PRE-FEASIBILITY STUDY TO ASSESS THE POTENTIAL LFG RECOVERY AT THE WHEIN TOWN

City of Monrovia, Liberia

Prepared by
Jose Luis Davila Cavazos
Consultant

4400 Creede Drive
Austin, Texas 78744

Phone: +1 (602) 820-2972
Email: pepedavila@yahoo.com

November 30, 2024

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 Whein Town 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 pre-feasibility study to assess the potential recovery of landfill gas from the Whein Town landfill including: the assessment of the current waste disposal site, including its technical aspects (i.e., stormwater, leachate, and landfill management) and historical waste disposal sequence and quantities, and develop a conceptual design for a landfill gas management system.

Site Assessment

The main objective of this activity was to present an analysis of the documentation gathered through publicly available information and data provided by various project stakeholders. In addition, an assessment of the technical aspects related to current site conditions, landfill operations, stormwater, leachate and landfill gas management was performed during the site visit the week of March 25, 2024.

Whein Town Landfill is located approximately 25 kilometers northeast of the Monrovia city center in Paynesville at 10 to 20 meters above sea level. The access to the landfill is located approximately 0.9 km west of the Monrovia-Kakata Highway. Whein Town Landfill has been in operation since 2008 and is expected to closed late 2025. The site property is approximately 41 acres. There waste disposal limits are composed of two areas, the old dump site, Cell 0, approximately 6 acres and the engineered cell, Cell 1, approximately 8 acres.

Whein Town Landfill can be classified as an unmanaged deep final disposal site per IPCC criteria. Cell 0 does not have a bottom line, while Cell1 was constructed with a bottom liner system and a leachate collection system. In addition, there are several leachate ponds that formed part of the leachate treatment system sized to treat up to 300 m^3/day with a Biological Oxygen Demand (BOD) loading of 1,800 kg/day. These ponds were not inspected during the site visit because access was restricted to that area of the landfill due to the fire hazard.

Stormwater controls is limited to an informal stormwater ditch at the bottom of the slope where leachates seeps are comingling with stormwater. Also, most of the waste had no soil cover, though historical aerial photographs show that cover material was placed on the waste several times over the years. During the site visit, the site presented a fire on the waste mass that covered 30% of the site. It was reported that the fire is been burning for several months. No landfill gas controls were observed on the site.

Preparation of Landfill Gas Assessment Report

The LFG assessment contains LFG generation and recovery projections. These projections forecast the amount of LFG 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 as well as observations made during the site visit the week of March 25, 2024 regarding current site conditions, waste disposal practices, and site operations. The following table presents the LFG model results from 2026-2043.

LFG Model Results Whein Town Landfill

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	340	170	0.3	11,181
2027	270	135	0.2	8,894
2028	221	111	0.2	7,289
2029	187	93	0.2	6,144
2030	161	81	0.1	5,312
2031	143	71	0.1	4,694
2032	128	64	0.1	4,222
2033	117	58	0.1	3,851
2034	108	54	0.1	3,551
2035	100	50	0.1	3,302
2036	94	47	0.1	3,090
2037	88	44	0.1	2,904
2038	83	42	0.1	2,738
2039	79	39	0.1	2,589
2040	74	37	0.1	2,452
2041	71	35	0.1	2,326
2042	67	34	0.1	2,209
2043	64	32	0.1	2,100

Note: Projected LFG recovery rates are in m3/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. IF the flaring project is implemented can potentially provide a reduction of approximately 38,821 tonnes CO2eq/yr from 2026-2030.

Preliminary Conceptual Closure Plan

In order to have a successful LFG recovery project and to mitigate environmental impacts a conceptual closure plan is necessary. The plan contains a conceptual design and budgetary capital cost estimations for the closure of Whein Town Landfill. The plan was prepared using industry standards, best management practices and the information collected during the site assessment. This plan includes the following: The final grading plan, stormwater management features, leachate management and control, LFG management and control.

The project capital costs were estimated based on the preliminary conceptual closure plan. The unit prices used were developed from similar projects developed in the United States and abroad. The following table presents a summary of the capital costs.

Closure Plan Budgetary Capital Cost Estimate

Area of Work	Total
Earthwork	$507,532
Geosynthetics	$884,250
Stormwater Management	$356,239
Leachate Management	$187,000
Gas Collection and Control System*	$686,500
Miscellaneous	$341,687
Capital Cost Subtotal	**$2,963,207**
10% Contingency	**$ 296,321**
Total Capital Cost	**$3,259,528**

This Budgetary Capital Cost includes cost up to flaring the LFG, does not include the cost related to the LFG utilization project. These cost most be developed upon determining if a utilization project is feasible.

LFG Utilization Assessment

Two potential opportunities for LFG utilization were identified during the assessment:

- Direct use project at the Coca Cola Bottling Company. This would be the project that requires the smallest investment, but further investigation is needed to learn if Coca Cola's energy needs and equipment requiring fuel such as boilers, or ovens. This project can provide 170 m^3/hr of LFG the first year with a decaying amount every year.

- Electricity generation project interconnected at the Paynesville Substation approximate 8 km away from the Landfill. Further evaluation is needed to determine if existing transmission line has the capacity to accept the energy generated form the project. Model results estimate a very limited amount of energy available for electricity production. 100 kW project from 2026 through 2044. The investment cost for an LFGE project is approximately USD 2.5 million/MW, plus an additional cost for interconnection. At 100 kW, this project will thus cost about USD 250,000 plus the cost of interconnection to the grid.

Recommendations

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

- More than half of the estimated capital cost are cost that could have been avoid if proper operations of the site have been following industry standards and best management practices. It is important that personnel in charge of operations of the site are technical capable for the management of the site, and that an adequate budget is set for a sustainable operation of the site.
- Use this assessment as a tool to seek for potential financing and contract arrangements. Full engineering design will be necessary prior to project implementation.
- Try to eliminate the high occurrences of smoldering fires by placing cover soil. Smoldering fires make difficult the estimation of LFG generation and recovery, since it is impossible to estimate the extent of these fires and determine the amount of organic waste consumed by these fires. In addition, landfill fires generate $PM_{2.5}$ and other pollutants which impacts negatively the air quality of the city. Likewise, landfill fires can become uncontrollable rapidly which can lead to losses of human lives and property.
- Maintain access roads to all areas of the site so that vehicles and heavy equipment can access such areas more safely and in a timely matter.
- Maintain and regrade side slopes at 3H:1V while placing waste to minimize the chances of waste slides and mitigate cover soil erosion.
- Applying daily cover to the waste whether with soil or tarps will help mitigate the incidence of vectors (flies, birds, rodents, etc.) on the waste, also mitigating any potential spread of infections.

Priority Actions

Priority actions provide guidance on how some of the current and existing issues can be mitigated and a successful LFG project can be reached.

1. Recontouring of the waste mass to maximum side slopes of 3:1 (H:V). This is important to mitigate slope erosion, potential slope failure as current slopes do not present any particular pattern and this makes it impossible for the placement of a proper final cover system.

2. Placement of a final soil cover layer. The proposed final cover system requires a 30 cm soil layer on top of the waste (this is typically an intermediate cover layer used on most sites). Placement of this layer will help mitigate leachate generation, presence of vectors, and odor control. The type of soil used will preferably be of low permeability (high clay content) and should be placed in layers of 10 cm, properly compacted. The placement of this soil cover layer must be done after the recontouring of the waste has been completed.

3. Placement of the geosynthetics and soil layer on top of geosynthetics will have to be done in conjunction to the installation of the GCCS. If the GGCS is not placed the accumulated gas under the liner will make the liner inflate like a balloon and you will have other operational problems.

4. Before moving forward with the LFG utilization project, you must review the LFG model assumptions to determine if any of these have changed, if they have changed it is important to run the model again to determine how much the model has change.

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

INTRODUCTION

The pre-feasibility study to assess the potential LFG recovery and utilization at the existing Whein Town Landfill located in the vicinity of the City of Monrovia is being 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 pre-feasibility study to assess the potential recovery of landfill gas from the Whein Town landfill including: the assessment of the current waste disposal site, including its technical aspects (i.e., stormwater, leachate, and landfill management) and historical waste disposal sequence and quantities, and develop a conceptual design for a landfill gas management system.

SITE ASSESSMENT

The site assessment included the review of documentation provided by Monrovia City Corporation (MCC) 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 provided by the Monrovia City Corporation (MCC), was gathered from online public sources, and 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. Environmental Impact Assessment Whein Town Landfill Facility, May 2008, provided by EPA.
4. Operations and Maintenance Guidelines and Environmental Management Plan for The Whein Town Sanitary Landfill Facility, July 2010. Downloaded from the World Bank Website.
5. Whein Town Landfill Gas Recovery Clean Development Mechanism (CDM) Project, Project Design Document, 2006 and Environmental and Social Management Plan (ESMP) March 2011.
6. Google Earth Aerial Images from 2008 thru 2023.
7. 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 Whein Town landfill 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 present the location of the city.

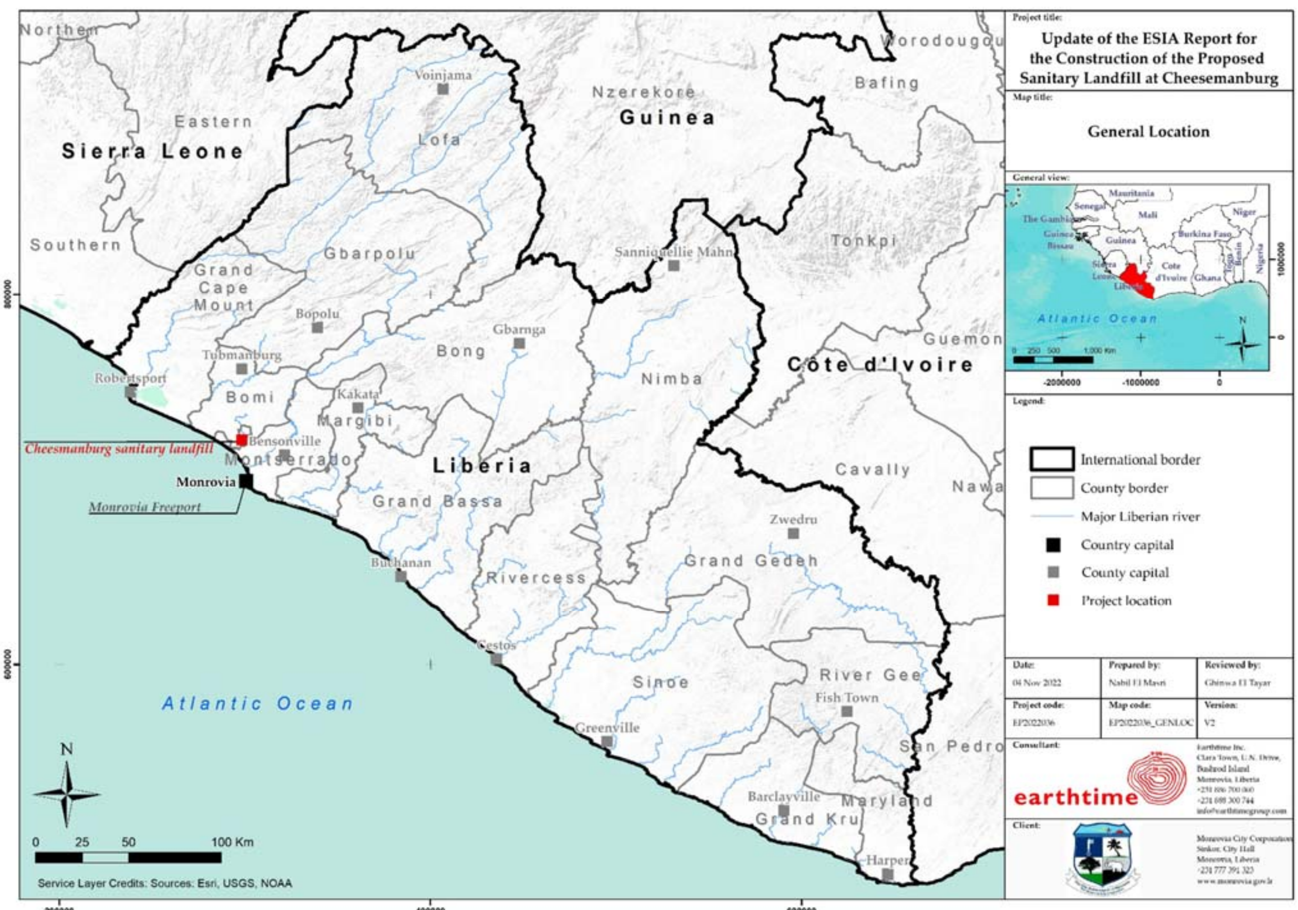


Figure 1. City of Monrovia Location

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 approximately 25 kilometers northeast of the Monrovia city center in Paynesville at 10 to 20 meters above sea level. The access to the Site is located approximately 0.9 km west of the Monrovia-Kakata Highway. These transfer stations are used primarily for temporary storage of waste and to transport waste to the landfill in larger trucks.

A new Cheesemanburg landfill is in the design stage. EPA has provided some comments on the design and these comments are being incorporated on the design. Some clearing of vegetation at the new property to prepare for construction has been completed as of the time of the site visit.

Figure 2 presents the location of the active landfill, future landfill and two transfer stations.

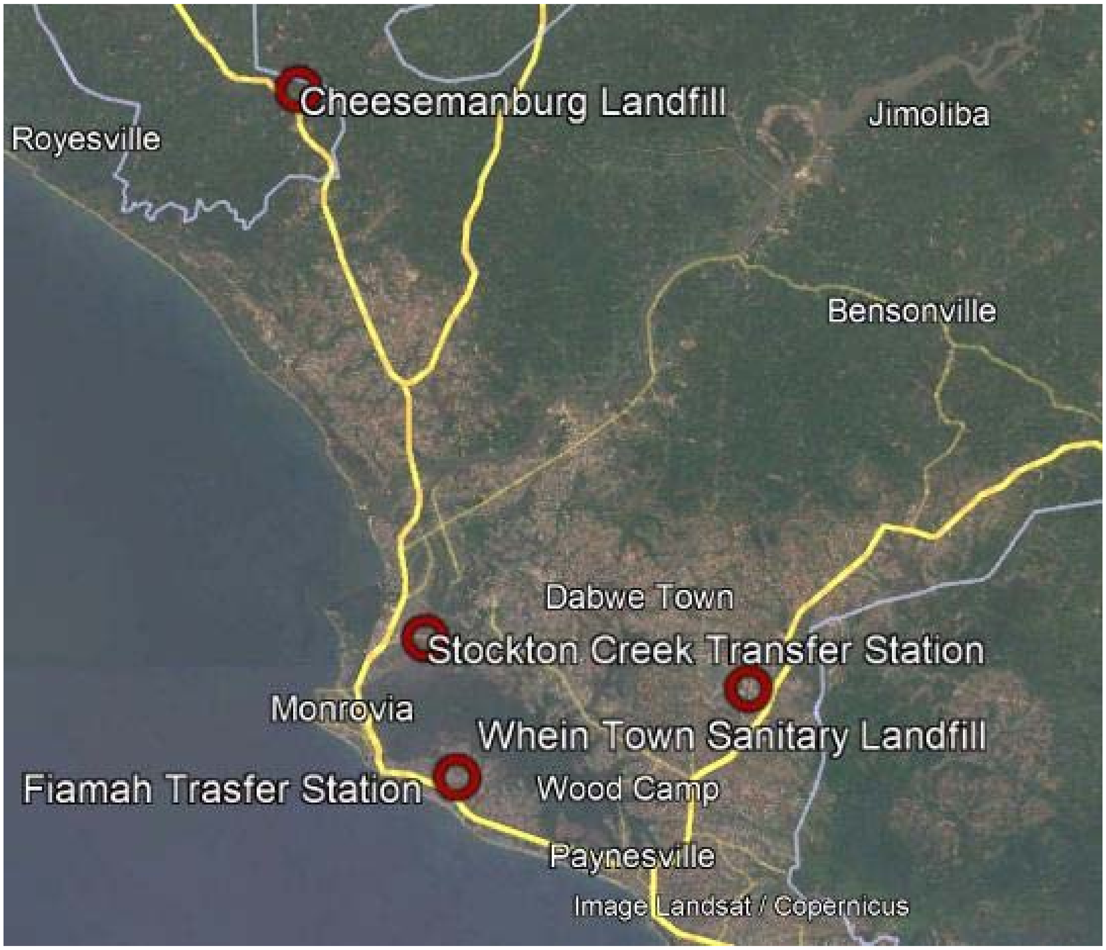


Figure 2. Waste Disposal Site Locations

Site Description

Whein Town Landfill has an area of approximately 41 acres, waste disposal limits are composed of two areas, the old dump site, Cell 0, approximately 6 acres and the engineered cell, Cell 1, approximately 8 acres. Figure 3 presents the current site layout, delineated in green is the property limits, delineated in red the waste limits for Cell 0 and Cell 1, in cyan 11 leachate ponds, in blue is the scale house and offices and in yellow the security check point.

Figures 4 through 10 presents current conditions of most site infrastructure mentioned before.

At the time of the visit Whein Town Landfill was not receiving any waste due to issues with an extensive fire that covers the northern slopes of waste disposal area (Cell 0 and Cell 1), and the firefighting activities that were taking place (see Figure 11). MCC reported that waste was being temporarily store at the two transfer stations: Stockton Creel and Fiamah until fire conditions are controlled to restart waste disposal. It was reported that the fire started during the dry season in around January 24, 2024. This situation also limited the areas that we were able to visually inspect on the site.

At the time of the visit, there was a small group of scavengers that was sorting thru waste in an area near the scale house just south of the two small leachate ponds.

As you can see in Figure 3 the site is surrounded by residential areas and commercial properties. No mayor surface water features are closed to the Site. Figure 4 through Figure 13 present the main features of the landfill site.

Figure 3. Site Layout


Figure 4. Main Entrance to the Landfill


Figure 5. Main Access Road


Figure 6. Weighbridge and Office Building


Figure 7. Security Checkpoint


Figure 8. View of Cell 0 Slopes


Figure 9. View of Cell 1


Figure 10. Main Access Road to the Landfill


Figure 11. Firefighting activities on Cell 1


Figure 12. Main Access Road to the Landfill


Figure 13. Exposed Waste on Cell 0

Site History

This section is based on observations made on the historical aerial photographs available in google earth and some of the statements made by the individuals that were interviewed during the site visit.

1. Cell 0 (Open Dump Site) was operational sometime from 2008 thru the construction of Cell 1 in early 2012.
2. In late 2009 there were two large leachate ponds constructed in the current area of Cell 1.
3. Cell 1 construction was completed in January 2012, the two large leachate ponds were replaced by 6 smaller leachate ponds located, two were located near the newly constructed scale house and office and four leachate ponds west of Cell 1.
4. In late 2012 one more leachate pond was constructed in the area west of Cell 1.
5. At the end of 2014 the engineered Cell 1 area was fully covered with solid waste.
6. In February 2015 soil was placed over the waste in the eastern part of the engineered Cell 1.
7. January 2016, aerial photograph presents waste over the soil that was placed in 2015.
8. January 2018, aerial photograph presents solid waste disposal activities in Cell 0.
9. January 2020, soil was placed in most of the top of the waste piles in both Cell 0 and Cell 1.
10. February 2021, aerial photograph present solid waste disposal activities in both Cell 0 and Cell 1, but mostly in Cell 0.
11. October 2021, waste disposal activities in Cell 1.
12. December 2022, waste disposal activities in Cell 0.
13. It was reported by EPA that a fire that covers most of the solid waste disposal area started in January 2024. There were firefighting activities taking place during the site visit in March 2024.

Appendix 1 presents the eleven google earth aerial photographs of the site history described above.

It was reported by EPA that a fire that covers most of the solid waste disposal area (Cell o and Cell 1) started in late January 2024. At the time of the visit there were firefighting activities taking place.

Leachate Management

Leachate travels by gravity from Cell 1 to the leachate ponds. Several leachate ponds have been constructed throughout the life of the landfill as presented in the site history section of this document. Starting with 2 large ponds while they operated Cell 0. Then, when Cell 1 was constructed in the area of the two large ponds in early 2012, six smaller leachate ponds where constructed, by late 2012 one more pond was constructed to manage the leachate.

According to the Operations and Maintenance Guidelines and Environmental Management Plan leachate treatment ponds were sized to treat up to 300 m^3/day with a Biological Oxygen Demand (BOD) loadings of 1800 kg/day. To ensure acceptable BOD effluent loadings of less than 50 mg/l, the leachate treatment pond system will consist of the following treatment ponds:

- Two anaerobic ponds
- Two facultative ponds
- Four maturation ponds
- Two polish ponds

These features were not inspected during the site visit because access was restricted to that area of the landfill due to the fire hazard.

Landfill Gas Management

During the site visit, landfill gas management activities or infrastructure was not visible on site.

Stormwater Management

During the site visit, several excavated ditches at the toe of the slope were observed. These are used to manage stormwater runoff from the waste disposal area. Since the waste disposal area is currently with no cover or with a very poor soil layer, stormwater comingles with leachate at these ditches (See Figure 14 and Figure 15).

Figure 14. Stormwater Ditch Cell 0

Figure 15. Stormwater Ditch Cell 1

Relevant Data

Site Data

Whein Town Landfill has two waste disposal areas: Cell 0 (open dump) and Cell 1 (engineered landfill). Table 2 presents the area in acres for each of these cells and the time of operation for each area. The entire site is fenced with a 1.8 m high concrete block fence to prevent unauthorized access.

Table 1. Site Waste Disposal Areas

Waste Disposal Areas	Bottom Liner System	Period of Operation	Approximate Area (Hectares)
Cell 0	No	~2008 to Present	3.2
Cell 1	Yes	2012 to Present	4.4
		Total	**7.6**

According with the Environmental Impact Assessment (EIA) for Whein Town Landfill prepared in 2008 these are some of key site characteristics:

- Groundwater ranges between 3.0 to 3.45 m below natural ground.
- Closest surface water features are creeks as far as 2 km away,
- There are some springs used for drinking water by the local residents in the proximity of the site, but does not specified distances.
- During the raining season, May through end of October, there are some swampy areas at the site.
- Several creeks flow in the general area especially to the eastern side of the landfill. Most of these creeks flow in the N-S direction. The distances between the creeks and the proposed site range between 3 and 4 km.
- Site is located on the Paynesville Sandstone Formation (Dp). This formation is characterized by soil with higher silt and lower clay content which are not considered acceptable for use as landfill liner. These materials would not compact well and are highly erodible.

- A bottom liner system was placed on Cell 1 as shown on Figure 16.

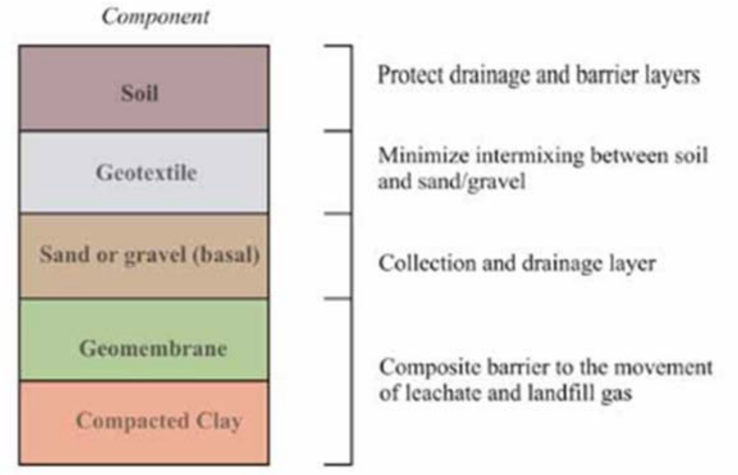


Figure 16. Bottom Liner System

- Based on the Operations and Maintenance Guidelines and Environmental Management Plan (EMP) for Whein Town Landfill (July 2010) there is a water well (located at coordinates 314 568.29 m E, 699 239.48 m N) at a point near the northwest corner of the property placed for water consumption by the locals (this was not confirmed due to the limited access to the site at the time of the visit). Figure 17 below provided on the EMP presents the location of some of the wells on the proximity of the site and the points where wetlands are present during raining season.

Figure 17: Water monitoring points (to be updated after final field work)

Appendix 2 provides the site visit checklist used to record current landfill conditions during the site inspection.

Waste Data

Table 3 presents te waste disposal data from three sources found during our online record research and data provided by MCC:

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

Based on waste disposal records from 2011 through 2023, 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. Waste collection is the responsibility of each town within the metropolitan area. During our 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 a good indication of waste collection coverage not being 100%.

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

Waste Characterization Data

Four municipal solid waste characterization studies were found in different documents available online. The documents found were 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 4 below provides a summary of the data. The documents from 2004, 2006 and 2008 have identical data and the 2012 document data is very similar with a few differences. In addition, for reference, data from the IPCC Guidelines for National Greenhouse Gas Inventories its included on the table. These waste characterization studies present categories of waste fractions. This data with some adjustments can 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 Data

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 and a dry season, but even the dry season gets precipitation. 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 1 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 utilization project. The following regulations and policies were found:

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

Table 5. Relevant Environmental Regulations

ID	Regulation
	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
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 CO2e per year by supporting the implementation of a landfill gas recovery system on When Town Landfill by 2022.
- Reduce emissions by 25.63 Gg CO2e per year by supporting the implementation of a landfill gas recovery system on Cheeseman burg Landfill by 2025.
- Reduce emissions by 0.84 Gg CO2e per year by supporting the development of small-scale composting of market waste with a production of 500 t/year each; by 2025.

Potential Use of The Landfill Gas

On March 27, 2024 at 3:30 pm, a meeting with Liberia Electricity Corporation (LEC) was held with Mr. D. Baccus Roberts, the General Services and Operations, Executive Director. LEC is a public utility created in 1973. This entity was developed with a mandate to produce and supply economic and reliable electric power to the entire nation. Therefore, they generate, transmit and sell power.

During the interview Mr. Roberts expressed great interest in the potential landfill gas to energy (LFGE) project as LEC is in need to increase their generation capacity. He 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.

During our discussion Mr. Baccus presented three possibilities for the LFGE interconnection:

- Direct use project at the Coca Cola Bottling Company. Further investigation will need to take place to learn about Coca Cola's energy needs and equipment requiring fuel such as boilers, or ovens.
- LFGE project interconnected at the Paynesville Substation approximate 8 km away from the Landfill.
- Mr. Roberts to evaluate if existing transmission line has the capacity to accept potentially a 1-MW LFGE project.

Information Needs

In order to continue with the evaluation and study as planned is necessary some additional information:

1. MCC manifested that they have a recent waste characterization study that they could share.

2. MCC to provide the latest topographic survey (in AutoCAD version) for Whein Town Landfill so I can estimate closure cost and prepare the conceptual design of the LFG system.
3. Liberia Electricity Corporation was going to research the best option for interconnection of a potential LFGE project.
4. MCC is currently updating the Cheesemanburg landfill design package due to EPA revision comments and recommendations, we need these to prepare the part of the project related to Cheesemanburg Landfill,

Observations

Whein Town Landfill average daily waste disposal rate has varied throughout its life from 200 to 460 tonnes/day. 460 tonnes/day was in 2015, it decreased to 234 tonnes/day in 2017 and started increasing again to reach 352 tonnes/day in 2020. These variations are not typical, and might indicate deficiencies on their solid waste collection coverage.

Whein Town Landfill can be classified as an unmanaged deep final disposal site per IPCC criteria. Even though the site was constructed as an engineered landfill with a bottom liner, the operation of the site has been such as a control dump. Whein Town Landfill does not have cover material, nor landfill gas management and the stormwater management is not up to industry standards as leachate seeping at the slopes can comingle with storm runoff.

A massive waste fire is been burning since late January 2024. To effectively exhaust a landfill fire is important to have soil cover on top of the waste. Something that it is not present in most of the waste disposal area.

Some waste has been placed outside the lined Cell 1 on the south side of Cell 1, see Appendix 1 Aerial Photograph from January 2018.

Recommendations

The following recommendations are activities MCC could take in consideration to improve the site conditions and the opportunity to have a more successful landfill gas utilization project:

- Lower sideslopes to at least 2.5:1 (horizontal:vertical) to be able to place compacted soil cover on top of the waste.
- Place soil cover in all areas to be able to exhaust the waste fire. Soil cover must be compacted so it stays in place as much as possible during rain events.
- Contour waste mass to provide for good stormwater drainage.
- Relocate waste that was placed outside the lined Cell 1(see Appendix 1 Aerial Photograph from January 2018), if not already performed.
- Maintain and reconditioned the perimeter access road to be able to access all points of the landfill at all times.

Access roads most be maintained regularly and with the used of proper construction materials, the use of boulders makes maintenance more difficult and deteriorates the waste trucks suspension system more quickly (see Figure 12).

LFG RECOVERY POTENTIAL

The LFG recovery and utilization assessment contains a forecast of LFG generation and recovery projections for Whein Town 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 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 and fire correction factor used on the IPCC Model, 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 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 collected 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 model 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. 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 having an annual rainfall of 3,582 mm (141 in) falls in the very wet category (>2,000 mm/yr) of the Colombia Model and is equivalent to the Colombia amazon region.

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 activities four municipal solid waste characterization studies were found in different documents available online. All waste characterization sources provide 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. Model 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.

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 for Whein Town Landfill

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

Based on the IPCC classification system, and the observations made during de site visit, Whein Town can be considered an unmanaged and over 5m deep site, therefore, the MCF of 0.8 is assigned.

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 is 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.

Table 8 presents the waste disposal data compiled up to 2023 and projections for 2024 and 2025 based on a 3.5% population increase (source: https://worldpopulationreview.com/cities/liberia/monrovia, United Nations population estimates and projections).

Table 8. Model Waste Disposal–Whein Town Landfill

Year	Annual Waste Disposal (tonnes/year)
Jun-Dec 2008	36,500
2009	109,500
2010	124,100
2011	26,930
2012	83,796
2013	94,868

Table 8. Model Waste Disposal–Whein Town Landfill

Year	Annual Waste Disposal (tonnes/year)
2014	86,921
2015	167,365
2016	127,042
2017	85,494
2018	126,730
2019	122,358
2020	128,644
2021	123,123
2022	122,824
2023	127,024
2024	131,369
2025	135,862

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 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 Whein Town Landfill.

Table 9. Model Collection Efficiency Calculations

	Collection Efficiency Calculations	Discount
Account for site management practices	85%	15% discount because the site was not operated as a managed landfill
Account for waste depth	85%	No discount because waste depth is >10 m
Account for wellfield coverage of waste area	85%	No discount as it is assumed the GCCS will cover all the waste area.
Account for cover type and extent	77%	Reduce collection efficiency by only 90%
Account for liner type and extent	77%	No discount as is assumed waste disposal was done over a liner system
Account for waste compaction	74%	3% discount as it is assumed compaction was not preformed properly
Account for focused tip area	72%	5% discount as it is assumed that there was not a dedicated tip area throughout the life of the landfill
Account for leachate	50%	22% discount as leachate seeps and pounding on the waste area is evident during the visit performed during dry season.
Calculated Collection Efficiency:	50%	

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.

Whein Town LFG Model Results

Table 10 below presents a summary of the model results for Whein Town Landfill from 2020–2043. LFG generation and recovery are projected to continue declining after 2025, once Whein Town Landfill is officially closed.

Table 10. LFG Model Results Whein Town Landfill

Year	LFG Generation (m^3/hr)	LFG Recovery (m^3/hr)	Maximum Power Plant Capacity (MW)	Methane Emissions Reduction Estimates (tonnes/CO_2eq/yr)
2020	272	0	0.0	0
2021	287	0	0.0	0
2022	297	0	0.0	0
2023	305	0	0.0	0
2024	316	0	0.0	0
2025	327	0	0.0	0
2026	340	170	0.3	11,181
2027	270	135	0.2	8,894
2028	221	111	0.2	7,289
2029	187	93	0.2	6,144
2030	161	81	0.1	5,312
2031	143	71	0.1	4,694
2032	128	64	0.1	4,222
2033	117	58	0.1	3,851
2034	108	54	0.1	3,551
2035	100	50	0.1	3,302
2036	94	47	0.1	3,090
2037	88	44	0.1	2,904
2038	83	42	0.1	2,738
2039	79	39	0.1	2,589
2040	74	37	0.1	2,452
2041	71	35	0.1	2,326
2042	67	34	0.1	2,209
2043	64	32	0.1	2,100

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

Figure 18, presents the model results in graphic form for Whein Town Landfill from 2008 through 2045.

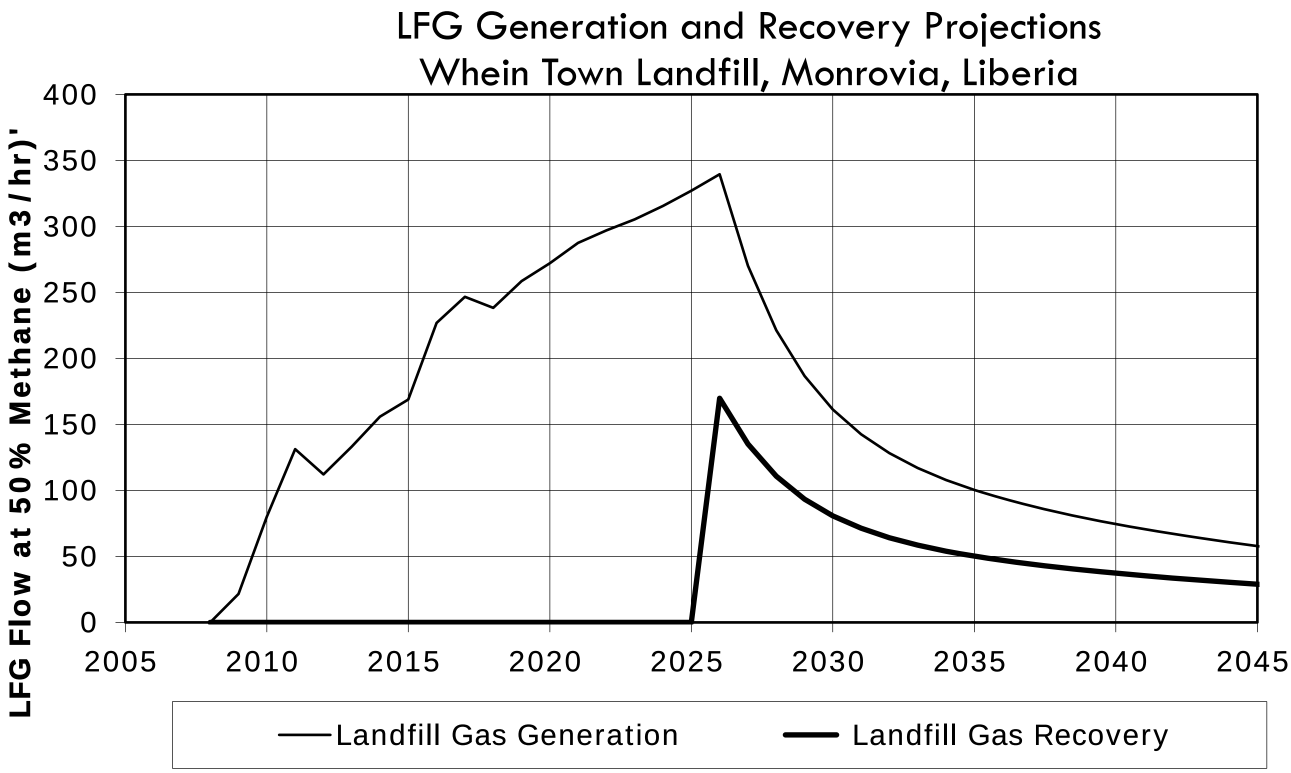


Figure 18. Whein Town Model Results

The maximum LFG recovery rate of 170 m^3/hr will be reached in 2026, one year after the closure of Whein Town Landfill. After 2026 LFG recovery rate will decrease rapidly. If this LFG is flared or given a beneficial use it can contribute to the reduction of approximately 84,556 tonnes of CO_2Eq from 2026 through 2046.

CONCEPTUAL CLOSURE PLAN

A conceptual closure plan was prepared based on Google Earth information, because the current topography was not available. This conceptual design most be considered conceptual and will have to be reviewed upon availability of a site topography. This closure plan was prepared using industry standards, best management practices and the information collected during the site assessment. The plan includes the following:

- Recontouring of the current waste disposal areas to mitigate potential slope stability issues.
- Final cover system to improve slope stability, minimize leachate generation and facilitate LFG recovery.
- Leachate management and control system to mitigate leachate impact in the surrounding areas and groundwater.

- Stormwater management to improve slope stability and minimize erosion to the final cover system.
- Landfill gas (LFG) management and control.

Recontouring of Waste Mass

Recontouring of the waste mass the most important step on the closure of Whein Town Landfill. Currently, most waste disposal areas present slopes approximately 1:1 (H:V) or steeper. The recontouring of the waste main goal is to provide slopes that are more stable and provide a based for the installation of the final cover system. The landfill surface will be graded to:

- Recontouring of approximately 6 ha where the waste mass is been place.
- A maximum sideslope of 3:1.
- One benches at 10 meters from the toe of the slope, Bench most be graded to 5% grade.
- A minimum slope of 5 percent at the top of the landfill, and
- An access road to provide post closure care access to the top of the landfill.

Final Cover System

The main objective of the proposed final cover system is to prevent infiltration of precipitation into the waste mass, minimizing leachate production. It also provides a barrier between the waste and the public and the environment. The final cover system will also increase LFG collection efficiency. The proposed final cover system from top to bottom, consist of the following elements from top to bottom:

- 45 cm of protective cover soil with the top 15 cm capable of supporting native plant growth
- Geosynthetics consisting of a drainage geocomposite having a minimum hydraulic conductivity of 10 cm/sec and a 40-mil (1 millimeter) linear low-density polyethylene (LLDPE) liner.
- 30 cm of soil cover placed over the waste before placement of the geosynthetics. The intermediate soil cover should consist of low-permeability soils placed to protect the integrity of the geosynthetics from the underlying waste.

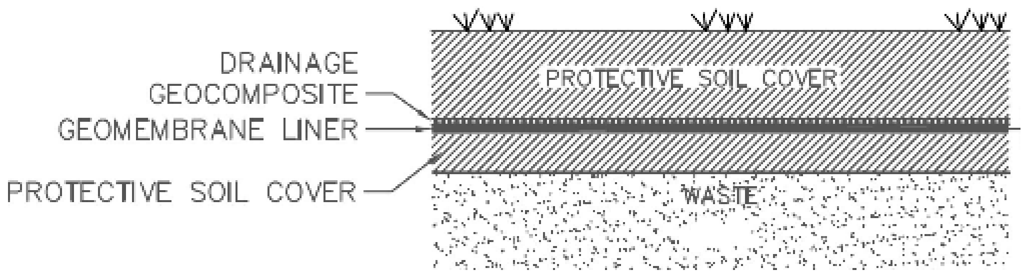


Figure 19. Proposed Final Cover System

Details for the final cover system are provided as part of the conceptual design drawings (see Appendix 4).

Leachate Management and Control

Leachate perimeter collection piping must be designed for conveying the estimated peak daily leachate generation flow prior to construction. The conceptual design for landfill leachate collection consists of a perforated pipe surrounded by gravel placed in the perimeter trench draining to leachate treatment area.

The leachate features must be properly sized based on the greatest peak daily leachate generation flow prior to construction. The general layout of the leachate management and control system is included in Appendix 4.

Stormwater Management

Stormwater management is important to minimize soil erosion and to minimize the generation of leachate created by stormwater infiltration through the final cover system. It is important that Whein Town have adequate slopes and stormwater run-off management features to avoid ponding of water and excessive soil erosion of the cover system.

The conceptual design drawings include a general layout and details for stormwater management features (see Appendix 4). Further stormwater run-off and conveyance analysis is recommended prior to closure construction to refine the quantity, layout, geometry and sizes for the stormwater conveyance and management features. Recommended stormwater conveyance and management features include:

- Perimeter ditch (channels) and pipes to convey stormwater run-off from the landfill to the stormwater pond with a longitudinal slope between 3% and 6% and sideslopes no greater than 25% to lessen the possibility of channel erosion. In addition, to assist in alleviating channel erosion, temporary matting along with grass seeding is recommended to be incorporated in ditch (channel) construction as well as riprap being placed in high flow or velocity areas.
- Site sideslope bench to collect and convey stormwater run-off, approximately 6 m wide and placed along the landfill slope at 10 m from the toe of the slope. It is recommended that the bench has a longitudinal slope between 3% and 5%. This bench can be constructed in the waste with soil cover or constructed of compacted soil placed on sideslope, also known as tack-on berms.
- Placement of six downslope drainpipes at low points along sideslope benches and at locations along the bench as needed to promote conveyance of stormwater from the

landfill. These pipes should be secured to the landfill at sufficient intervals with a soil mass or with other methods.

- 6,500 m^2 stormwater detention pond to accumulate stormwater conveyed from the site and release it over time, and to assist in the removal of sediment and other contaminants from stormwater run-off is ideal but due to site constrains there is no space to construct a stormwater retention pond in Whein Town. Medan will have to evaluate if additional land can be purchased to accommodate for stormwater retention on site. This feature is not included on the conceptual design. The current design run-off must be directed towards existing site surface water drainage features such as creeks, channels, and/or rivers.

Table 11. Summary of Main Elements of The Conceptual Closure Plan

Area of Work	Units	Amounts
Final cover system, soil and geosynthetics	ha	6.0
Stormwater management - Sideslope channel/berms	lm	1,100
Stormwater management - Downslope ditch	lm	480
Stormwater management - Erosion matting for sideslope ditches	m^2	960
Leachate Management - Perimeter Collection	lm	1,100
Access road	lm	100

Note: The quantities were estimated for budgetary purposes and must be reevaluated upon the availability of a Topographic map and a full engineering design.

Landfill Gas Management and Control

The LFG recovery projections were used to prepare a conceptual design for the GCCS (see Appendix 4). 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 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. 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.

- **Isolation Valves.** 4 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 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. The conceptual design considers two blowers with maximum capacity of 350 m^3/hr. Typically, the design is performed for the maximum LFG generation.

- **Control Device.** The control device can be an open or enclosed flare, using the Table # above we can establish the following the need for a flare with a capacity of 350 m^3/hr is needed. Typically, we design 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.

Table 11 presents a summary of the quantities needed to for each of the main elements for preliminary closure plan and Table 12 presents a summary of the quantities needed for the implementation of the GCCS:

Table 12. Main Elements Summary for Conceptual GCCS

Element	Amounts
Vertical extraction well	19
Header piping (m)	1000
Lateral piping (m)	500
Condensate sump	3
Isolation valve	4
Road crossing	1
Blower	1-350 m^3/hr
Flare	1-350 m^3/hr
Monitoring System	1

Closure Cost Estimate

Table 13 presents a summary of the project cost. Project cost was estimated based on the conceptual closure 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, some cost such as soil, are material costs provided by Medan. This cost estimate assumes the construction of the Area C and rehabilitation of the leachate treatment area under another project. A more detail capital cost estimate is presented in Appendix 5.

Table 13. Summary of Closure Plan Capital Cost

Area of Work	Total
Earthwork	$507,532
Geosynthetics	$884,250
Stormwater Management	$356,239
Leachate Management	$187,000
Gas Collection and Control System*	$686,500
Miscellaneous	$341,687
Capital Cost Subtotal	**$2,963,207**
10% Contingency	**$ 296,528**
Total Capital Cost	**$3,259,528**

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.

On March 27, 2024 at 3:30 pm, a meeting with Liberia Electricity Corporation (LEC) was held with Mr. D. Baccus Roberts, the General Services and Operations, Executive Director. LEC is a public utility created in 1973. This entity was developed with a mandate to produce and supply economic and reliable electric power to the entire nation. Therefore, they generate, transmit and sell power.

During the interview Mr. Roberts expressed great interest in the potential landfill gas to energy (LFGE) project as LEC is in need to increase their generation capacity. He 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.

During our discussion Mr. Baccus presented three possibilities for the LFGE interconnection:

- Direct use project at the Coca Cola Bottling Company. Further investigation will need to take place to learn about Coca Cola's energy needs and equipment requiring fuel such as boilers, or ovens.
- LFGE project interconnected at the Paynesville Substation approximate 8 km away from the Landfill.
- Mr. Roberts to evaluate if existing transmission line has the capacity to accept potentially a 1-MW LFGE project.

Model results estimate a very limited amount of energy available for electricity production. 100 kW project from 2026 through 2044. The investment cost for an LFGE project is approximately USD 2.5 million/MW, plus an additional cost for interconnection. At 100 kW, this project will thus cost about USD 250,000 plus the cost of interconnection to the grid.

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. IF the flaring project is implemented can potentially provide a reduction of approximately 38,821 tonnes CO_2eq/yr from 2026-2030. This do not include CO_2 emission reduced for substituting the use of fossil fuels.

APPENDIX 1 – HISTORICAL AERIAL PHOTOGRAPHS

December 2008, Cell 0 (Open Dump Site) was operational sometime from 2008 thru the construction of Cell 1 in early 2012.


January 2010, In late 2009 there were two large leachate ponds constructed in the current area of Cell 1.

January 2012, Cell 1 construction was completed in January 2012, the two large leachate ponds were replaced by 6 smaller leachate ponds located, two were located near the newly constructed scale house and office and four west of Cell 1.

January 2013, In late 2012 one more leachate pond was constructed in the area west of Cell 1.


January 2014, At the end of 2014 the engineered Cell 1 area was fully covered with solid waste.

February 2015, aerial photograph presents waste over the soil that was placed in 2015.

January 2018, aerial photograph presents solid waste disposal activities in Cell 0. It also shows waste being placed outside lined cell on the south edge of the engineered Cell 1.

January 2020, soil was placed in most of the top of the waste piles in both Cell 0 and Cell 1.

February 2021, aerial photograph present solid waste disposal activities in both Cell 0 and Cell 1, but mostly in Cell 0.

October 2021, waste disposal activities in Cell 1.

December 2022, waste disposal activities in Cell 0.

APPENDIX 2 - SITE VISIT CHECKLIST

Information	Checked	Comments
1. What is current Land Use?	X	Site is solely use for the solid waste disposal.
2. What are the neighboring Land Uses?	X	Mainly residential plots, with the exception of a plot of land on the south perimeter that seems to be agricultural.
3. What is the size of the site?	X	41 hectares property, 14 hectares dedicated to solid waste disposal.
4. What is the topography?	X	Area with some slopes but relatively flat bounded by hills elevation not exceeding 60 m above sea level.
5. Are there potential receptors (if yes, give details)?	X	There are several areas that are considered wetlands during raining season. There closest creeks are between 3 to 4 km from the site.
Houses	X	There are houses in around the most of the perimeter of the landfill.
Surface water features (if yes, distance and direction of flow)	X	There are no surface water features closed by, but it was reported that there is a water well in the landfill property. There closest creeks are between 3 to 4 km from the site.
Any wetland or protected areas	X	There are several areas that are considered wetlands during raining season, but are not considered protected.
Public Water Supplies		
Private Wells	X	There area several private water wells in the surroundings of the landfill property.
Services	X	There is electricity supply to the landfill property.
Other buildings	X	Weighbridge, office building, maintenance building, and security station.
Other		
6. Are there any potential sources of contamination (if yes, give details)?	X	There is potential contamination of groundwater from the leachate that comingles with stormwater at the stormwater ditches located at the toe of the slopes.
Surface waste (if yes, what type?)	X	Yes, litter was observed throughout the site, potentially due to blow outs and the lack of using daily cover.
Surface ponding of leachate	X	Some leachate was observed during our walk through the disposal area and the ditches at the toe of the slope.

APPENDIX 2 - SITE VISIT CHECKLIST

Information	Checked	Comments
Leachate seepage	X	Leachate seepage was observed during the site visit, even though it was during dry season.
Landfill gas odors	X	No landfill gas odors were identified, perhaps due to the large waste fire occurring since January and present during the site visit.
7. Are there any outfalls to surface water? (If yes, are there discharges and what is the nature of the discharge?)	X	None were observed.
8. Are there any signs of impact on the environment? (If yes, take photographic	X	No impact was observed, but not all areas of the landfill were available to inspect due to the fire hazard.
Vegetation die off, bare ground	X	None was observed.
Gas bubbling through water	X	None was observed.
Signs of settlement,	X	None was observed.
Subsidence areas	X	None was observed.
Drainage or hydraulic issues	X	The site doesn't seem to have a comprehensive stormwater management design, but again not all areas of the site were available for inspection.
Downstream water quality appears poorer than upstream water quality	X	Not Applicable.
9. Are there any indications of remedial measures?	X	Not Applicable.
Capping	X	At the time of the site visit most of the waste disposal area was uncovered.
Landfill gas collection	X	No landfill gas management features exist at the time of the site visit.
Leachate collection	X	Leachate collection is done at the bottom of Cell 1 and transported by gravity to the leachate pond where is treated.
10. Describe fences and security features (if any)	X	There is a two-meter-high concrete fence in the perimeter of the site.
Any other relevant information?	X	Most of the North side of the solid waste disposal area is being on fire since January and continues. Firefighting activities were taking place the day of the site visit.

APPENDIX 3

LANDFILL GAS MODEL RESULTS

PROJECTION OF LANDFILL GAS GENERATION AND RECOVERY
WHEIN TOWN 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)
2008	36,500	36,500	0	0	0.0	0%	0	0	0.0	0.0	0	0	0
2009	109,500	146,000	21	13	0.4	0%	0	0	0.0	0.0	0	0	0
2010	124,100	270,100	80	47	1.4	0%	0	0	0.0	0.0	0	0	0
2011	26,930	297,030	131	77	2.3	0%	0	0	0.0	0.0	0	0	0
2012	83,796	380,826	112	66	2.0	0%	0	0	0.0	0.0	0	0	0
2013	94,868	475,694	133	78	2.4	0%	0	0	0.0	0.0	0	0	0
2014	86,921	562,615	156	92	2.8	0%	0	0	0.0	0.0	0	0	0
2015	167,365	729,981	169	99	3.0	0%	0	0	0.0	0.0	0	0	0
2016	127,042	857,023	227	134	4.1	0%	0	0	0.0	0.0	0	0	0
2017	85,494	942,517	247	145	4.4	0%	0	0	0.0	0.0	0	0	0
2018	126,730	1,069,247	238	140	4.3	0%	0	0	0.0	0.0	0	0	0
2019	122,358	1,191,605	258	152	4.6	0%	0	0	0.0	0.0	0	0	0
2020	128,644	1,320,249	272	160	4.9	0%	0	0	0.0	0.0	0	0	0
2021	123,123	1,443,372	287	169	5.1	0%	0	0	0.0	0.0	0	0	0
2022	122,824	1,566,196	297	175	5.3	0%	0	0	0.0	0.0	0	0	0
2023	127,024	1,693,220	305	180	5.5	0%	0	0	0.0	0.0	0	0	0
2024	131,369	1,824,589	316	186	5.6	0%	0	0	0.0	0.0	0	0	0
2025	135,862	1,960,451	327	192	5.8	0%	0	0	0.0	0.0	0	0	0
2026	0	1,960,451	340	200	6.1	50%	170	100	3.0	0.3	0	532	11,181
2027	0	1,960,451	270	159	4.8	50%	135	79	2.4	0.2	0	424	8,894
2028	0	1,960,451	221	130	4.0	50%	111	65	2.0	0.2	0	347	7,289
2029	0	1,960,451	187	110	3.3	50%	93	55	1.7	0.2	0	293	6,144
2030	0	1,960,451	161	95	2.9	50%	81	47	1.4	0.1	0	253	5,312
2031	0	1,960,451	143	84	2.5	50%	71	42	1.3	0.1	0	224	4,694
2032	0	1,960,451	128	75	2.3	50%	64	38	1.1	0.1	0	201	4,222
2033	0	1,960,451	117	69	2.1	50%	58	34	1.0	0.1	0	183	3,851
2034	0	1,960,451	108	63	1.9	50%	54	32	1.0	0.1	0	169	3,551
2035	0	1,960,451	100	59	1.8	50%	50	30	0.9	0.1	0	157	3,302
2036	0	1,960,451	94	55	1.7	50%	47	28	0.8	0.1	0	147	3,090
2037	0	1,960,451	88	52	1.6	50%	44	26	0.8	0.1	0	138	2,904
2038	0	1,960,451	83	49	1.5	50%	42	24	0.7	0.1	0	130	2,738
2039	0	1,960,451	79	46	1.4	50%	39	23	0.7	0.1	0	123	2,589
2040	0	1,960,451	74	44	1.3	50%	37	22	0.7	0.1	0	117	2,452
2041	0	1,960,451	71	42	1.3	50%	35	21	0.6	0.1	0	111	2,326
2042	0	1,960,451	67	39	1.2	50%	34	20	0.6	0.1	0	105	2,209
2043	0	1,960,451	64	38	1.1	50%	32	19	0.6	0.1	0	100	2,100
2044	0	1,960,451	61	36	1.1	50%	30	18	0.5	0.1	0	95	1,997
2045	0	1,960,451	58	34	1.0	50%	29	17	0.5	0.0	0	91	1,901
2046	0	1,960,451	55	32	1.0	50%	27	16	0.5	0.0	0	86	1,810
2047	0	1,960,451	52	31	0.9	50%	26	15	0.5	0.0	0	82	1,724
2048	0	1,960,451	50	29	0.9	50%	25	15	0.4	0.0	0	78	1,643
2049	0	1,960,451	48	28	0.8	50%	24	14	0.4	0.0	0	75	1,566
2050	0	1,960,451	45	27	0.8	50%	23	13	0.4	0.0	0	71	1,493
2051	0	1,960,451	43	25	0.8	50%	22	13	0.4	0.0	0	68	1,424

Colombia Landfill Gas Model v.1

Release Date: September 2010

Developed by SCS Engineers for the U.S. EPA Landfill Methane Outreach Program

PROJECTION OF LANDFILL GAS GENERATION AND RECOVERY
WHEIN TOWN 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)
2052	0	1,960,451	41	24	0.7	50%	21	12	0.4	0.0	0	65	1,359
2053	0	1,960,451	39	23	0.7	50%	20	12	0.4	0.0	0	62	1,297
2054	0	1,960,451	38	22	0.7	50%	19	11	0.3	0.0	0	59	1,238
2055	0	1,960,451	36	21	0.6	50%	18	11	0.3	0.0	0	56	1,182

MODEL INPUT PARAMETERS

Assumed Methane Content of LFG: 50%

Methane Correction Factor (MCF): 0.8

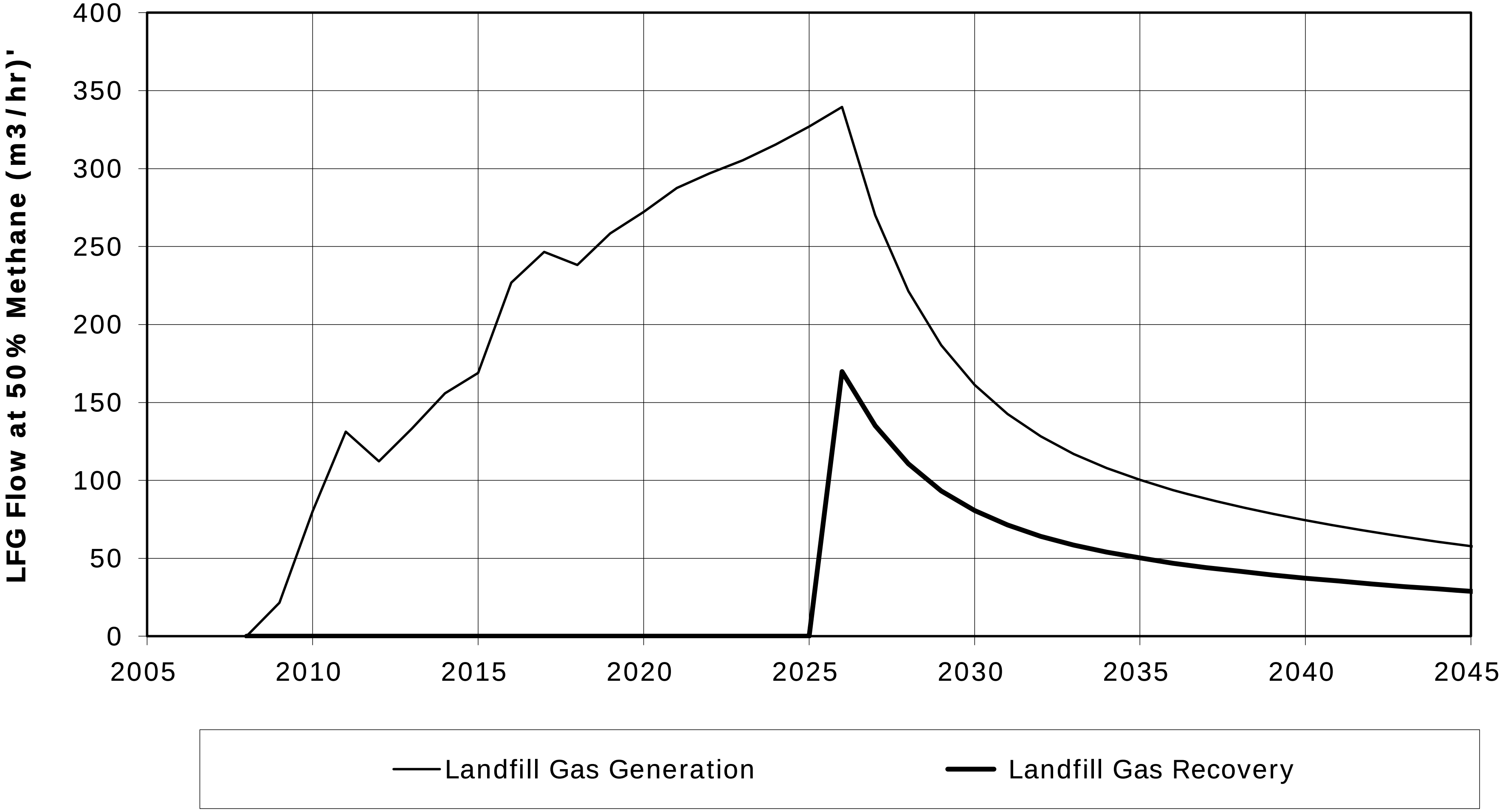
Waste Category:	Fast Decay	Moderately Fast Decay	Moderately Slow Decay	Slow Decay
CH4 Generation Rate Constant (k):	0.400	0.170	0.070	0.035
CH4 Generation Potential (Lo) (m3/Mg):	17	22	39	48

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
Whein Town Landfill, Monrovia, Liberia



1/27/2025

APPENDIX 4

LANDFILL GAS SYSTEM CONCEPTUAL DESIGN

LEGEND

- PROPERTY LIMITS
- WASTE LIMITS
- ACCESS ROADS
- LEACHATE PONDS

N

BASE ON GOOGLE EARTH AERIAL PHOTOGRAPH, DATED DEC 2022

1:2500
SCALE

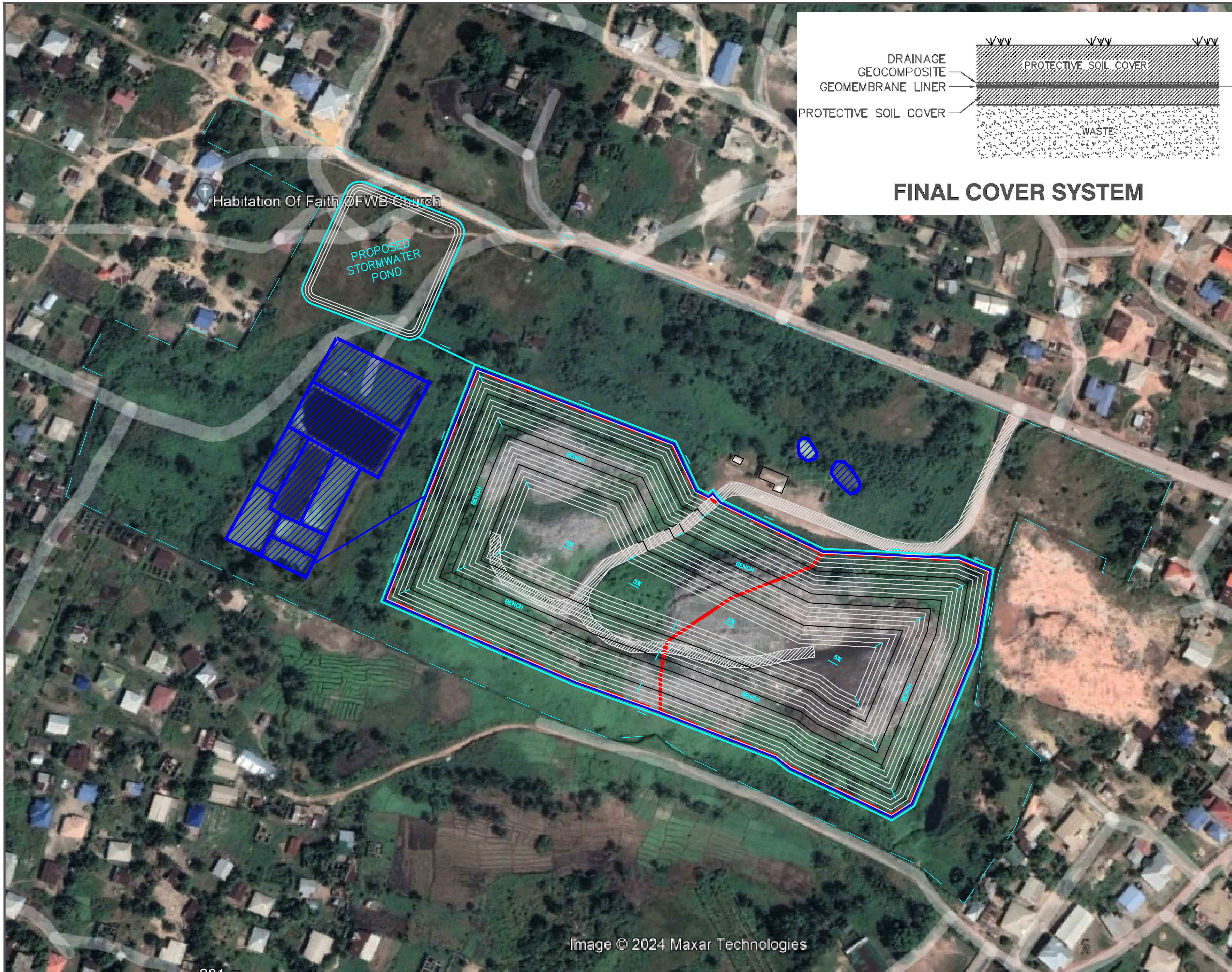
DATE JAN 2025

FIGURE 1 of 5

EXTISTING CONDITIONS
LFG ASSESSMENT
WHEIN TOWN LANDFILL
MONROVIA, LIBERIA

NOT FOR CONSTRUCTION

JOSE LUIS DAVILA
INDEPENDENT CONSULTANT
4400 CREEDE DRIVE
AUSTIN, TEXAS, 78744
PHONE: +1 (602) 820-2972
pepedavila@yahoo.com



LEGEND

- PROPERTY LIMITS WASTE
- LIMITS ACCESS ROADS
- LEACHATE PONDS
- LEACHATE COLLECTION DITCH
- STORMWATER DRAINAGE
- CONTOUR LINES

N

BASE ON GOOGLE EARTH AERIAL PHOTOGRAPH, DATED DEC 2022

1:2500
SCALE

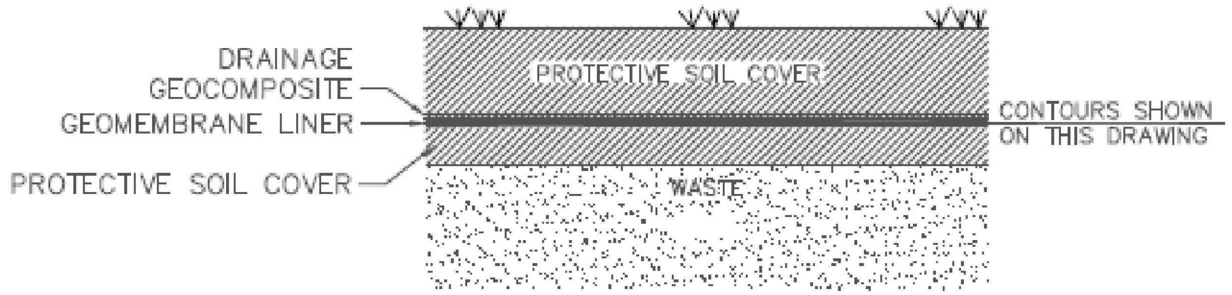
DATE JAN 2025

FIGURE 2 of 5

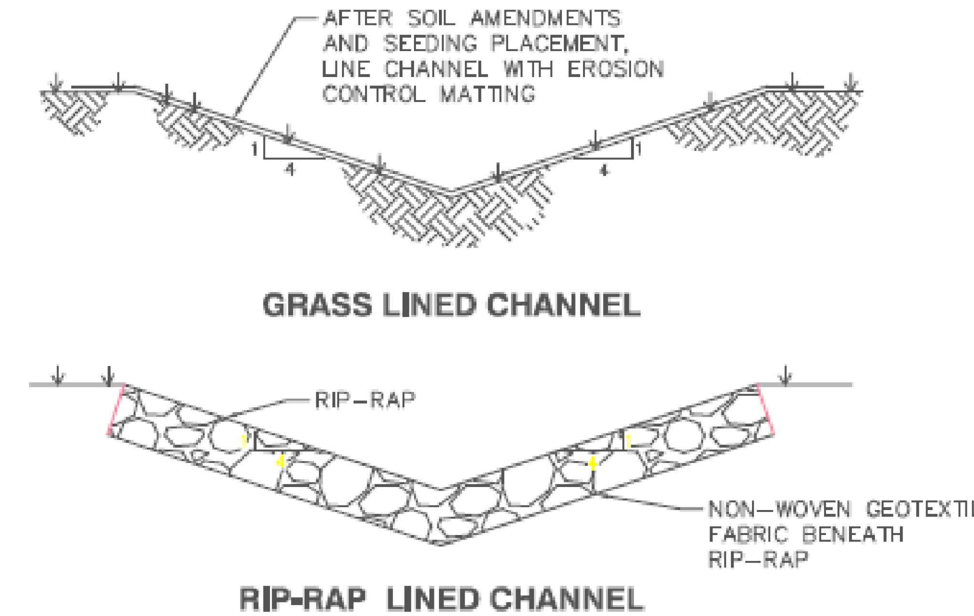
CONCEPTUAL RECONDITIONING PLAN
LFG ASSESSMENT
WHEIN TOWN LANDFILL
MONROVIA, LIBERIA

NOT FOR CONSTRUCTION

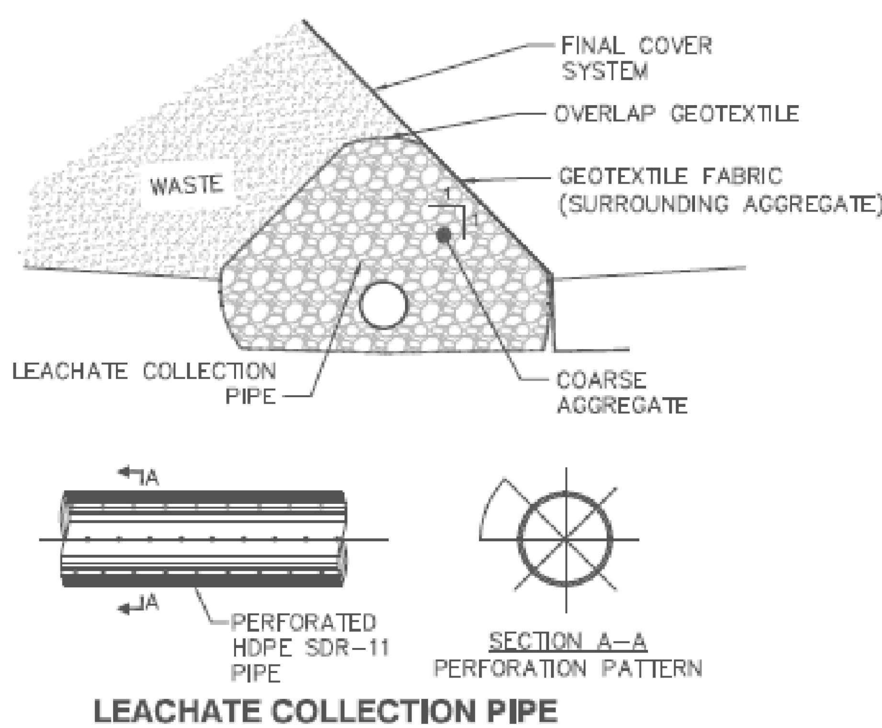
JOSE LUIS DAVILA
INDEPENDENT CONSULTANT
4400 CREEDE DRIVE
AUSTIN, TEXAS, 78744
PHONE: +1 (602) 820-2972
pepedavila@yahoo.com



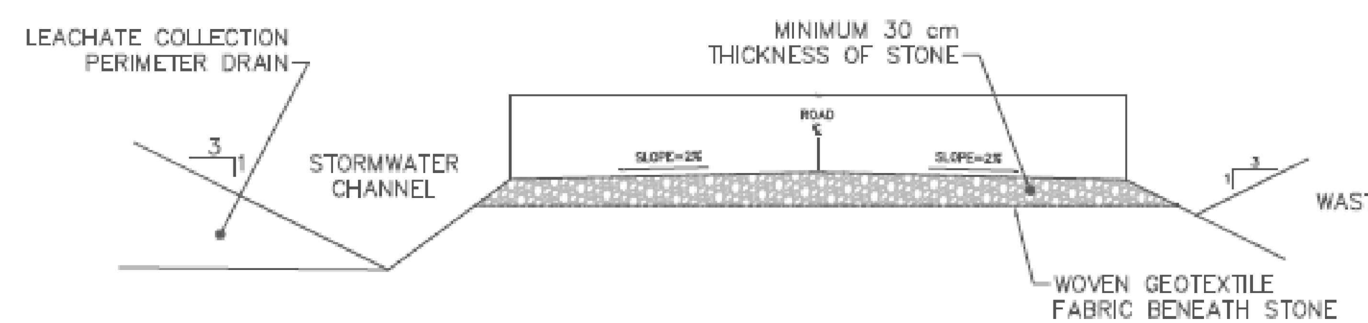
DETAIL 1
FINAL COVER SYSTEM



DETAIL 3
STORMWATER CHANNEL DETAIL



DETAIL 2
LEACHATE COLLECTION PERIMETER DRAIN



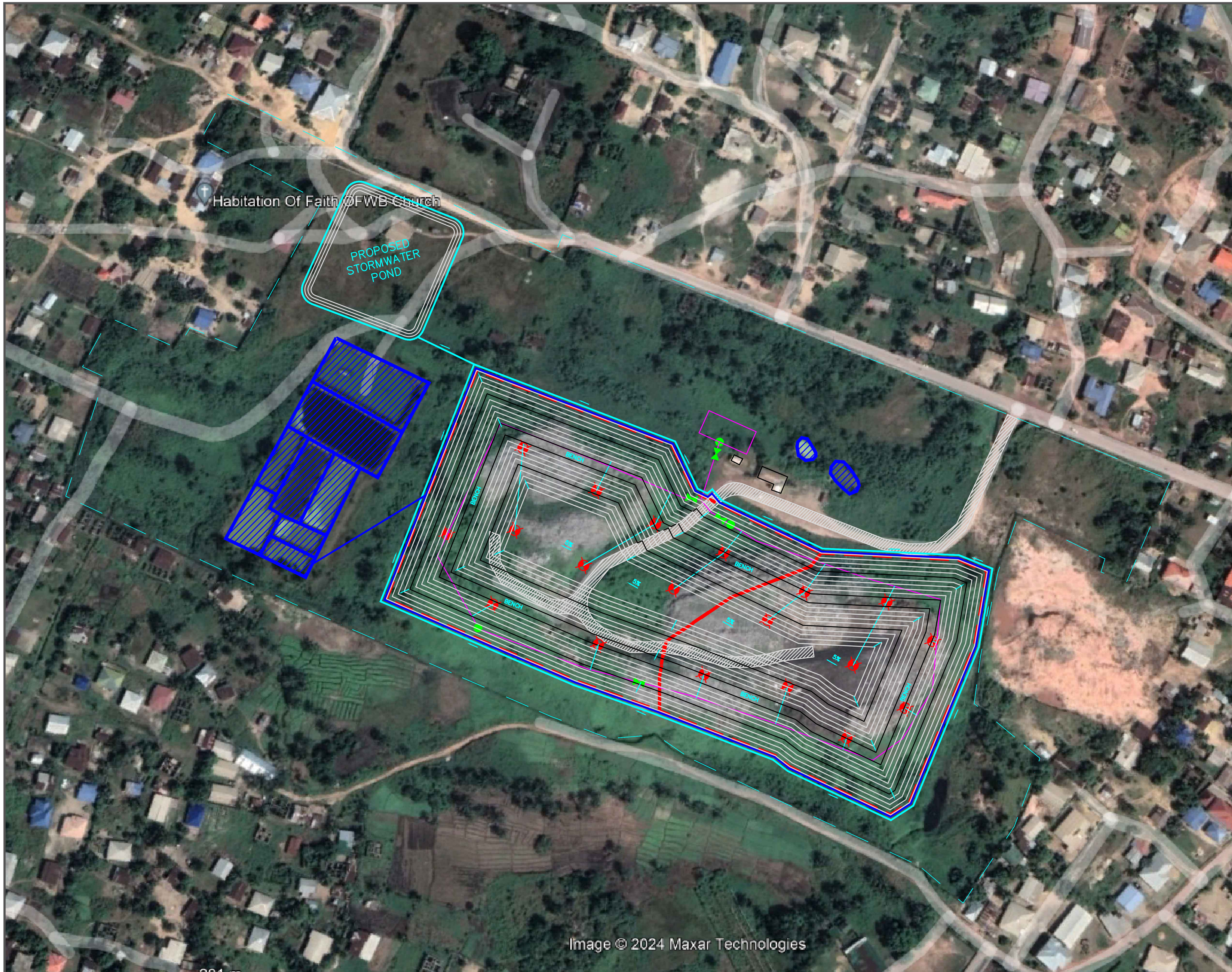
DETAIL 4
LANDFILL PERIMETER ROAD

DATE JAN 2025
FIGURE 3 of 5

CONCEPTUAL RECONDITIONING PLAN DETAILS
LFG ASSESSMENT
WHEIN TOWN LANDFILL
MONROVIA, LIBERIA

NOT FOR CONSTRUCTION

JOSE LUIS DAVILA
INDEPENDENT CONSULTANT
4400 CREEDE DRIVE
AUSTIN, TEXAS, 78744
PHONE: +1 (602) 820-2972
pepedavila@yahoo.com



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

1:2500
SCALE

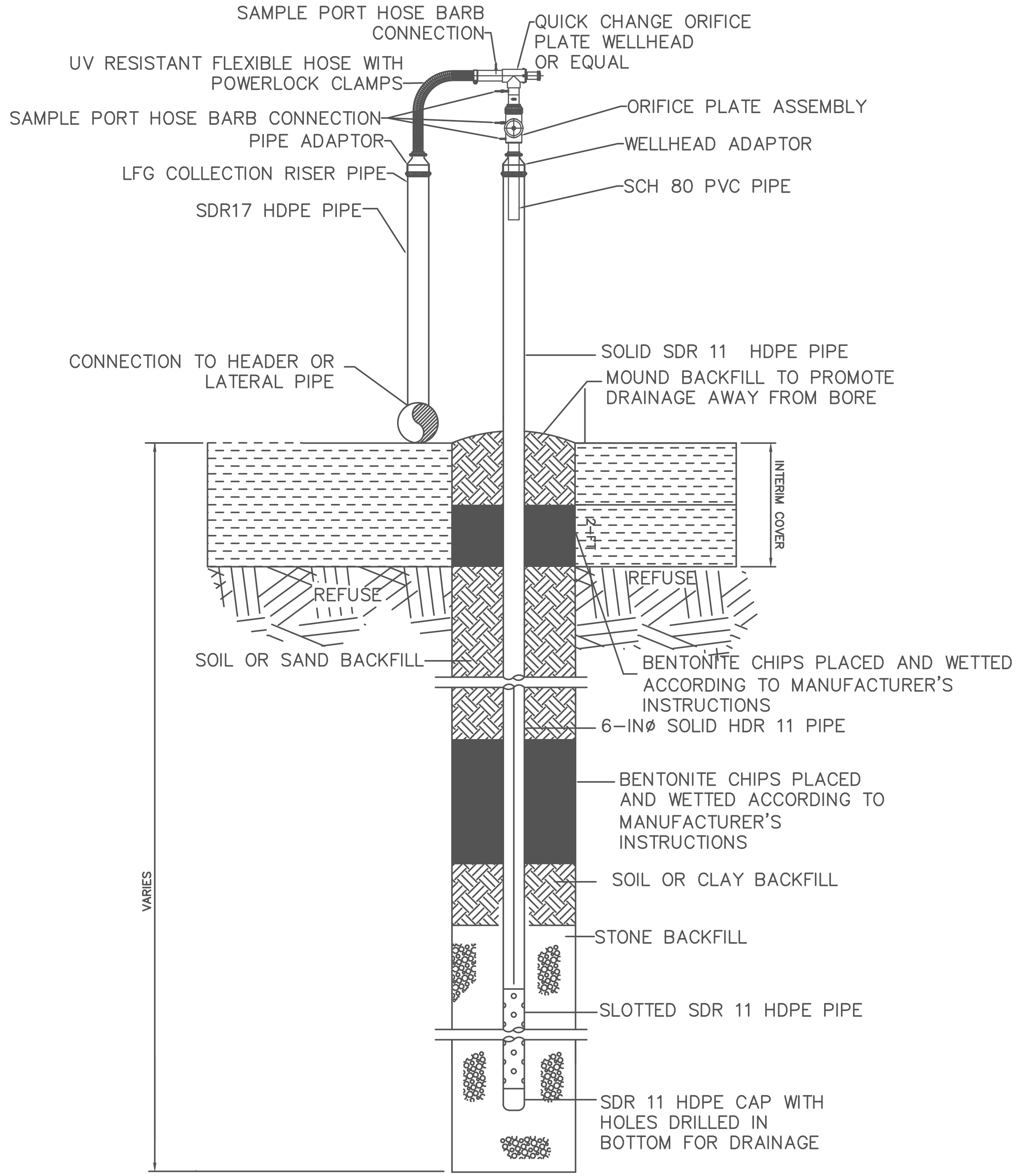
DATE
JAN 2025

FIGURE
4 of 5

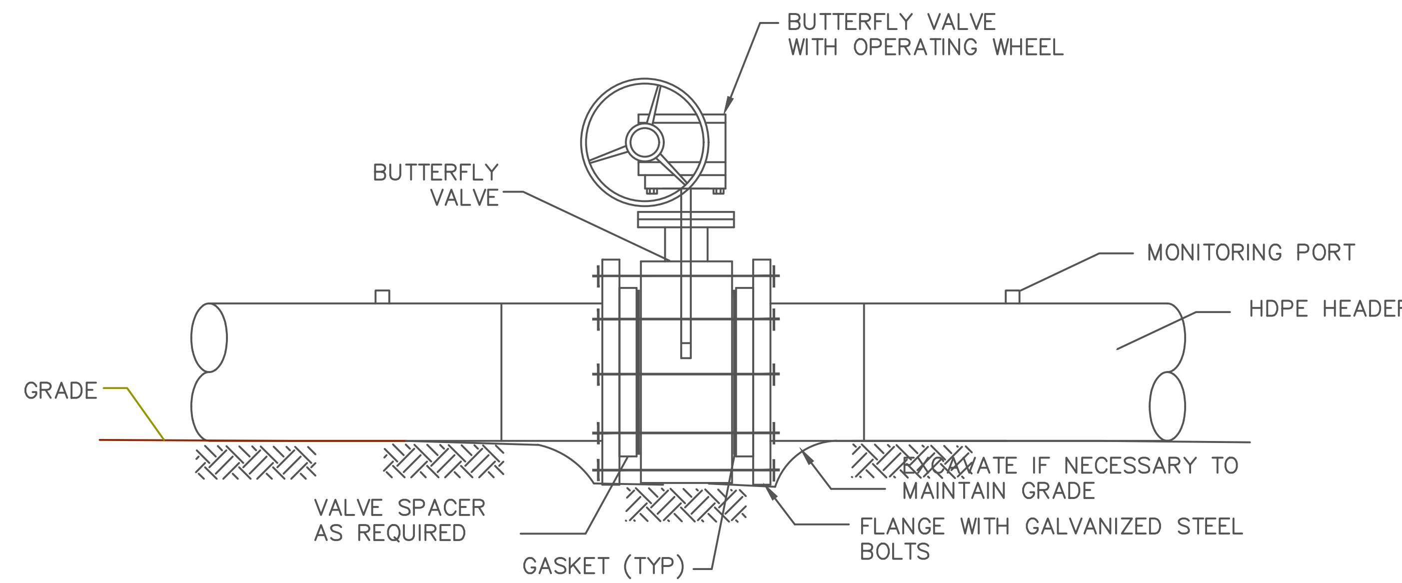
EXTISTING CONDITIONS
LFG ASSESSMENT
WHEIN TOWN LANDFILL
MONROVIA, LIBERIA

NOT FOR CONSTRUCTION

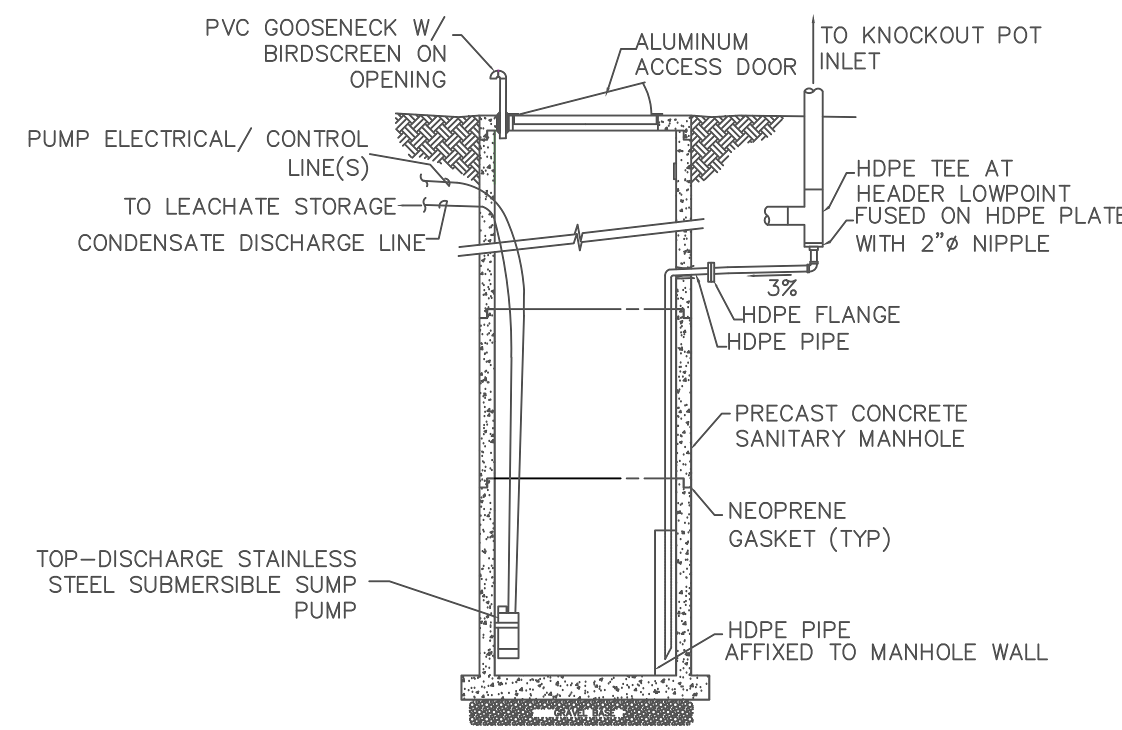
JOSE LUIS DAVILA
INDEPENDENT CONSULTANT
4400 CREEDE DRIVE
AUSTIN, TEXAS, 78744
PHONE: +1 (602) 820-2972
pepedavila@yahoo.com



DETAIL 5
VERTICAL EXTRACTION WELL



DETAIL 6
ISOLATION VALVE



DETAIL 7
CONDENSATE SUMP

GCCS DETAILS
LFG ASSESSMENT
WHEIN TOWN LANDFILL
MONROVIA, LIBERIA

NOT FOR CONSTRUCTION

JOSE LUIS DAVILA
INDEPENDENT CONSULTANT
4400 CREEDE DRIVE
AUSTIN, TEXAS, 78744
PHONE: +1 (602) 820-2972
pepedavila@yahoo.com

APPENDIX 5

BUDGETARY PROJECT COST ESTIMATE

Budgetary Project Cost Estimate

Whein Town Landfill

		Hectares
2D Area (m^2) =	60,000	6.00
3D Surface Area (m^2) =	65,000	6.50

	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 ($)	EXTENDED COST($)
EARTHWORK						
1	Mobilization/Demobilization	GC Mobilization (5%)	LS	1	$ 115,728.50	$ 115,729
2	Final Grade Preparation	Grading of Waste to 3:1 Slope	hectare	6.50	$ 3,500.00	$ 22,750
3	Soil Cap	Excavation and Soil Hauling from Soil Stockpile (30% increase for compaction and swell)	m^3	25,350	$ 2.48	$ 62,868
4	Soil Cap	Compacted intermediate soil cover installation	m^3	19,500	$ 6.12	$ 119,340
5	Geosynthetic Cap	Anchor trench material and installation	meter	1,100	$ 36.00	$ 39,600
6	Geosynthetic Cap	Toe drain installation	meter	1,100	$ 100.00	$ 110,000
8	Vegetative Cover	Protective soil and vegetative cover installation	m^3	9,750	$ 3.82	$ 37,245
GEOSYNTHETICS						
9	Mobilization/Demobilization	Installer Mobilization and Demobilization	LS	1	$ 10,000.00	$ 10,000
10	Geosynthetic Cap	Supply and Install LLDPE Textured Liner	m^2	65,000	$ 5.70	$ 370,500
11	Geosynthetic Cap	Supply and Install Drainage Geocomposite	m^2	65,000	$ 7.75	$ 503,750
STORMWATER MANAGEMENT						
12	Cap Stormwater Control	Sideslope Channel/Berms	meter	2,200	$ 35.00	$ 77,000
13	Cap Stormwater Control	Downslope Pipe	meter	480	$ 120.00	$ 57,600
14	Cap Stormwater Control	Sideslope pipe inlets	EA	12	$ 5,500.00	$ 66,000
15	Cap Stormwater Control	Seeding	hectare	6.50	$ 10,400.00	$ 67,600
16	Cap Stormwater Control	Erosion matting for sideslope berms	m^2	960	$ 1.90	$ 1,824
17	Cap Stormwater Control	Sideslope pipe outlets and riprap protection	EA	10	$ 2,500.00	$ 25,000
18	Perimeter Stormwater Control	Regrade perimeter ditch, install erosion matting and seeding	meter	1,100	$ 55.65	$ 61,215
LEACHATE MANAGEMENT						
19	Leachate Control	HDPE perforated and solid pipe and fittings includes stone and geotextile fabric	meter	1,100	$ 170.00	$ 187,000
GAS COLLECTION AND CONTROL SYSTEM						
22	Gas Collection and Control System	New vertical extraction wells with wellhead	EA	19	$ 10,000.00	$ 190,000
23	Gas Collection and Control System	Collection piping and fittings	meter	1,500	$ 135.00	$ 202,500
24	Gas Collection and Control System	Condensate sumps and/or traps	EA	3	$ 30,000.00	$ 90,000
25	Gas Collection and Control System	Isolation Valves	EA	4	$ 1,000.00	$ 4,000
26	Gas Collection and Control System	Blower/flare station - 350 m3/hr	EA	1	$ 200,000.00	$ 200,000
MISCELLANEOUS						
27	General Condition	Bonds and insurance (3%)	EA	1	$ 72,908.96	$ 72,909
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
31	Gravel Covered Access Road	Gravel covered access road	m^2	700	$ 12.54	$ 8,778
					CONSTRUCTION COST SUBTOTAL	**$2,963,207**
					10% CONTINGENCY	**$296,321**
					TOTAL CONSTRUCTION COST	**$3,259,528**
					COST PER HECTARE	**$501,466**