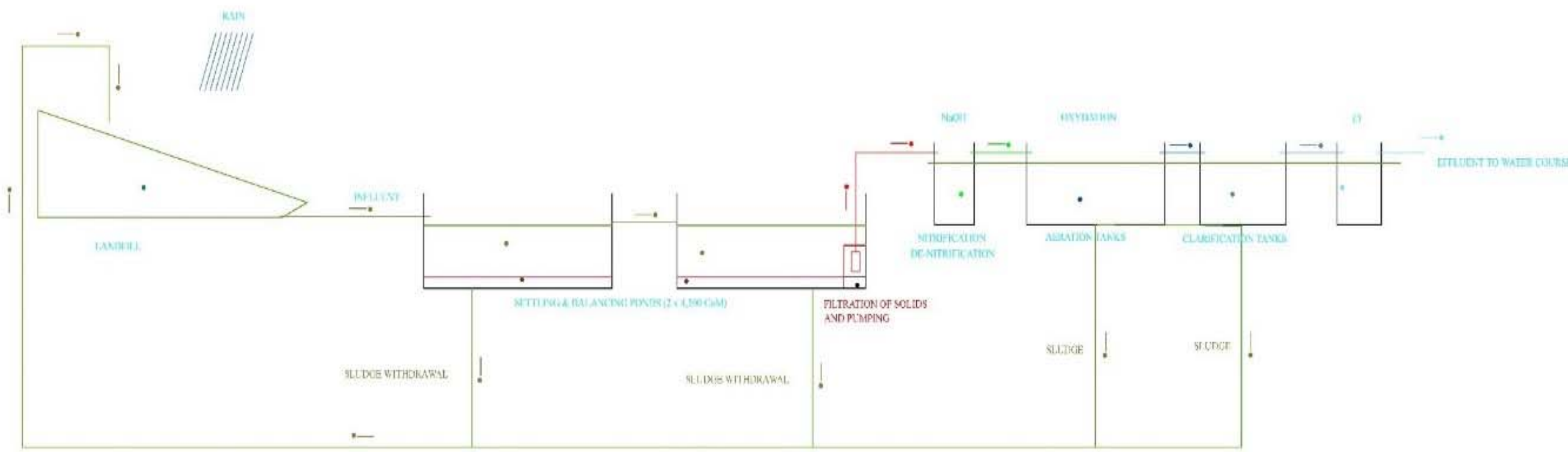


Figure 3-15 Leachate treatment process (provided by Constar JV, 2022)

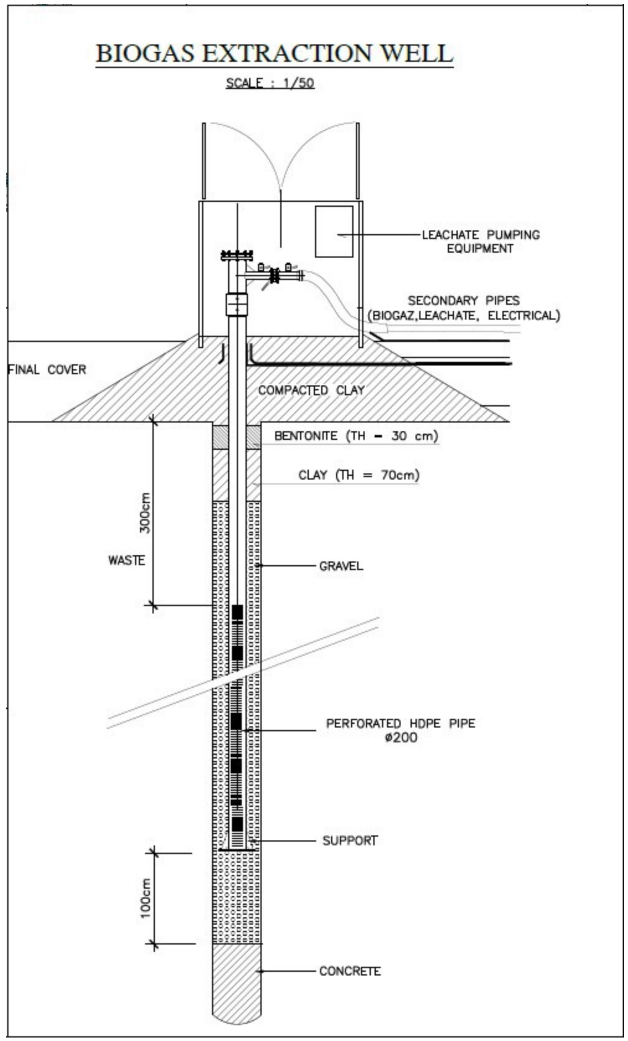


Figure 3-16 Design of a typical landfill gas extraction well (provided by Constar JV, 2022)

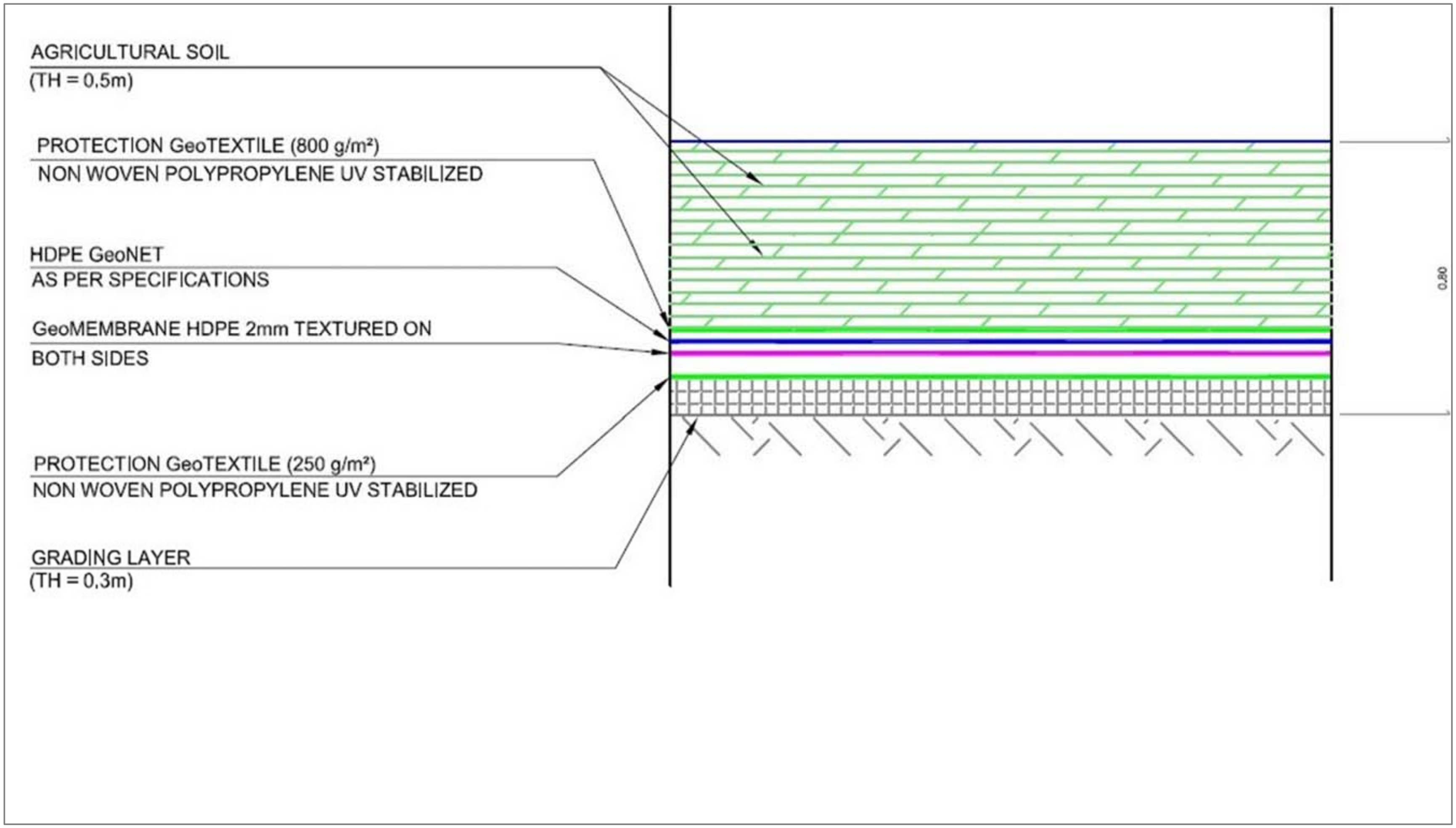


Figure 3-18 Final cover design (Constar JV, 2022a)

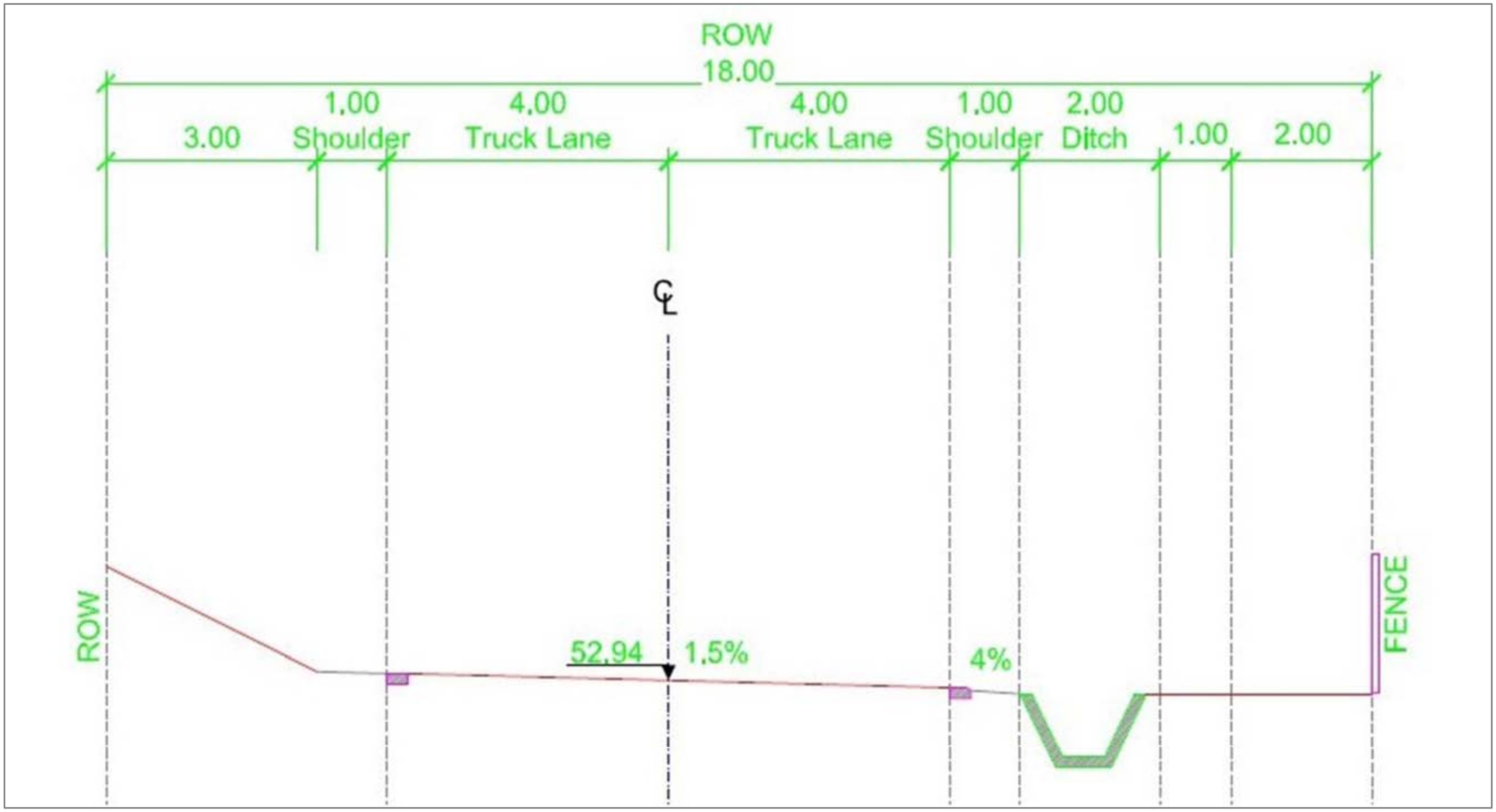


Figure 3-19 Typical cross-section of Landfill Access Road (Constar JV, 2022a)

APPENDIX 2

LANDFILL GAS MODEL RESULTS

PROJECTION OF LANDFILL GAS GENERATION AND RECOVERY
CHEESEMANBURG LANDFILL

Year	Disposal (Mg/yr)	Refuse In-Place (Mg)	LFG Generation			Collection System Efficiency (%)	Predicted LFG Recovery			Maximum Power Plant Capacity* (MW)	Baseline LFG Flow (m3/hr)	Methane Emissions Reduction Estimates**	
			(m^3/hr)	(cfm)	(mmBtu/hr)		(m^3/hr)	(cfm)	(mmBtu/hr)			(tonnes CH_4/yr)	(tonnes CO_2eq/yr)
2026	139,258	139,258	0	0	0.0	0%	0	0	0.0	0.0	0	0	0
2027	144,020	283,278	342	201	6.1	0%	0	0	0.0	0.0	0	0	0
2028	148,950	432,228	601	354	10.7	0%	0	0	0.0	0.0	0	0	0
2029	154,040	586,268	804	473	14.4	0%	0	0	0.0	0.0	0	0	0
2030	159,310	745,578	971	571	17.3	0%	0	0	0.0	0.0	0	0	0
2031	164,760	910,338	1,113	655	19.9	52%	579	341	10.3	1.0	0	1,814	38,101
2032	170,390	1,080,728	1,238	729	22.1	52%	644	379	11.5	1.1	0	2,019	42,401
2033	176,220	1,256,948	1,353	796	24.2	52%	704	414	12.6	1.2	0	2,206	46,334
2034	182,250	1,439,198	1,461	860	26.1	52%	760	447	13.6	1.3	0	2,383	50,035
2035	188,480	1,627,678	1,565	921	28.0	52%	814	479	14.5	1.3	0	2,552	53,592
2036	194,930	1,822,608	1,666	981	29.8	52%	867	510	15.5	1.4	0	2,717	57,067
2037	201,600	2,024,208	1,767	1,040	31.6	52%	919	541	16.4	1.5	0	2,881	60,504
2038	208,490	2,232,698	1,867	1,099	33.4	52%	971	571	17.3	1.6	0	3,044	63,934
2039	215,620	2,448,318	1,967	1,158	35.2	52%	1,023	602	18.3	1.7	0	3,208	67,378
2040	222,990	2,671,308	2,069	1,218	37.0	52%	1,076	633	19.2	1.8	0	3,374	70,854
2041	230,620	2,901,928	2,172	1,278	38.8	52%	1,129	665	20.2	1.9	0	3,542	74,375
2042	238,510	3,140,438	2,276	1,340	40.7	52%	1,184	697	21.2	2.0	0	3,712	77,951
2043	246,670	3,387,108	2,382	1,402	42.6	52%	1,239	729	22.1	2.0	0	3,885	81,591
2044	255,110	3,642,218	2,491	1,466	44.5	52%	1,295	762	23.1	2.1	0	4,062	85,302
2045	263,830	3,906,048	2,602	1,531	46.5	52%	1,353	796	24.2	2.2	0	4,242	89,092
2046	0	3,906,048	2,715	1,598	48.5	52%	1,412	831	25.2	2.3	0	4,427	92,966
2047	0	3,906,048	2,161	1,272	38.6	52%	1,124	661	20.1	1.9	0	3,524	74,004
2048	0	3,906,048	1,772	1,043	31.7	52%	922	542	16.5	1.5	0	2,890	60,689
2049	0	3,906,048	1,495	880	26.7	52%	777	458	13.9	1.3	0	2,438	51,193
2050	0	3,906,048	1,293	761	23.1	52%	673	396	12.0	1.1	0	2,109	44,290
2051	0	3,906,048	1,143	673	20.4	52%	595	350	10.6	1.0	0	1,865	39,156
2052	0	3,906,048	1,029	606	18.4	52%	535	315	9.6	0.9	0	1,678	35,235
2053	0	3,906,048	939	553	16.8	52%	488	287	8.7	0.8	0	1,531	32,155
2054	0	3,906,048	866	510	15.5	52%	450	265	8.0	0.7	0	1,413	29,663
2055	0	3,906,048	806	474	14.4	52%	419	247	7.5	0.7	0	1,314	27,590
2056	0	3,906,048	754	444	13.5	52%	392	231	7.0	0.6	0	1,229	25,819
2057	0	3,906,048	709	417	12.7	52%	369	217	6.6	0.6	0	1,156	24,272
2058	0	3,906,048	669	393	11.9	52%	348	205	6.2	0.6	0	1,090	22,895
2059	0	3,906,048	632	372	11.3	52%	329	193	5.9	0.5	0	1,031	21,650
2060	0	3,906,048	599	353	10.7	52%	311	183	5.6	0.5	0	977	20,511
2061	0	3,906,048	568	334	10.2	52%	295	174	5.3	0.5	0	927	19,460
2062	0	3,906,048	540	318	9.6	52%	281	165	5.0	0.5	0	880	18,483
2063	0	3,906,048	513	302	9.2	52%	267	157	4.8	0.4	0	837	17,570
2064	0	3,906,048	488	287	8.7	52%	254	149	4.5	0.4	0	796	16,713
2065	0	3,906,048	465	273	8.3	52%	242	142	4.3	0.4	0	758	15,908
2066	0	3,906,048	442	260	7.9	52%	230	135	4.1	0.4	0	721	15,148
2067	0	3,906,048	421	248	7.5	52%	219	129	3.9	0.4	0	687	14,431
2068	0	3,906,048	402	236	7.2	52%	209	123	3.7	0.3	0	655	13,754
2069	0	3,906,048	383	225	6.8	52%	199	117	3.6	0.3	0	624	13,113
2070	0	3,906,048	365	215	6.5	52%	190	112	3.4	0.3	0	595	12,505
2071	0	3,906,048	348	205	6.2	52%	181	107	3.2	0.3	0	568	11,930
2072	0	3,906,048	332	196	5.9	52%	173	102	3.1	0.3	0	542	11,385

PROJECTION OF LANDFILL GAS GENERATION AND RECOVERY
CHEESEMANBURG LANDFILL

Year	Disposal (Mg/yr)	Refuse In-Place (Mg)	LFG Generation			Collection System Efficiency (%)	Predicted LFG Recovery			Maximum Power Plant Capacity* (MW)	Baseline LFG Flow (m3/hr)	Methane Emissions Reduction Estimates**	
			(m^3/hr)	(cfm)	(mmBtu/hr)		(m^3/hr)	(cfm)	(mmBtu/hr)			(tonnes CH_4/yr)	(tonnes CO_2eq/yr)
2073	0	3,906,048	317	187	5.7	52%	165	97	2.9	0.3	0	517	10,867

MODEL INPUT PARAMETERS

Assumed Methane Content of LFG: 50%

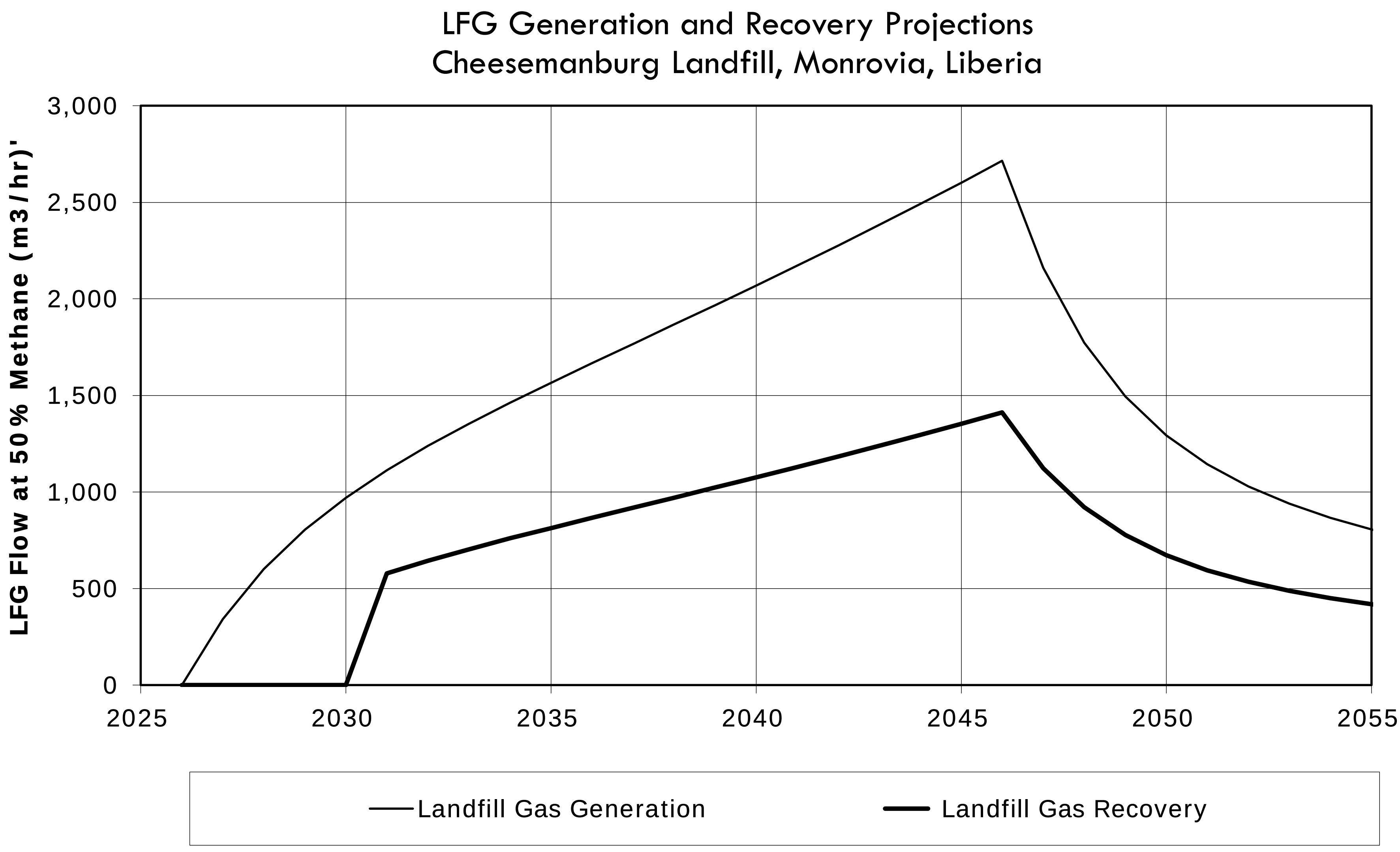
Methane Correction Factor (MCF): 1.0

Waste Category:	Fast Decay	Moderately Fast Decay	Moderately Slow Decay	Slow Decay
CH4 Generation Rate Constant (k):	0.400	0.170	0.070	0.035
CH4 Generation Potential (Lo) (m3/Mg):	70	93	161	200

NOTES

* Maximum power plant capacity assumes a gross heat rate of 10,800 Btus per kW-hr (hhv).

**Emission reductions do not account for electricity generation or project emissions and are calculated using a methane density (at standard temperature and pressure) of 0.0007168 Mg/m3.



LFG Generation and Recovery Projections
Cheesemanburg Landfill, Monrovia, Liberia
LFG Flow at 50% Methane (m3/hr)'
0
500
1,000
1,500
2,000
2,500
3,000
2025
2030
2035
2040
2045
2050
2055
Landfill Gas Generation
Landfill Gas Recovery

1/31/2025

APPENDIX 3

GCCS CONCEPTUAL DESIGN

LEGEND

- PROPERTY LIMITS
- WASTE LIMITS ACCESS
- ROADS
- LEACHATE PONDS
- HEADER PIPE
- LATERAL PIPE
- LFG EXTRACTION WELL
- ISOLATION VALVE
- CONDENSATE SUMP

N

BASE ON GOOGLE EARTH AERIAL PHOTOGRAPH, DATED DEC 2022

1:3000 SCALE

JAN 2025

GCCS PHASE I
LFG ASSESSMENT
CHEESEMANBURG LANDFILL
MONROVIA, LIBERIA

NOT FOR CONSTRUCTION

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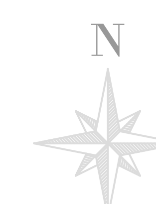
LEGEND

- PROPERTY LIMITS
- WASTE LIMITS ACCESS
- ROADS
- LEACHATE PONDS
- HEADER PIPE
- LATERAL PIPE
- LFG EXTRACTION WELL
- ISOLATION VALVE
- CONDENSATE SUMP



BASE ON GOOGLE EARTH AERIAL PHOTOGRAPH, DATED DEC 2022

1:3000 SCALE

JAN 2025

GCCS PHASE II
LFG ASSESSMENT
CHEESEMANBURG LANDFILL
MONROVIA, LIBERIA

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LEGEND

- PROPERTY LIMITS
- WASTE LIMITS ACCESS
- ROADS
- LEACHATE PONDS
- HEADER PIPE
- LATERAL PIPE
- LFG EXTRACTION WELL
- ISOLATION VALVE
- CONDENSATE SUMP

N

BASE ON GOOGLE EARTH AERIAL PHOTOGRAPH, DATED DEC 2022

1:3000
SCALE

JAN 2025

3 of 5

GCCS PHASE III
LFG ASSESSMENT
CHEESEMANBURG LANDFILL
MONROVIA, LIBERIA

NOT FOR CONSTRUCTION

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LEGEND

- PROPERTY LIMITS
- WASTE LIMITS ACCESS
- ROADS
- LEACHATE PONDS
- HEADER PIPE
- LATERAL PIPE
- LFG EXTRACTION WELL
- ISOLATION VALVE
- CONDENSATE SUMP

N

BASE ON GOOGLE EARTH AERIAL PHOTOGRAPH, DATED DEC 2022

1:3000
SCALE

GCCS PHASE IV
LFG ASSESSMENT
CHEESEMANBURG LANDFILL
MONROVIA, LIBERIA

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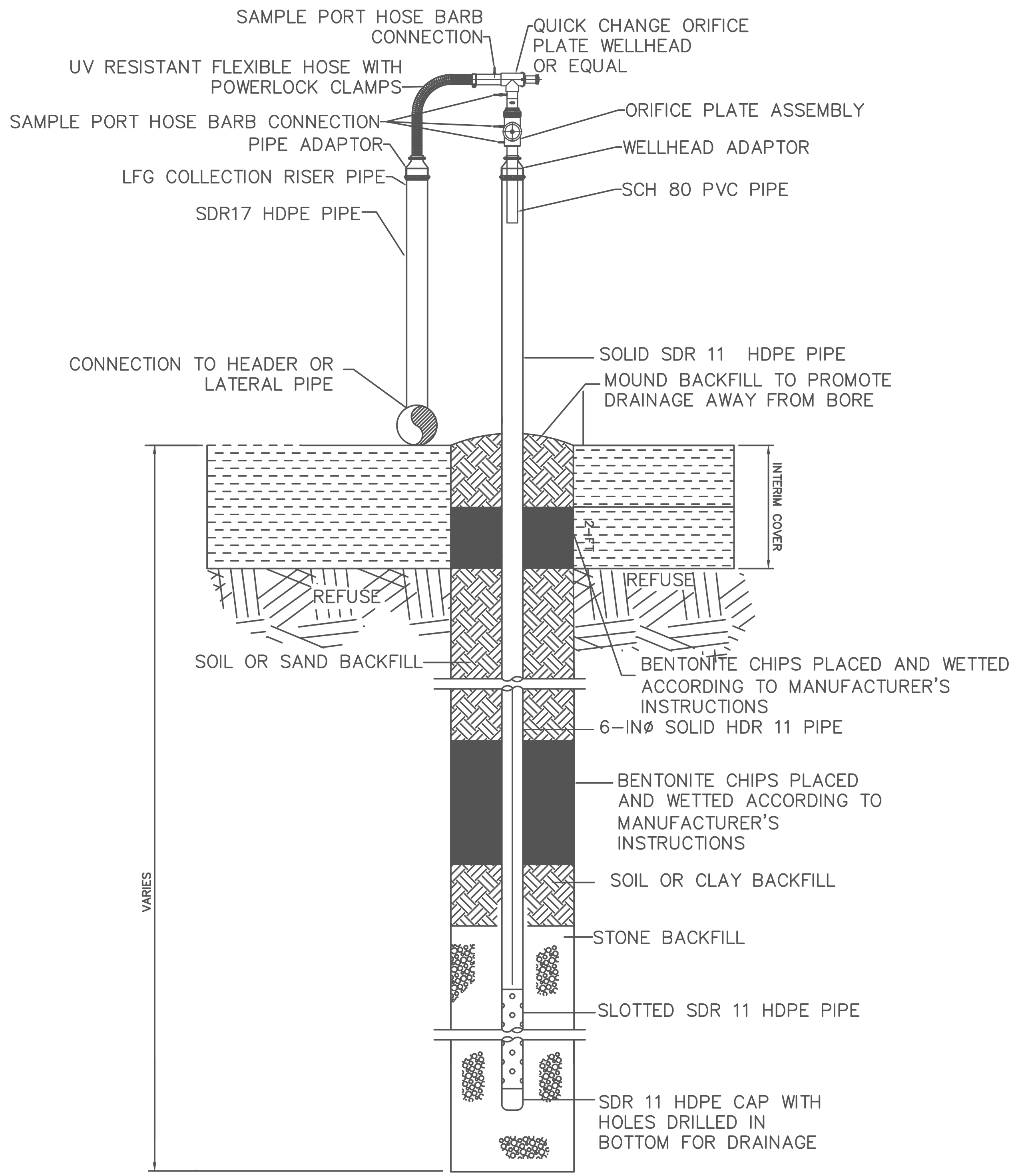
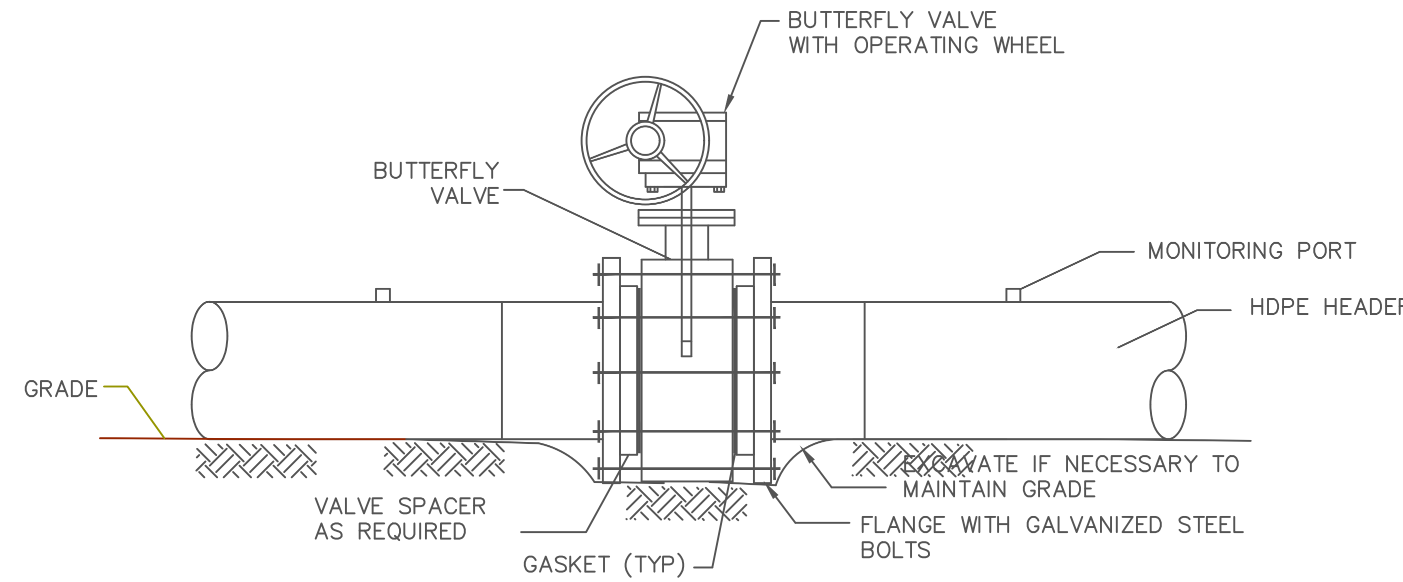
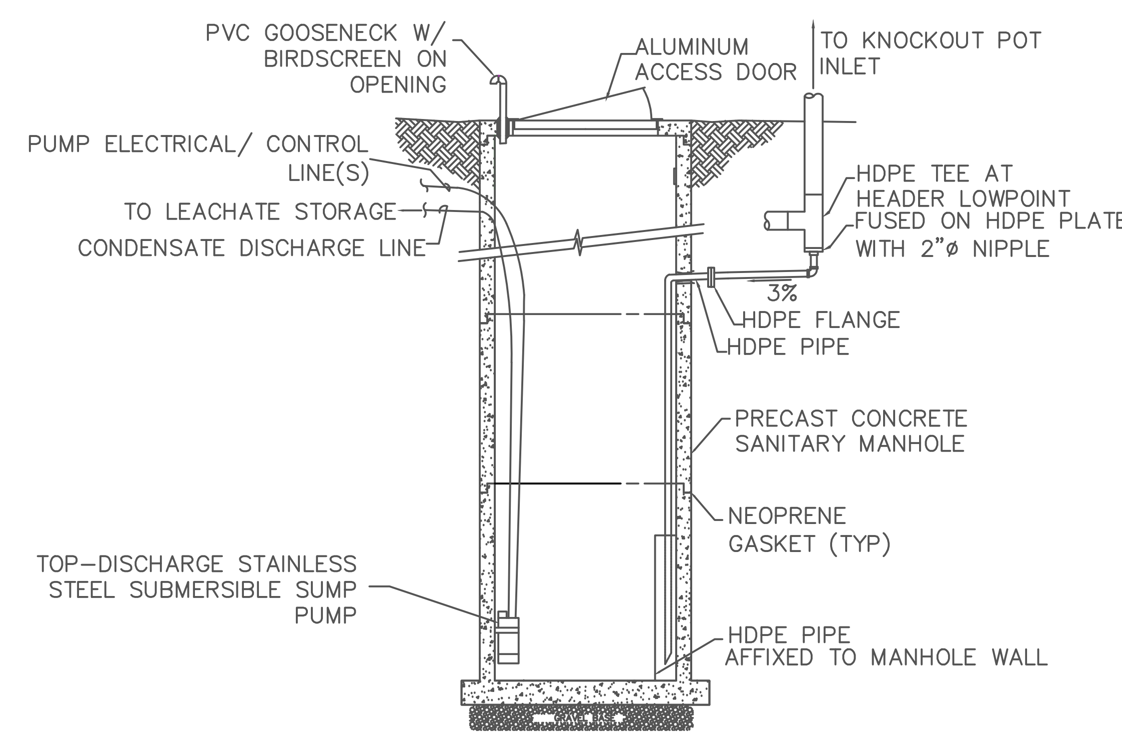


VERTICAL EXTRACTION WELL



ISOLATION VALVE



CONDENSATE SUMP

JAN 2025

GCCS DETAILS
LFG ASSESSMENT
CHEESEMANBURG LANDFILL
MONROVIA, LIBERIA

NOT FOR CONSTRUCTION

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APPENDIX 4

BUDGETARY PROJECT COST ESTIMATE

Budgetary Gas Collection and Control System Cost Estimate

Cheesemanburg Landfill

	AREA OF WORK	TYPE	UNIT	CLOSURE ESTIMATE These costs are in U.S. dollars, based on average costs in the U.S.				
				ESTIMATED QUANTITY	ESTIMATED PRICE PER UNIT ($)		EXTENDED COST($)	
PHASE I - 2030								
22	Gas Collection and Control System	New vertical extraction wells with wellhead	EA	16	$	10,000.00	$	160,000
23	Gas Collection and Control System	Collection piping and fittings	meter	1,000	$	135.00	$	135,000
24	Gas Collection and Control System	Condensate sumps and/or traps	EA	1	$	30,000.00	$	30,000
25	Gas Collection and Control System	Isolation Valves	EA	2	$	1,000.00	$	2,000
26	Gas Collection and Control System	Blower/flare station - 2,700 m^3/hr	EA	1	$	350,000.00	$	350,000
					Subtotal		**$**	**680,000**
PHASE II - 2035								
22	Gas Collection and Control System	New vertical extraction wells with wellhead	EA	16	$	10,000.00	$	160,000
23	Gas Collection and Control System	Collection piping and fittings	meter	1,350	$	135.00	$	182,250
24	Gas Collection and Control System	Condensate sumps and/or traps	EA	0	$	30,000.00	$	-
25	Gas Collection and Control System	Isolation Valves	EA	2	$	1,000.00	$	2,000
					Subtotal		**$**	**350,000**
PHASE III - 2040								
22	Gas Collection and Control System	New vertical extraction wells with wellhead	EA	15	$	10,000.00	$	150,000
23	Gas Collection and Control System	Collection piping and fittings	meter	650	$	135.00	$	87,750
24	Gas Collection and Control System	Condensate sumps and/or traps	EA	2	$	30,000.00	$	60,000
25	Gas Collection and Control System	Isolation Valves	EA	2	$	1,000.00	$	2,000
					Subtotal		**$**	**300,000**
PHASE IV - 2045								
22	Gas Collection and Control System	New vertical extraction wells with wellhead	EA	32	$	10,000.00	$	320,000
23	Gas Collection and Control System	Collection piping and fittings	meter	1,850	$	135.00	$	249,750
24	Gas Collection and Control System	Condensate sumps and/or traps	EA	0	$	30,000.00	$	-
25	Gas Collection and Control System	Isolation Valves	EA	0	$	1,000.00	$	-
					Subtotal		**$**	**570,000**
MISCELLANEOUS								
27	General Condition	Bonds and insurance (3%)	EA	1	$	20,400.00	$	20,400
28	Engineering and Bidding	Engineering and bidding	EA	1	$	40,000.00	$	40,000
29	Construction Quality Assurance	Construction quality assurance	EA	1	$	200,000.00	$	200,000
30	Surveying	Construction and CQA surveying	LS	1	$	20,000.00	$	20,000
		(Includes Phase I + Miscellaneous)			**INITIAL COST SUBTOTAL**			**$970,000**
					10% CONTINGENCY			**$97,000**
					INITIAL COST TOTAL			**$1,067,000**