WATER REUSE AND ENVIRONMENTAL CONSERVATION PROJECT

CONTRACT NO. EDH–I–00–08–00024–00 ORDER NO. 04

AQABA WASTE MANAGEMENT AND LANDFILL DESIGN REPORT

October 2014

IMPLEMENTED BY AECOM

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OCTOBER 2014

Submitted to:

USAID Jordan

Prepared by:

AECOM

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LIST OF ACRONYMS

ASEZ	Aqaba Special Economic Zone
ASTM	Standard Test Method
BS	British Standard
ET	Evapotranspiration
FA	Feasibility Assessment
GCL	Geosynthetic Clay Liner
GoJ	Government of Jordan
HDPE	High Density Polyethylene
LandGem	Landfill Gas Emissions Model
LFG	Landfill Gas
LGP	Low Ground Pressure
MRF	Materials Recovery Facility
MSW	Municipal Solid Waste
PE	Polyethylene
PPE	Personal Protection Equipment
PVC	Polyvinyl Chloride
RCRA	Resource Conservation and Recovery Act
RCP	Reinforced Concrete Pipe Casing
ROI	Radius of Influence
SDR	Standard Dimension Ratio
SPT	Standard Penetration Test
USEPA	United States Environmental Protection Agency

1 INTRODUCTION

The USAID Water Reuse and Environmental Conservation Project works throughout Jordan in institutional capacity building, pollution prevention for industries, solid waste and wastewater management, and water reuse. The project goal is to protect and conserve scarce resources through regulation, education, and coordination with industry, local communities and the private sector. The project is implemented by AECOM and a team of international and Jordanian partner firms. This five-year project has four primary tasks:

- Task 1 – Institutional and Regulatory Strengthening
- Task 2 – Pollution Prevention and Industrial Water Management
- Task 3 – Disposal sites Rehabilitation and Feasibility Studies
- Task 4 – Water Reuse for Community Livelihood Enhancement , including biosolids

As part of Task 3, this Design Report presents the design for the Aqaba Landfill Facility. Aqaba City is a central industrial and tourist hub for Jordan, in addition to being home to the only port in the country. The city is expanding as investments pour into the local economy, and the population is increasing rapidly. As noted in a March 2014 project report, current municipal solid waste (MSW) generation rates in Aqaba City are at approximately 120 tons/day (*Aqaba Waste Management and Landfill Feasibility and Environmental Considerations Report*). This MSW is currently disposed of in an unlined landfill approximately 12 km south-southeast of Aqaba City and adjacent to the base of the Aqaba Mountains.

This Design Report addresses and outlines the technical requirements of the project and demonstrates that the design meets the goals for the project. More specifically, the purpose of this report is to:

- Provide a description of the current site conditions
- Present a discussion of the design strategies for Aqaba Landfill
- Identify the design criteria for the design
- Present design analyses and evaluations, in addition to drawings illustrating the components of the design

Design drawings are included in Appendix A.

1.1 Site Location

The Aqaba Landfill is approximately 12 km southeast of the City of Aqaba and 5 km east of the eastern section of the coastal flatlands of the Gulf of Aqaba, at the base of the mountains range (See Figure 1-1, Regional Map). The facility is in a very arid location characterized by very hot summers and mild winters. Annual average temperatures typically range from 24.6 to 26.6°C, reaching up to 41.8°C in summer. Rainfall is scarce in the area, with an average rainfall of 15.88 mm/yr. recorded for 2008-2012. The maximum annual rainfall recorded as 32.8 mm in 2012 (King Hussein International Airport Metrological Station, which is the nearest station to the study area).

The MSW landfill receives most of the MSW generated in the ASEZ. The operating hours of the disposal site are 16 hours/day (6 days/week), but the landfill receives tipping 24 hours per day (7 days/week). The landfill is accessed from approximately a 2.4 km long minor road off Route 15 major highway (See Figure 1-2, Site Location Map).

Figure 1-1: Regional Site Map

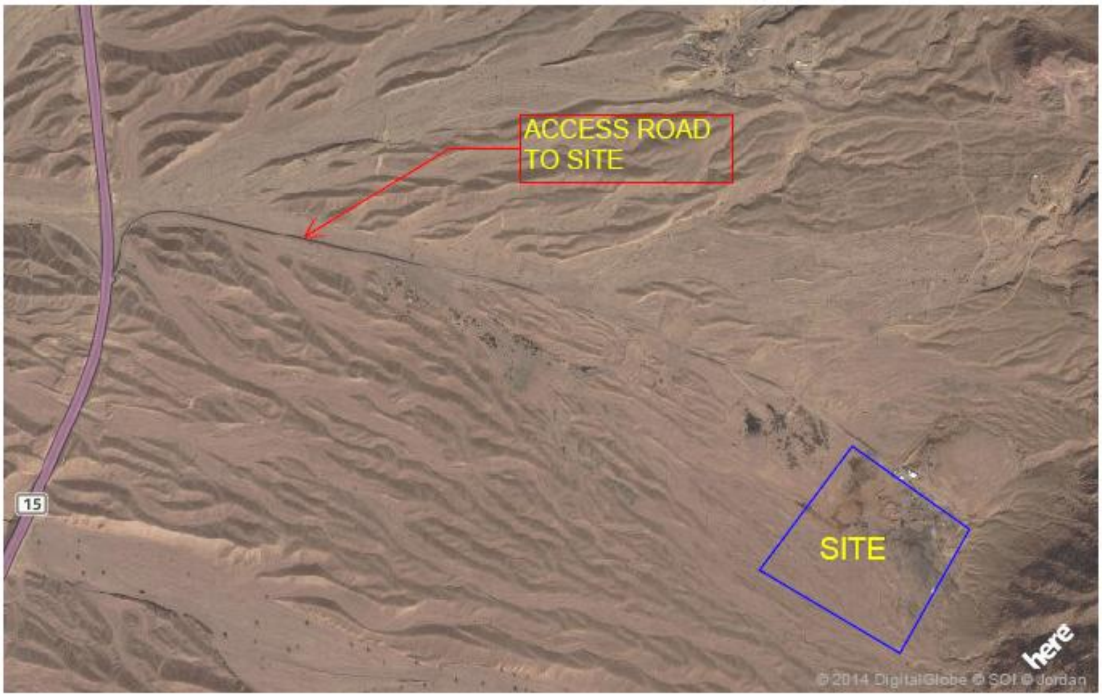

Figure 1-2: Site Location Map

1.2 Site Issues

The existing Aqaba Landfill is currently broken up into two areas, the Old Landfill site and the Active Landfill site. The Old Landfill site consists of blackened piles, which are the result of burning practices at the time of disposal in the 1980s, when waste was sometimes burnt and sometimes left without burning. Within the last few years, waste scavengers returned to the site and dug up some of this old waste to collect recyclables and left the site's soil cover disturbed and the old waste exposed.

Current waste recycling practices at the Active Landfill site consist of contracted laborers picking recyclables directly from the freshly dumped waste on the active working face of the landfill before it gets compacted and covered. This is not an acceptable or efficient method for recycling. This practice also poses potential health and safety risks for workers, such as exposure to contaminants, contact with vectors, and personal injury. Waste is also typically left uncovered and uncompacted, which is prohibited by Regulation No.27 for 2005.

In addition to being unlined, the existing landfill has no environmental controls to protect groundwater and air resources. This leaves the soil and air vulnerable to pollution and may expose landfill employees and users of the surrounding area to health risks. The lack of daily cover also raises concerns regarding vector breeding and landfill fires. Moreover, the site does not have a scale and lacks proper fencing and security to eliminate unauthorized access.

The primary challenge concerning the Aqaba site is to develop an integrated solid waste management plan, consisting of a waste segregation/treatment facility and a properly engineered sanitary landfill.

2 Overall Design Strategy

The design of the Aqaba landfill will be based primarily on the Resource Conservation and Recovery Act (RCRA) Subtitle D requirements. The Jordanian Ministry of the Environment (MoEnv) regulations and the Aqaba Special Economic Zone Authority (ASEZA) regulations were reviewed and used as general guidance, but were found not to include sufficiently detailed guidance for landfill design, construction, closure, and post closure care.

This Design Report for Aqaba landfill addresses the following components:

- Access control for site
- Material Recovery Area to replace current waste scavenging practices
- Re-utilization of existing waste/burnt waste/soil mass to allow for stabilization of existing in-place waste
- Design of individual landfill cells with the bottom of each cell sloping towards leachate collection system
- Design of a base geosynthetic liner to prevent liquids collected from entering subsurface soils and regional groundwater
- Design of leachate collection, conveyance and storage/treatment system
- Design of final grading plan to allow surface water drainage
- Design of final cap and storm water management system
- Design of landfill gas management system.

The design strategy is based on achieving the following objectives:

- Control the amount of infiltration of storm water through the landfilled waste by

  - Developing the landfill cells into distinct landfill cells with base slopes and sumps to capture leachate

  - Capping the landfill surface with an evapotranspiration (ET) cover

  - Installing a surface water management system consisting of open channels, chutes, culverts, and a lagoon

- Minimize potential landfill fires and control landfill gas migration by installing landfill gas wells and collection pipes; and,

- Excavate and utilized existing burnt waste/soil mix as daily cover material.

3 Access Control

3.1 Access Controls

Access controls that will be implemented to eliminate unauthorized access to the facility will consist of perimeter fencing, gates, and signage. Administrative measures will consist of the education of authorized personnel on site-specific security and health and safety concerns. Furthermore, a health and safety plan must be developed by the site operators.

3.2 Security and Fencing and Gates

Access to the site will be controlled by installing a security fence (minimum height 2000 mm) with a barbed extension section around the entire site with lockable security gates to prevent unauthorized access. Additional fencing may be installed around interior facilities (blower/flare system, materials recovery area, fuel dispensary, etc.) in order to restrict access to specific personnel and to reduce potential theft and vandalism. Regular inspection of boundary, gate(s) and fencing must be conducted and damage immediately repaired.

An adequate number of well-trained staff must be available on-site when the facility is open and the entrance shall be closed and locked during non-operating hours.

3.3 Signage

Based on typical landfill signage used across the United States, a facility sign must be permanently posted at the site entrance stating the name and purpose of the facility, the contact information for the responsible Owner/Operator, and the hours of operation. The sign must also include a list of wastes not allowed to be received or handled in the facility. These include:

- Asbestos
- Soluble wastes (e.g. fly ash or salts)
- Bulk liquids
- Sludge
- Batteries and PCBs (polychlorinated biphenyl)
- Pesticides and pesticide containers
- Oil and used/waste oil
- Hazardous wastes
- Biomedical and infectious wastes
- Corrosive, reactive and toxic wastes
- Electronic wastes
- Industrial and special wastes
- Radioactive material

Appropriate signage should also be placed around the landfill perimeter, stating the following:

- Unlawful entry and unauthorized scavenging are prohibited
- No smoking, burning or littering is allowed

Due to the length of the landfill access road from major highway Route 15, additional signage may be necessary to direct vehicles from Route 15 onto the access road to the landfill.

4 Support Facilities/Infrastructure

4.1 Access

The landfill will be accessed by waste haulers via the existing roadway from Route 15 to the proposed site entrance driveway. Incoming traffic will be directed by landfill personnel to either cross the weighing scales just inside the facility entrance or to bypass the scales. This arrangement will allow immediate visibility of incoming/egressing traffic to operations personnel stationed at the facility entrance. A paved entrance driveway of sufficient width for two-way vehicle traffic, queuing area, scale facility area, and ramp to the landfill are proposed. Crushed stone or gravel surfacing (typically 150mm to 230mm thick, depending on anticipated loads) is proposed for all other areas requiring vehicle access and parking. Two-way gravel surfaced roads will also be constructed around the landfill perimeter and onto the landfill development surface.

4.2 Scale House and Landfill Management Building

In order to minimize construction cost, security responsibilities, and long-term O&M a single facility is proposed for use as the Scale House and Landfill Management Building. The building will be of sufficient size to include the communications equipment, computers, offices, convenience and locker room facilities, and storage areas to accommodate the weigh master, landfill management team, and landfill operators/laborers. The building elevation will be such that the weigh master may visually inspect incoming waste loads through window(s) as vehicles cross the scale in addition to facilitating direct communication with waste haulers. The building will be equipped with external/internal lighting, portable fire extinguishers, and appropriate personal protective equipment (PPE) for landfill personnel (hard hats, high-visibility safety vests, hearing protection, etc.) with sufficient reserves for use by authorized visitors. Connection(s) to available water supply and electric utilities will be provided or bottled potable water may be provided if necessary. Convenience facilities will drain to a septic/leach field. Separate parking areas will be provided for landfill personnel and authorized visitors so that an accurate assessment of personnel present at the site can be made.

4.3 Vehicle Maintenance and Equipment Parking Area

The gravel-surfaced infrastructure area will be of sufficient size to securely accommodate parked construction/operation vehicles within the fenced facility boundary. A sloped concrete pad of sufficient size to accommodate the largest piece of equipment will be located within the infrastructure area with curbing along the perimeter of the pad. This pad will be utilized to contain potential spills during any required engine work, lubrication, or any fluids transfer (other than vehicle fueling) related to maintenance.

4.4 Materials Recovery Facility / Segregation Pad

An enclosed Materials Recovery Facility (MRF) within the infrastructure area is proposed. The MRF will generally consist of an enclosed building with a concrete tipping floor of sufficient size to accommodate the following: multiple (number to be determined) incoming waste hauling vehicles; maneuvering space for a wheeled loader to transfer tipped waste to the recovery area; materials handling/sorting equipment such as screens, magnets, conveyors, and crushers/compactors/balers; storage area(s) for separated recovered material; and a load-out area for loading vehicles with waste materials to be disposed of at the landfill and for loading recovered materials onto vehicles for transfer to end market users.

4.5 Fuel Dispensary

An above-ground equipment fuel dispensary (storage tank, manual or electrically operated fuel transfer pump, filling hoses) will be installed within the securely fenced area for use by operations equipment and on-site vehicles. The storage tank will be located within a secondary containment berm or tank to contain potential leaks.

4.6 Leachate Storage/Evaporation Lagoon

A lined leachate storage/evaporation lagoon of sufficient capacity to store the design leachate production volume with sufficient freeboard to contain precipitation will be constructed within the infrastructure area adjacent to the site entrance. The 2-meter-deep lagoon has been designed with approximately 4,160 cubic meters (4,160,000 liters) of storage capacity from its invert to its crest, which exceeds the minimum storage requirements evaluated within the HELP Model leachate generation calculations and the storage capacity required for the largest open cell (Cell 2) in the event a large storm event occurs when the cell is initially opened. The lagoon will receive pumped leachate from each landfill disposal cell through the HDPE force main.

For the Aqaba site, only passive/natural evaporation from exposure of the contained water surface to solar radiation and wind is proposed. No additional enhanced evaporation proposed by hydraulic/mechanical means such as sprinklers, misters, or aerators is proposed. For added conservatism, evaporation of stored water *has not* been accounted for in leachate lagoon sizing.

The leachate lagoon will be lined with a base liner containment system equivalent to the landfill cells anchored at the lagoon crest and consisting of the following components in ascending order over the excavation/subgrade:

- 150 mm (minimum) of compacted select fill/liner cushion soil material
- Geosynthetic Clay Liner (GCL) with a maximum hydraulic conductivity of 5×10^{-9} cm/s
- 1.5mm (60mil) textured HDPE geomembrane liner
- Nonwoven geotextile cushion
- 450mm (minimum) thick granular drainage layer with a hydraulic conductivity of >= 1×10^{-1}cm/s, functioning as a protective layer

4.7 Stormwater Management Basin

A stormwater management basin with sufficient capacity to contain the maximum anticipated run-on/run-off from the contributing landfill development area will be constructed within the infrastructure area adjacent to the site entrance. The basin storage capacity from its invert (elevation 359.3) to the invert elevation of contributing stormwater culverts (elevation 362.3) has been designed as 5,055 cubic meters (5,055,000 liters), which exceeds the minimum required 205.2 cubic meters (205,200 liters) estimated from the stormwater management calculations. Additional freeboard above elevation 362.3 has been provided to elevation 366 in order to facilitate continuity with surface grading of the adjacent infrastructure area and stormwater diversion channels.

For the Aqaba site, only passive/natural evaporation from exposure of the contained water surface to solar radiation and wind is proposed. No additional enhanced evaporation proposed by hydraulic/mechanical means such as sprinklers, misters, or aerators is proposed. For added conservatism, evaporation of stored water *has not* been accounted for in stormwater basin sizing.

4.8 Landfill Gas Management Facility

A 1200-mm-diameter HDPE landfill gas condensate knockout will be located at the low point of the HDPE landfill gas header as it enters the infrastructure area. Condensate collected within the knockout will be drained via a 110-mm-diameter HDPE drain pipe to a buried condensate holding tank. Condensate will be periodically pumped out of the storage tank for off-site disposal. After the condensate management knockout, the landfill gas header will be routed to a blower/flare station for destruction of landfill gas in the infrastructure area adjacent to the site entrance. Calculations within Appendix B indicate that a blower (estimated differential pressure across the blower of 20 inches or 508 mm W.G.) and flare rated for a capacity of 600 scfm are appropriate for this project, with step down/ turndown capabilities for lower flows.

Other potential options for gas management include construction/utilization of a small generation power facility or compression and sale of gas to potential end-users.

Based on the landfill gas generation model included in Appendix B (updated from the Feasibility Study), the maximum annual gas generation rate was estimated as 449.5 ft^3/min (12.73 m^3/min). Based on an assumed conservative 50% system efficiency for the purposes of estimating power generation potential, the maximum gas collection rate is estimated at approximately 225 ft^3/min (6.36 m^3/min) near the end of the landfill active life. This corresponds to the maximum annual generating capacity of 691 kW (6,052,974 kW hr). Calculations indicate that a 250 to 300 kW electric generator could be installed at year 7 and another identical one could be added at year 16. One potential engine/generator for this option is the Caterpillar Energy Solutions (CES) GmbH TCG 2016 V-08C 50 Hz. This 3.09-m-long x 1.49-m-wide x 2.19-m-high engine set has a 400 kW electrical output rating and weighs 5,340 kilograms and would be located on a reinforced concrete foundation pad within the infrastructure area. A 3-m-wide x 11-m-long x 3-m-high “Containerized Cogeneration Plant” is also available for this genset, which integrates the container, equipment, and switchgear.

5 Geotechnical Investigation

A geotechnical investigation was conducted at the site by ACES, a specialized geotechnical firm in Jordan, in order to provide sufficient geotechnical parameters for the design and construction of the proposed project. The purpose of the geotechnical investigation was to determine the subsurface conditions at the existing Aqaba Landfill in addition to the physical and chemical properties of the ground materials. More specifically, the investigation aimed firstly to verify through in-situ exploration the soil-rock strata, water table elevation in the boreholes and quality of available water for the project site and secondly, to identify any groundwater table or any liquid present, as well as the depth of waste at the desired location. The study can be found in Appendix C.

5.1 Field Exploration and Laboratory Testing

A total of nine boreholes were drilled to approximate depths of 25 to 75 m below the ground surface at the site between 21 October and 24 December, 2013. These can be seen in Figure 5-1 below.

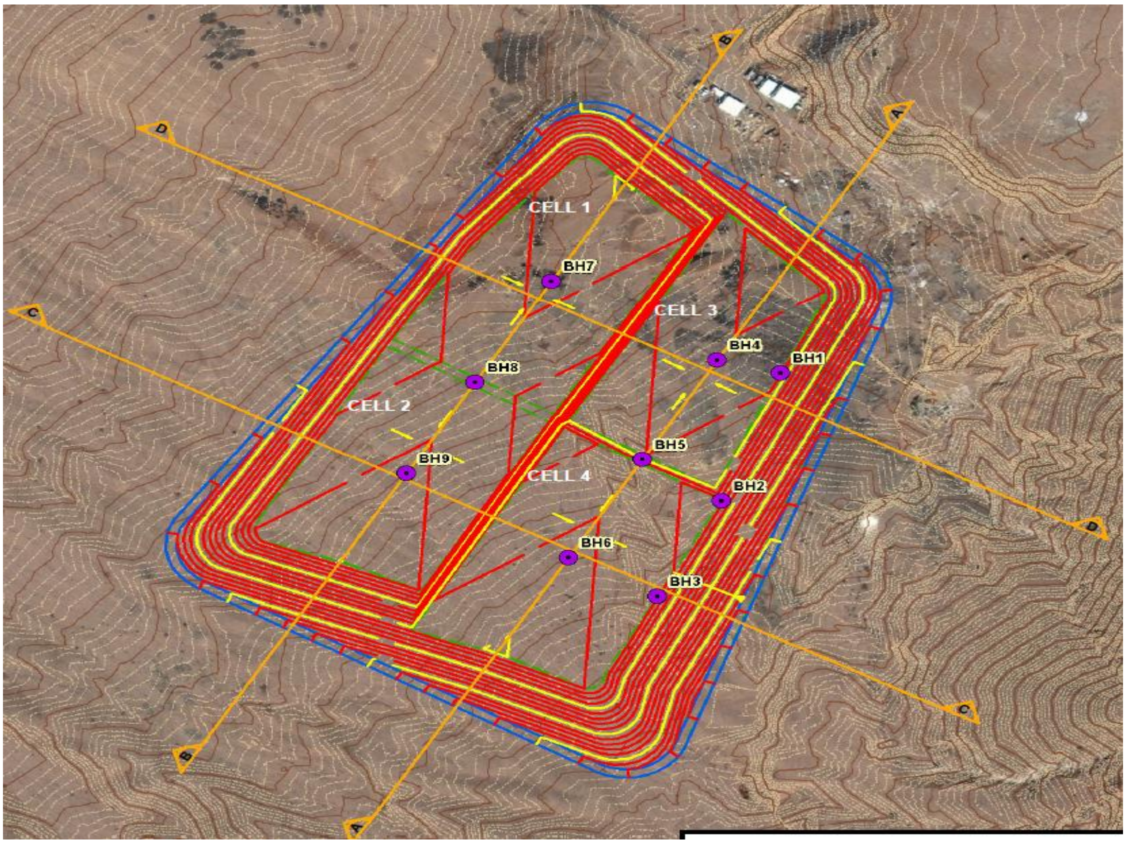

Figure 5-1: General Location of Boreholes in Lined Disposal Area

In addition to the nine boreholes, three test pits were excavated at the project site in order to visually inspect the shallow subsurface and obtain soil samples for the laboratory testing. The following tables, 5-1 and 5-2, show the details of the boreholes and test pits, respectively.

Table 5.1: Boreholes and corresponding information

BH No.	Elevation (m)	Coordinates		Depth (m)
		Northing	Easting	
BH01	386.256	256046.00	309722.17	25
BH02	390.992	255953.44	309688.71	25
BH03	393.955	255884.25	309652.11	40
BH04	384.184	256055.2	309686.06	25
BH05	389.219	255983.42	309643.71	75
BH06	389.912	255912..14	309601.66	30
BH07	377.674	256112.69	309592.26	25
BH08	380.269	256039.31	309548.97	25
BH09	382.643	255973.24	309509.99	25

Table 5.2: Test Pits and Corresponding Information

Test Pit No.	Coordinates		Depth (m)
	Northing	Easting	
T.P.1	256096	309813	3.0
T.P.2	256115	309577	3.0
T.P.3	255978	309532	3.0

Disturbed but representative samples were obtained from the drilled boreholes at regular intervals in the fill and alluvial deposits (granular soils) using the split spoon samplers with open driving shoe. Standard Penetration Tests (SPT) were performed in accordance with BS 1377: 90: Part 9, Clause 3.3. Percussion drilling techniques (using tricone rock bit) were used at intervals where neither SPTs nor undisturbed sampling were carried out. Disturbed samples were obtained during this process.

5.2 Geotechnical Testing

In-Situ testing consisted of the Standard Penetration Test (SPT) in accordance with ASTM D 1586-08a and the Falling Head Permeability Test, in accordance to BS 5930-1999 CI.25.4.

Laboratory tests were also performed on samples obtained from the excavated test pits to identify the physical and mechanical properties of the encountered materials:

- Classification and Index Tests: Moisture Content (ASTM D 2216-05), Particle Size Distribution (ASTM D 422-63 – 2007) and Atterberg Limits (ASTM D 4318-10)

- Strength Tests: Direct Shear Test under Consolidated Drained Conditions (ASTM D 3080-04)

- Permeability Test (ASTM D 5084-00)

5.3 Summary

In summary, the ground materials encountered at the site showed general homogeneity and continuity in spite of some relative variation in textural properties and relative densities in both the horizontal and vertical extents. The encountered materials were mainly alluvial deposits with some waste/fill materials. No groundwater or cavities were encountered in any of the borings at the drilled depths during or at the completion of drilling activities.

The following conservative geotechnical parameters for the existing (foundation) soil have been selected for the evaluation of the landfill based on a review of the data and recommendations presented within the geotechnical study included in Appendix C:

- Unit Weight: γ = 1,922 kg/m^3 (18.9 kN/m^3)
- Internal Shear Strength: Φ = 38°, c = 0 kPa
- Seismic Acceleration: Ca = 0.24g
- Permeability: k = 8.27 E-03 cm/sec
- Depth to Groundwater: Not encountered

6 Subgrade Construction

6.1 Design Strategy

Each phase (or cell) of development will require excavation and/or fill from the design top of subgrade elevations (cell floor and perimeter berm) to the existing topographic elevations. Cut and fill slopes will generally be no greater than 3H:1V, except in limited areas where steeper slopes may be required for clearance issues or to minimize disturbance of adjacent features while maximizing available space for monofill disposal. Drawing No. 3 depicts the base grade preparation (top of subgrade prior to installation of liner cushion layer) for the four (4) disposal areas (cells).

6.2 Soil Balance

Drawing No. 4 depicts a cut/fill iso-pach indicating the depth of excavation cut and height of fill required to form the landfill subgrade elevations in a grid format. Surplus excavated soils will be loaded and hauled to stockpile area(s) for future use as structural fill, daily cover, intermediate cover, and evapotranspiration (ET) cap soil. Table 6-1 summarizes the site soil balance based on the design grading plans as presented on this drawing and the landfill phasing plans.

Table 6.1: Subgrade Excavation/Fill Quantities

Cell Designation	Gross Excavation (m^3)	Gross Fill (m^3)	Surplus (Deficit) (m^3)
Infrastructure	93,642	29,379	64,263
Cell 1	247,902	47,926	199,976
Cell 2	291,324	59,353	231,971
Cell 3	163,353	24,037	139,316
Cell 4	187,622	5,250	182,372
Totals	**983,843**	**165,945**	**817,898**

6.3 Excavation and Perimeter Slope Stability

The short-term (undrained) and long-term (drained) stability of the in-situ foundation soil (subgrade) after excavation to the maximum 3H:1V slopes was evaluated to determine if the subgrade may be excavated with an adequate factor of safety versus slope failure. This evaluation models conditions that may exist during or shortly after construction. If the slope is left open for an extended period of time, surface raveling could occur. Stability of the landfill perimeter berm fill was also evaluated.

The results of the stability analyses are provided in Appendix D. Table 6-2 summarizes these results.

Table 6.2: Summary of Excavation and Perimeter Berm Stability

Stability Cross Section	Condition Analyzed	Static Factor of Safety
B-B’	Perimeter Berm at Final Build out	3.4
C-C’	Subgrade Excavation Stability	2.4

The analyses demonstrate that perimeter berm fill is stable at the final build-out condition of the landfill and that cell excavation to the maximum proposed slope (3H:1V) and depth (Cell 4 development) will be stable.

7 Landfill Capacity and Global Landfill Stability

7.1 Design Strategy

The targeted minimum airspace for the Aqaba Landfill is to provide for 20 years of waste disposal for the population of Aqaba. The incoming waste is expected to be about 0.95 kg/person-day, according to the "Country Report on the Solid Waste Management in Jordan" prepared by SWEEP-Net (2012).

Three slope stability cross-section locations were analyzed to determine the stability of the waste mass during the site development, interim filling and final closure conditions at the landfill. The desired factors of safety are based on the loading condition and normal engineering practice. For effective stress (drained, long-term) loading conditions, a safety factor of safety of 1.5 or greater is generally considered acceptable for static analyses. For the total stress (undrained, short-term) condition a factor of safety of 1.3 or greater is considered acceptable. A factor of safety of 1.0 or greater is required for seismic slope stability analyses.

7.2 Landfill Capacity

Table 7-1 summarizes the phased capacity of the landfill.

Table 7-1: Landfill Design Capacity

Cell	Lined Area (m^2)	Gross Capacity[1] (m^3)	ET Cover[2] (m^3)	Void Volume[3] (m^3)	Daily Cover Volume[3] (m^3)	Net Waste Volume (m^3)	Cell Life (years)	Cumulative Life Expectancy (years)
Cell 1	29,790	211,599	12,986	198,613	29,792	168,821	2.29	2.29
Cell 2	30,485	339,631	17,327	322,304	48,346	273,958	3.71	6.00
Cell 3	23,245	383,507	13,928	369,579	55,437	314,142	4.26	10.26
Cell 4	29,335	1,530,093	131,193	1,398,900	209,835	1,189,065	16.11	**26.37**
Totals	**112,855**	**2,464,830**	**175,434**	**2,289,396**	**343,410**	**1,945,986**	**26.36**	

Notes:

1. *Gross capacity is calculated from top of closure/intermediate grades to top of protective cover and includes daily cover soil.*
2. *ET Cover is 1.5 meters thick.*
3. *Void volume is calculated as gross capacity – ET cover volume.*
4. *Daily cover soil is calculated as 15% of void volume.*
4. *Cell Life expectancy is based on 0.5933 tonnes/cum, 120 tonnes/day, and 7 days/week*.

7.3 Landfill Stability

7.3.1 Geotechnical Parameters

Geotechnical laboratory testing was performed on representative site-specific soil samples obtained during the field investigation. The laboratory tests included grain size distribution (sieve analysis), moisture content, Atterberg limits, direct shear under consolidated drained ("CD") conditions, and permeability. As there is no compressible/fine grained in-situ soil, short-term (i.e. during and at the end of construction) and long-term (i.e. during the post-closure period) geotechnical parameters are equivalent. The following conservative geotechnical parameters for the existing (foundation) soil have been selected for the evaluation of the landfill based on a review of the data and recommendations presented within the geotechnical study included in Appendix D:

- Foundation Unit Weight: γ = 1,922 kg/m^3 (18.9 kN/m^3)
- Foundation Internal Shear Strength: Φ = 38°, c = 0 kPa

According to the site investigation report, no groundwater or cavities were encountered in any of the borings at the drilled depths during or after completion of the drilling activities. The deepest borehole was drilled to an approximate depth of 75 meters (approximate elevation 314 meters). Therefore, no groundwater piezometric surface was modeled within the foundation soils.

While the waste stream is anticipated to have a high food waste as presented within the Feasibility Study (estimated unit weight of 599.2 kg/m^3, or 37.4 lb/ft^3), the waste parameters within the stability analyses were conservatively assumed to be a more typical municipal waste/daily cover soil mix with the following parameters:

- Waste Unit Weight: γ = 1,122 kg/m^3 (11 kN/m^3)
- Waste Internal Shear Strength: Φ = 35°, c = 20 kPa

The base liner system was assumed to act as a single material and was modeled as one meter thick. The interface shear strength of the base liner system was varied (iteration process) to achieve the adequate factor of safeties described above. Liner interface testing should be conducted to determine the critical peak and corresponding critical residual friction angles.

Table 7-2 summarizes the parameters selected for the foundation soils, composite liner components, waste, and final cover components.

Table 7-2: Geotechnical Parameters

Soil Type	Unit Weight (kg/m^3)	Cohesion "c" (kPa)	Angle of Internal Friction "Φ" (degrees)
On Site Soil	1,922	0	38
Base Liner	866	0	See below
Waste	1,122	20	35

Table 7-2 Notes:

1. *On-site soil (foundation and cover soil) parameters are based on Appendix D.*
2. *Base liner system (geosynthetics and protective cover/granular drainage layer) parameters are represented by the unit weight of the granular layer and the calculated lowest (i.e. performance based) liner interface shear strength that will maintain factors of safety of 1.3 (short term) and 1.5 (long term) for the critical section (see §7.3.2 below).*

7.3.2 Liner System Stability

An iterative process was used to determine the minimum friction angle for the composite liner to achieve minimum factor values of 1.5 for static condition and 1.0 for the seismic condition, respectively. (Note that the minimum friction angle means the performance-based interface strength that may be compared to future lab testing on site/project-specific samples.) The iterative process was performed for the interim and final build out of the waste mass for each of the three cross-sections. The base liner was modeled as a 1000-mm-thick layer with the parameters selected to simulate the interface friction angle of the weakest interface. A block failure (i.e. sliding along the base liner system components) was determined to be the critical failure mode. The results of the stability analyses are provided in Appendix D. Table 7-3 summarizes these results.

Table 7.3: Liner System Slope Stability Results

Stability Cross Section	Condition	Required Angle of Internal Friction "Φ" for Static Analysis (degrees)	Static Factor of Safety	Required Angle of Internal Friction "Φ" for Seismic Analysis (degrees)	Seismic Factor of Safety
A-A'	Final Build out	12	1.9	15	1.0
	Interim Filling	12	1.5	15	NA
B-B'	Final Build out	12	2.8	15	1.1
	Interim Filling	12	1.5	15	NA
C-C'	Final Build out	12	2.3	15	1.0
	Interim Filling	NA	NA	15	NA

Based on the analyses, the minimum peak liner system interface shear strength to achieve both static and seismic factors of safety is represented by a friction angle of 15°, with adhesion (cohesion) conservatively neglected. While this value is sufficient for global landfill stability, it will limit placement of protective cover over the liner system with low ground pressure (LGP) equipment. The minimum interface shear strength for placement of protective cover along the entire 3:1 perimeter berm slope is represented by a friction angle of approximately 25°.

Liner interface friction angle testing should be conducted with the proposed liner system materials prior to construction to confirm that minimum interface friction angle can be achieved. Modifications to the slope stability analyses may be warranted if the minimum shear strength cannot be achieved.

7.3.3 Global Landfill Stability

The global stability of the landfill at final build out was evaluated to determine the factors of safety for the foundation, base liner system, and waste mass. These analyses were performed using both circular and sliding block (presented above) failure surfaces that intersect the foundation soils, liner system, waste mass and perimeter berm. The cross-sections analyzed were selected based on the combination of subgrade excavation depth, perimeter berm fill height, waste thickness, and final waste slopes at the final build out configuration which result in the most critical cross-sections. Minimum factor values of 1.5 for static condition and 1.0 for the seismic condition were evaluated. Slope/W was used to analyze each cross-section to determine the critical surface (those with the lowest factors of safety).

The results of the stability analyses are provided in Appendix D and are summarized in Table 7-4.

Table 7-4: Landfill Global Slope Stability at Final Build-out Results

Stability Cross Section	Analysis Type	Static Factor of Safety	Seismic Factor of Safety
A-A'	Sliding Block through Waste and Liner System	1.9	1.0
	Circular through Waste and Liner System	3.0	1.6
	Circular through Waste, Liner System and Foundation	6.0	NA
B-B'	Sliding Block through Waste and Liner System	2.8	1.1
	Circular through Waste and Liner System	3.6	1.6
	Circular through Waste, Liner System and Foundation	7.4	NA
C-C'	Sliding Block through Waste and Liner System	2.3	1.0
	Circular through Waste and Liner System	3.2	1.6
	Circular through Waste, Liner System and Foundation	NA	NA

Based on the analyses, the minimum static factor of safety (1.5) and the minimum seismic factor of safety (1.0) are achieved for each of the cross-sections and condition analyzed. The proposed landfill will be stable.

7.3.4 Liquefaction Evaluation

Liquefaction occurs when saturated coarse grained soils are subjected to cyclic loading induced by an earthquake. Based on the soils that are present at the landfill site, liquefaction is not a concern. The liquefaction evaluation is provided in Appendix D.

8 Landfill Base Liner System

8.1 Design Strategy

The proposed composite liner system will generally conform to the United States Environmental Protection Agency (USEPA) Subtitle D requirements. Subtitle D requires (as a minimum) a composite liner that consists of two layers: the upper is a flexible membrane liner (minimum of 60-mil (1.52 mm) if HDPE is installed); the lower is a soil layer of at least two feet thick with a hydraulic conductivity of no more than $1x10^{-7}$ cm/sec. This compacted clay layer could be replaced by a Geosynthetic Clay Liner (GCL).

8.2 Description of Base Liner System

The proposed Aqaba Landfill liner system will consist of the following components in ascending order over the excavation/subgrade:

- 150 mm (minimum) of compacted select fill/liner cushion soil material
- Geosynthetic Clay Liner (GCL) with a maximum hydraulic conductivity of 5×10^{-9} cm/s
- A 1.5 mm (60mil) textured HDPE geomembrane liner
- A 530 (minimum) g/m^2 nonwoven geotextile cushion
- A 450 mm (minimum) thick granular drainage layer with a hydraulic conductivity of $>= 1\times10^{-1}$cm/s (functions as protective layer and leachate collection layer)

An anchor trench will be constructed along the perimeter of the proposed liner area as a means of securing the liner in place.

8.3 Material Evaluation and Selection

8.3.1 Select Fill / Liner Cushion

After the facility subgrade (excavation/fill) grades have been constructed, a 150 mm (minimum) thick layer of select fill will be installed as a liner cushion layer, protecting the underside of the liner system from potential protrusions or irregularities near the surface of the subgrade. This sub-cushion layer will also provide a smooth surface for installation of the subsequent, overlying geosynthetics, reducing the possibility of puncturing the geosynthetics from above during installation. The soil will be comprised of clean, locally available soil, free of potentially deleterious material, with a maximum particle size of 50 mm.

8.3.2 Geosynthetic Clay Liner (GCL)

Due to increased cost for construction/ construction Quality Assurance (CQA) in addition to poor local availability of acceptable low permeability (typical $k <= 1x10^{-7}$ cm/sec) clay soil required as the soil component of the Subtitle D composite liner, a geosynthetic clay liner (GCL) will be installed as an alternative. The GCL will be installed directly on the 150 mm thick select fill / liner cushion layer. The GCL consists of a layer of sodium montmorillonite (bentonite) between two layers of nonwoven geotextile. Fibers from the nonwoven geotextile are needle-punched through the layer of bentonite and incorporated into the structure of the GCL. This process significantly increases the internal shear strength of the product. The GCL will be installed on the floor and the side slopes throughout the entire disposal area.

8.3.3 High Density Polyethylene (HDPE) Geomembrane

HDPE is a chemically inert polymer used to manufacture geomembranes for waste containment applications. The inertness of HDPE is attributable to its molecular structure and morphology. HDPE has a simple molecular structure containing a six-member repeating unit consisting of two carbon and four hydrogen atoms. The hydrogen atoms are covalently bonded to the carbon atoms. Each carbon-hydrogen bond is equivalent and has the same bond energy. Most degenerative reactions in hydrocarbons occur through displacement of a hydrogen atom. However, due to covalent bonding, hydrogen atoms on the HDPE repeating unit are stable, and HDPE is not reactive under normal conditions.

Manufacturers' product compatibility testing shows that HDPE is unaffected by typical municipal solid waste leachate and is resistant to most compounds including inorganic acids, organic acids, volatile organics, petroleum based products, and poly-chlorinated biphenyls. HDPE geomembranes are widely used throughout the United States in the solid waste industry because they not only have acceptable physical properties, such as tensile strength, strain characteristics, and chemical compatibility, but also are relatively easy to deploy, seam, and test for defects. For these reasons, HDPE geomembranes are considered the industry standard for the geomembrane component in a landfill composite liner.

Manufacturers' data show little variation in HDPE physical properties over a range of temperatures from -40°F (-40°C) to 180°F (82.2 °C). Therefore, HDPE should not be affected by temperature variations. During construction, any loose ends or edges of the HDPE geomembrane will be secured in backfilled anchor trenches, tack welded, or weighted with sand bags to prevent wind-induced movement.

HDPE is resistant to ultraviolet degradation by the addition of carbon black and anti-oxidants during the manufacturing process. Long-term durability tests conducted by geomembrane manufacturers indicate that no surface cracks were observed even under significantly harsher conditions than those which occur in a landfill. In addition to its inherent resistance to ultraviolet degradation, the HDPE geomembrane will be protected by the geotextile cushion placed directly above it.

8.3.4 Nonwoven Geotextile

A nonwoven geotextile will be placed over the HDPE geomembrane to serve as a cushion against the overlying granular drainage layer in the base, trench, and sump liner systems. The burst resistance, grab tensile strength, and puncture resistance of the geotextile cushion were evaluated for loaded construction vehicles and the maximum anticipated landfill waste load to assure that the geotextile will provide adequate protection for the underlying HDPE geomembrane. The analyses were performed based on a granular drainage layer material having a gradation equivalent to AASHTO No.8 and AASHTO No.57 materials, which are common in protective cover / leachate collection layer installations in the United States. The results of the analyses are provided in Appendix D and are summarized in Table 8-1.

Table 8-1: Minimum Nonwoven Geotextile Specifications

Drainage Layer Material	Required Burst Resistance	Required Grab Tensile Strength	Required Puncture Strength	Minimum Mass per Unit Area
Sub-Rounded AASHTO No.8	35 psi	5 lbs.	13 lbs.	15 g/m^2
Sub-Angular AASHTO No.8	35 psi	5 lbs.	13 lbs.	34 g/m^2
Sub-Rounded AASHTO No.57	46 psi	9 lbs.	17 lbs.	244 g/m^2
Sub-Angular AASHTO No.57	46 psi	9 lbs.	17 lbs.	529 g/m^2

To allow flexibility during construction, a 529 g/m^2 (minimum) nonwoven geotextile will be installed.

8.3.0 Protective Cover / Granular Drainage Layer

To provide a highly permeable and transmissive protective cover layer for the liner system, a 450 mm layer of sub-rounded to sub-angular aggregate (generally with a gradation equivalent to AASHTO No. 8 or AASHTO No. 57) will be installed over the 529 g/m^2 (minimum) nonwoven geotextile.

During installation of the protective cover, temporary access roads with a minimum of 1.0 meter of aggregate will be installed in the disposal cell to maintain a protective cushion between non-low ground pressure (LGP) equipment and the liner system. Non-LGP equipment (> 5 psi contact pressure) will only be allowed to operate on these temporary access roads within the disposal cell. After all the protective cover aggregate is delivered to the disposal cell, the temporary roads are removed (spread out) and the 450 mm thick protective cover layer is completed

8.4 Settlement

Soil settlement is a result of the combination of elastic (or instantaneous) settlement of granular soils and primary consolidation and secondary consolidation of fine-grained soils. Settlement due to secondary consolidation of fine-grained soils is typically very small and is typically neglected.

Soils encountered in all borings from surface to the maximum 25 to 75 meter terminations are generally described in the geotechnical investigation (see Appendix C) as primarily medium dense to very dense, light brown to varicolored, fine to coarse sand with some intercalations of silty sand and occasional gravel horizons. Grain size distribution results for sampling from 0.0 to 3.0 meters below grade indicate course-grained soils with a very minor fine-grained component (5% average silt and 0.9% average clay).

It is anticipated that most of the settlement will occur during construction due to re-orientation of coarse-grained soils and reduction in void ratio. The maximum anticipated load for the final build out of the landfill (including a factor of safety of 1.5) has been estimated within the pipe loading calculations as 76,949.6 kg/m^2 (or 110 psi). As this value is nearly equivalent to typical maximum heavy equipment wheel loads (70,307 kg/m^2 or 100 psi), settlement due to loading will primarily occur during cell construction. Therefore, detailed settlement calculations have not been performed.

8.5 Veneer Stability

Stability of the proposed composite liner on the side slope was analyzed to represent short-term conditions during placement of the granular protective cover / leachate collection layer. The analysis assumes 0.45 m of stone/aggregate on a 3H:1V side slope. A transient load is applied by typical construction equipment (Caterpillar D6N LGP dozer). The minimum acceptable interface shear strength for the composite liner on the side slopes must maintain a minimum factor of safety of 1.3, since this represents a short term condition.

The longest 3:1 slope length occurs within Cell 4. For stability of the composite liner on the <u>entire</u> side slope during placement of the 0.45 meter thick granular protective cover / leachate collection layer with a LGP dozer, a minimum <u>peak</u> interface friction angle of 24.5^o is required. Protective cover should also be staged up side slopes in shorter slope length intervals if a <u>peak</u> interface friction angle of 24.5^o is not achieved during interface testing of the geosynthetics prior to installation. The maximum stage length should be computed by the engineer based upon actual interface friction testing results as required.

Veneer Stability calculations are included in Appendix D.

8.6 Specifications and Quality Assurance

The specifications for each of the geosynthetic liner system components are included within the "Quality Assurance Manual for Base Liner System Installation at Aqaba Waste Management and Landfill" in Appendix E.

9 Leachate Collection and Transmission System

9.1 Design Strategy

EPA regulations (Subpart D) require a leachate collection system that is designed and constructed to maintain less than 300 mm depth of leachate above the liner. The proposed design for leachate collection is perforated PVC pipes incised into the granular protective cover layer which will be spaced to maintain leachate head of less than 300 mm. The leachate collection pipes within each cell will drain to a sump near the perimeter, where the collected leachate will be pumped out to an onsite leachate evaporation lagoon. The landfill base grade slopes will be 1% (minimum) along the leachate collection pipes and 2% (minimum) perpendicular to the pipes.

9.2 Description of Leachate Collection System

The proposed design for the leachate collection system will consist of perforated pipes incised into the protective cover / leachate collection layer at regular intervals and connected to a common solid central trunk line draining to a sump near the perimeter of the cell, from which the collected leachate will be pumped out and stored/treated. The landfill base grade slopes will be a minimum 1% along the leachate collection pipes and a minimum of 2% perpendicular to the pipes. The maximum length for cleaning out leachate pipes will be 365 meters (1,200 feet), which is the limit of most modern jetting equipment.

The leachate collection pipes will be 150-mm-diameter perforated SCH40 PVC lateral pipes (or an equivalent HDPE pipe as approved by the engineer) connected to a 225-mm-diameter perforated trunk line along the centerline of the cell. Perforations will be drilled along the lower half of the pipe at 60° angles from the perpendicular. The holes will be alternately staggered and will have a diameter of 15 mm unless alternate perforation size is required by the engineer for compatibility with the proposed coarse aggregate surrounding the pipes.

9.3 HELP Model Analysis, Leachate Head, and Pipe Spacing

HELP Model leachate generation calculations are included within Appendix F. The model has been used to evaluate leachate head on the liner system for a variety of protective cover permeabilities and the maximum anticipated perpendicular drainage length in each cell (62 meters).

While leachate pipe spacing is typically designed to complement the permeability of the leachate collection/protective cover layer in order to allow no greater than 300 mm of head buildup on the base liner system, results of the HELP Model runs indicate that lateral pipes are not required to maintain head at less than or equal to 300 mm. The longest perpendicular flow path to the central trunk line (62 meters) coupled with the permeability of the protective cover layer is sufficient without laterals. However, laterals have been included for contingency purposes at the approximate midpoint of each cell on either side of the collection trunk.

Pipe loading calculations within Appendix F indicate that SCH40 PVC (or thicker) is appropriate for the leachate collection piping within each cell.

9.4 Description of Leachate Transmission System and Pump Calculations

The perforated leachate collection trunk lines will terminate at the low point of the leachate collection system over an excavated sump within each cell, allowing collected liquid to "drop out" into the sump. The perforated pipe will transition to solid piping up the perimeter berm for use as a cleanout riser. The sump will be lined with additional non-woven geotextile and will be filled with coarse aggregate. A perforated 610-mm-diameter PE pipe section will be installed within the sump area to house the submersible pump and will be connected to a solid 610-mm-diameter riser pipe. The side slope riser will terminate at its upper end with a face plate assembly above ground level. The pump discharge for the leachate collection system will be connected through the riser termination to 100 mm (minimum) diameter HDPE perimeter force main, which will discharge to the lined leachate lagoon.

A 3.0 horsepower (HP) submersible pump (EPG model WSD 12-5 or an equivalent as approved by the engineer) and discharge piping will be lowered through the solid riser into the perforated sump section by support cables. Based on the proposed force main system and system head curve, it is anticipated that the pump will operate at about 208 liters per minute and 36.3 meters of total head. Pump Calculations are provided in Appendix F.

9.5 Description of Leachate Storage/Treatment Facilities

As described in Section 4.6, a 2-meter-deep lined leachate storage/evaporation lagoon will be constructed within the infrastructure area adjacent to the site entrance. The lagoon will receive pumped leachate from each landfill disposal cell through the HDPE force main.

For the Aqaba site, only passive/natural evaporation from exposure of the contained water surface to solar radiation and wind is proposed. No additional enhanced evaporation proposed by hydraulic/mechanical means such as sprinklers, misters, or aerators is proposed. For added conservatism, evaporation of stored water *has not* been accounted for in leachate lagoon sizing.

The leachate lagoon will be lined with a base liner containment system equivalent to the landfill cells anchored at the lagoon crest and consisting of the following components in ascending order over the excavation/subgrade:

- 150 mm (minimum) of compacted select fill/liner cushion soil material
- Geosynthetic Clay Liner (GCL) with a maximum hydraulic conductivity of $5x10^{-9}$ cm/s
- 1.5 mm (60mil) textured HDPE geomembrane liner
- Nonwoven geotextile cushion
- 450mm (minimum thickness) granular drainage layer with a hydraulic conductivity of >= 1×10^{-1}cm/s (functions as protective layer)

10 Storm Water Management System

10.1 Design Strategy

The average annual precipitation in the project vicinity is not significant. Smaller, short duration storms have caused flooding that damage property and transmit sediment to the Gulf of Aqaba. EPA regulations (Subpart C) requires that surface water run-off from the active portion of the landfill be collected and controlled for at least the water volume resulting from a 25-year storm. Stormwater conveyance structures (channels, culverts, and basins) for the Aqaba Landfill have been sized using the peak flow calculated using the rational equation and the 20-year return interval. Additional capacity has been provided in drainage channels and the stormwater management basin for larger storms by incorporating a minimum 300 mm of freeboard above the 20-year storm flow depth.

10.2 Stormwater Run-On

Surface water catchment areas draining from outside the landfill development area into/onto the site (run-on) were identified so that diversion channels and culverts could be designed to convey this surface water around the development area, bypassing the stormwater (runoff) management basin. Run-on intercepted from the mountain peak area to the east of the facility will be diverted around the landfill through lined Diversion Channels 1.1 to the south and Diversion Channels 1.2 and 1.3 to Culvert No.1 near the connection of the paved entrance road to the landfill perimeter access road in the vicinity of the existing scavenger shacks. Culvert No.1 will discharge to Diversion Channel 1.4, which will drain along the existing roadway to Culvert No. 2 beneath the connection of the proposed paved site entrance road to the existing access road.

10.2.1 Run-On Diversion Channels

Diversion Channels 1.1, 1.2, 1.3, and 1.4 have been designed with trapezoidal cross-sections and the Manning's equation to convey the peak flow with at least 300 mm of freeboard above the 20-year storm event. Each channel has been designed with two separate design/construction alternatives to provide flexibility for use of more readily available and/or less expensive materials at the time of construction. Alternative 1 is riprap channel lining with average stone diameter (d50) indicated below underlain by a woven geotextile filter fabric. Alternative 2 is long-term (permanent), UV-resistant synthetic erosion control matting with manufacturer's shear strength rating for bare earth equivalent to or greater than the values indicated. Detailed calculations are included within Appendix G of this Report. Table 10-1 summarizes the design alternatives.

Table 10-1: Run-on Diversion Channel Summary

Channel Reach	Design Flow (m^3/sec)	Slope (m/m)	Bottom Width (mm)	Side Slope (H:V)	Alternative 1 Riprap d50 (mm)	Alternative 2 Erosion Mat Minimum Shear Strength (Pa)	Minimum Channel Depth (mm)
1.1	3.78	0.010	2000	3:1	75	52	1000
1.2	1.08	0.050	2000	3:1	75	87	600
1.3	4.75	0.020	2000	3:1	150	98	1000
1.4 R1	4.93	0.044	2000	3:1	150	179	850
1.4 R2	4.93	0.080	2000	3:1	230	278	850
1.4 R3	4.93	0.100	2000	3:1	230	328	850

10.2.2 Run-On Diversion Culverts

Culverts have been designed to convey the design flow from the 20-year storm event without overtopping at the inlet constraint (top of channel or adjacent roadway, etc.), with sufficient soil cover over the pipe crest to withstand maximum anticipated vehicle loads, and with outlet protection to prevent scour in the downstream channel. Culverts will be either reinforced concrete pipe (RCP, for cover depth less than 600mm) or smooth-bore corrugated polyethylene (CPE, for cover depths >= 600mm). Multiple circular culverts were selected if required to pass the design flow without overtopping the inlet, with sufficient cover over the pipe crest. Alternative designs (box culverts, arch pipes, etc.) may be reviewed and approved by the engineer prior to construction. Detailed calculations are included within Appendix G of this Report. Table 10-2 summarizes the run-on diversion culvert design.

Table 10-2: Run-on Diversion Culvert Summary

Culvert	Design Flow (m^3/sec)	Invert In (m)	Invert Out (m)	Plan View Length (m)	Culvert Slope (m/m)	Culvert Type	Number Of Culverts	Culvert Diameter (mm)
1	6.34	380.0	378.0	60	0.033	CPE	2	915
2	5.95	360.0	359.0	50	0.020	CPE	2	1070

10.3 Stormwater Run-Off

Surface water catchment areas draining from within the landfill development area and draining off of the site (run-off) were identified so that conveyance channels and culverts could be designed to convey this surface water to the stormwater (runoff) management basin. Runoff from a portion of the landfill final cover area will be collected within the Landfill Access Road Channel 3 and Landfill Bench Channel 4, which will convey surface water through Culvert No.3 to Perimeter Channel 2. Runoff from Perimeter Channel 2 will convey surface water through Perimeter Channel 5 to the Drop Inlet. Perimeter Channel 6 will convey runoff collected from the south and west sides of the landfill surface to the Drop Inlet. Runoff from the Drop Inlet will combine with flows from Channels 7.1 through 7.3 and then discharge through Culvert No.6 to the stormwater management basin. Runoff from the infrastructure area will be collected in Channel 8 and then will discharge through culvert No.7 to the stormwater management basin.

10.3.1 Runoff Diversion Channels

Trapezoidal runoff diversion channels have been designed to collect runoff from the landfill final development surface, the landfill perimeter access road, the infrastructure area and from the toe of the perimeter berm along the west side of the landfill and convey it to the stormwater management basin. Each channel has been designed with the Manning’s equation to convey the peak flow with at least 300 mm of freeboard above the 20-year storm event. Each channel has been design with two separate design/construction alternatives to provide flexibility for use of more readily available and/or less expensive materials at the time of construction. Alternative 1 is riprap channel lining with average stone diameter (d50) indicated below underlain by a woven geotextile filter fabric. Alternative 2 is long-term (permanent), UV-resistant synthetic erosion control matting with manufacturer’s shear strength rating for bare earth equivalent to or greater than the values indicated. Detailed calculations are included within Appendix G of this Report. A summary of the design alternatives is provided in Table 10-3.

Table 10-3: Run-off Diversion Channel Summary

Channel Reach	Function	Design Flow (m^3/sec)	Slope (m/m)	Base Width (mm)	Side Slope (H:V)	Alternative No.1 Riprap d50 (mm)	Alternative No.2 Erosion Mat Shear Strength (Pa)	Minimum Channel Depth (mm)
2	Perimeter	0.66	0.037	2000	3:1	150	53	1000
3	Landfill Access	0.81	0.060	1000	2:1	75	123	560
4	Landfill Bench	0.36	0.070	500	2:1	75	118	525
5	Perimeter	1.97	0.026	2000	3:1	150	75	1000
6 (min) 6 (max)	Perimeter Perimeter	1.08 1.08	0.024 0.053	2000 2000	3:1 3:1	150 150	51 91	1000 1000
7.1 R1	Toe	0.41	0.100	1000	2:1	75	147	600
7.1 R2	Toe	0.41	0.032	1000	2:1	75	48	600
7.2	Toe	3.15	0.020	1000	2:1	150	109	1000
7.3	Toe	0.40	0.020	1000	2:1	75	37	550
8	Infrastructure	0.37	0.010	5000	3:1	75	25	625

10.3.2 Runoff Diversion Culverts

Culverts have been designed to convey the design flow from the 20-year storm event without overtopping at the inlet constraint (top of channel, adjacent roadway, etc.), with sufficient soil cover over the pipe crest to withstand maximum anticipated vehicle loads, and with outlet protection to prevent scour in the downstream channel. Culverts will be either reinforced concrete pipe (RCP, for cover depth less than 600mm) or smooth-bore corrugated polyethylene (CPE, for cover depths >= 600mm). Multiple circular culverts were selected if required to pass the design flow without overtopping the inlet, with sufficient cover over the pipe crest. Alternative designs (box culverts, arch pipes, etc.) may be reviewed and approved by the engineer prior to construction. Detailed calculations are included within Appendix G of this Report. A summary of the run-off diversion culvert design is provided in Table 10-4.

Table 10-4: Run-on Diversion Culvert Summary

Culvert	Design Flow (m^3/sec)	Invert In (m)	Invert Out (m)	Plan View Length (m)	Culvert Slope (m/m)	Culvert Type	Number Of Culverts	Culvert Diameter (mm)
3	1.39	381.5	381.2	15	0.020	CPE	2	760
4	2.12	381.0	380.4	27	0.036	RCP	2	915
5	3.00	372.9	371.0	27	0.070	CPE	1	915
6	3.65	362.3	362.0	25.7	0.012	CPE	2	760
7	0.37	364.8	363.6	20	0.060	CPE	1	610

10.3.3 Surface Water Management Basin

As described in Section 4.7, a surface water management basin will be located at the low point along the western side of the site and will ultimately receive runoff from the landfill and support areas.

For the Aqaba site, only passive/natural evaporation from exposure of the contained water surface to solar radiation and wind is proposed. No additional enhanced evaporation proposed by hydraulic/mechanical means such as sprinklers, misters, or aerators is proposed. For added conservatism, evaporation of stored water *has not* been accounted for in stormwater basin sizing.

The basin will be equipped with an HDPE side slope riser and submersible pump assembly or assemblies (similar to each landfill disposal cell) or suction pump connected to a truck load out facility or facilities so that stored water may be used for landfill operations activities such as dust control or fire protection. To facilitate storage and retention of water, the stormwater management basin will be lined with a base liner containment system anchored at the basin crest to facilitate retention of water consisting of the following components in ascending order over the excavation/subgrade:

- 150 mm (minimum) of compacted select fill/liner cushion soil material
- GSE Bentoliner CNSL GCL (Geosynthetic Clay Liner with a polypropylene geofilm adhered to the upper surface), or approved equivalent
- 300 mm (minimum thickness) native soil cover layer with 25 mm maximum particle size

11 Final Cover System

11.1 Design Strategy

EPA Regulations (Subpart F) require that *“owners and/or operators of all municipal solid waste landfill units must have a final cover system that is designed to minimize infiltration and erosion. The final cover system is to be designed and constructed to: (1) Have a permeability less than or equal to the permeability of any bottom liner system or natural subsoil’s present or permeability no greater than $1x10^{-5}$ cm/sec, whichever is less, and (2) Minimize infiltration through the closed MSWLF by the use of an infiltration layer that contains a minimum 18 inches of earthen material, and (3) Minimize erosion of the final cover by the use of an erosion layer that contains a minimum 6 inches of earthen material that is capable of sustaining native plant growth.”*

In addition to long-term minimization or elimination of stormwater infiltration into the waste, the cover system will also eliminate direct exposure to waste, minimize air intrusion into the landfill, and to help minimize fugitive LFG emissions from the landfill. To promote LFG generation and minimize infiltration, the landfill shall be capped intermittently as waste filling reaches design elevations in each phase. This phased closure is a requirement typical of Subtitle D facilities in the United States.

11.2 Description of ET Cover

For the Aqaba landfill, an evapotranspiration (ET) cover system is proposed as a more economical alternative to commonly used clay and/or geosynthetic liners. The choice of using an ET cover was also influenced by the fact that the region is considered arid, with precipitation in the study area rarely exceeding 50 mm/year. ET covers rely on storing moisture within the cover system itself until the water either transpires or evaporates. Typical ET cover designs are either monolithic (single fine-grained soil layer) or include a capillary break. The capillary break allows the ET cover to retain more moisture especially under unsaturated conditions. The design of such covers depends on climate conditions of the landfill area, ET soil properties, and type of vegetation to be used in the cover.

After final waste placement, a monolithic ET cover will be installed. The surface of the ET cover will then be covered with an aggregate layer for erosion control. The ET cover was chosen due to its proven suitability in arid and semi-arid areas, its limited long-term maintenance requirements, as well as its economic feasibility. The ET cover design for the Aqaba Landfill will consist of a minimum of 1350 mm (1.35 m) of ET native soil cover overlain by 150 mm (minimum) of aggregate for erosion control.

12 Landfill Gas Management System

12.1 Design Strategy

Landfill gas control is a requirement of Subtitle D Subpart C in addition to EPA's New Source Performance Standards (NSPS) and Emission Guidelines for Municipal Solid Waste Landfills - NSP/EG 60.759. The LFG Management System at the Aqaba Landfill has been designed to control the release of LFG to the atmosphere on-site and to prevent the migration of LFG away from the site.

For the Aqaba landfill, vertical gas extraction wells are proposed with connections to an enclosed flare station (optionally to landfill gas electric generator or compression facility for sale to end users) via a network of collection laterals and header piping. Perforated collection pipe within sloped horizontal trenches may also be installed at lower elevations in the waste mass in order to collect produced gas before final waste heights are reached and vertical wells are installed. As the gas cools in the collection system, moisture in the gas condenses. Gas collection piping will be sloped towards condensate knockout trap(s) where applicable to prevent pipes from becoming obstructed by accumulated condensate water. The system will be installed to accommodate potential differential settlement by using 2% slopes on the landfill development surface and flexible connections from gas wells to transmission piping.

12.2 Landfill Gas Generation

The annual future potential of the landfill to generate LFG was calculated using the EPA landfill gas modeling equation presented in the USEPA Landfill Gas Emissions Model (LandGEM). The equation is as follows:

$$Q_{CH_4} = \sum_{t=1}^{n} \sum_{j=0.1}^{1} kL_0 \left(\frac{M_t}{10}\right) e^{-kt_{ij}}$$

Where,

Q_{CH4}= Annual methane generation in the year of calculation (m^3/year),
i= 1 year time increment,
n= (year of the calculation) - (initial year of waste acceptance),
j= 0.1 year time increment,
k= methane generation rate ($year^{-1}$),
L_0= potential methane generation capacity (m^3/Mg),
M_i= mass of waste accepted in the i^{th} year (Mg),
t_{ij}= age of the j^{th} section of waste mass M accepted in the i^{th} year (decimal years, ex. 3.2 years)

Of the above equation components, all require site-specific data to produce generation estimates except for k and L_0 which are given constants. These two constants are defined as follows:

- **Methane Generation Rate Constant (k):** a model constant that determines the estimated rate of landfill gas generation. The first-order decomposition model assumes that k values before and after peak landfill gas generation are the same. k is a function of moisture content in the landfill waste, availability of nutrients for methanogens, pH and temperature. The unit used for k is 1/year. A typical value for k is 0.04 yr^{-1} for landfills in the United States. The k value is expected be lower in dry climate conditions but higher if the waste has high moisture contents and nutrients. In the case of the Aqaba site, the rainfall is very low (19mm annual average, with 32.8mm annual maximum) while the food waste component of Jordanian waste is high (average of 53%). Adjustments to the typical k value for Aqaba using the Solid Waste Association of North America (SWANA) “Landfill Gas Generation and Modeling Manual of Practice, Final Draft” (February 2005) and typical precipitation and organics content yields k=0.016.

- **Potential Methane Generation Capacity (L_0):** L_0 is a model constant that represents the potential capacity of a landfill to generate methane. It is dependent on the amount of cellulose in the waste (i.e. it increases as organic content increases) and is measured in m^3/Mg. Adjustments to the typical L_0 value for Aqaba using the Solid Waste Association of North America (SWANA) “Landfill Gas Generation and Modeling Manual of Practice, Final Draft” (February 2005) and typical precipitation and organics content yields L_0 = 174.4.

The above data were used to run the EPA LandGEM model. The results are included within Appendix F of this Report.

The gas collection efficiency was assumed to be 50% and was converted to potential electric power generation as presented in Appendix B. If the landfill gas system is constructed as designed and operated as intended, the LFG collection efficiency should be more than 70%. However, a conservative 50% collection efficiency was assumed. The electric generation potential from Aqaba was found to be relatively low but potentially feasible. A 250 to 300 kW electric generator could be installed at year 7 and another identical one could be added at year 16.

12.3 Landfill Gas Collection, Transmission and Utilization System

At a minimum, the proposed LFG management system will consist of 28 permanent vertical extraction wells, transmission piping, condensate collection and handling facilities, a blower to draw the LFG from the well field and an enclosed flare to reduce atmospheric emissions.

12.3.1 Vertical Gas Collection Wells

The layout and density of the vertical gas wells has been designed for efficient extraction and transmission of landfill gas from all portions of the landfill. While well spacing (horizontal distance between the wells) may be standardized in a grid pattern, well spacing may also be determined by calculating a radius of influence (ROI) of each well. The ROI defines an area from which gas can be extracted without drawing excessive air into the landfill. The layout configuration for the Aqaba Landfill employs an approximate 60 m of equidistant spacing between wells, with a design maximum ROI of 40 meters such that their radii of influence overlap. It is noted that minimum well spacing for “typical” North American municipal solid waste industry LFG is about 1 well per hectare.

The minimum LFG well borehole diameter will be 1000 mm (1m) and the pipe casing for the wells will have a diameter of 225 mm (0.225m). Twenty-eight vertical gas wells are proposed. The well depth will vary with waste depth but will be no deeper than 30 meters, with a minimum clearance of 3 meters between the base of the well and the protective cover layer of the base liner system. The wellheads will be equipped with quick change orifice plate assemblies and precision control valves, as can be seen in the Design Details.

12.3.2 Gas Transmission Piping

The LFG laterals and header piping will be installed within a compacted backfill layer with a minimum of 150 mm of compacted backfill above and below each pipe. This facilitates the collection of LFG and provides structural support to the pipe. A minimum 600 mm (0.6m) thick layer of general backfill with an embedded utility identification tape will be installed above the compacted backfill, followed by the final cover soil.

All LFG pipes shall be PE 100 polyethylene, standard dimension ratio 17 (SDR 17) unless noted otherwise. Changes in horizontal alignment and vertical PE LFG pipes shall be accomplished by taking advantage of the flexural properties of the PE pipes whenever possible. The minimum bend radius for these shall be 27 times that of the pipe's outer diameter or 100 times that of the pipe's outer diameter when fittings fall on the bend.

Gas conveyance piping was designed to the appropriate minimum diameter that will convey flow at no greater than the selected maximum velocities for concurrent and countercurrent flow. Based on experience, the following maximum LFG flow velocities were used: 6.1m/s when LFG and condensate flow in opposite directions (counter-current flow) and 12.2m/s when LFG and condensate flow in the same direction (concurrent flow). The minimum lateral pipe size (gas well connection to main header) shall have a minimum nominal diameter of 100 mm. The minimum header pipe size on the landfill (connecting well field to the perimeter header) shall have a minimum nominal diameter of 150 mm. The minimum nominal diameter of the perimeter header pipe to the flare station will be 300mm. The contractor shall ensure that the LFG pipe slope is maximized while pipe depth is minimized. The LFG collection header system at Aqaba is designed with a minimum slope of 2.0% to provide for gravity flow of condensate to designed low points.

The LFG header pipe system will facilitate efficient LFG control by employing a looped piping system to provide an even distribution of blower vacuum to the vertical extraction wells. LFG header valves (butterfly valves or equivalent as approved by the engineer) will be distributed along the system as indicated on the Design Drawings.

12.3.3 Gas Condensate Management

Landfill gas condensate will be removed from the LFG header at a condensate knock-out (or knock-outs). Knock-outs may be designed to allow the condensate to drain back into the refuse mass and ultimately to the landfill's leachate collection system, or to a temporary holding tank outside the limits of waste. Based on assumed temperature, the amount of condensate generated at the proposed Aqaba Landfill was calculated to be an average of approximately 324 liters/day. The permanent LFG system piping will be sloped at a minimum of 2% to convey condensate to the engineered low point in the system adjacent to the flare station.

Due to the relatively small size of the landfill, the proposed geometry and alignment of the gas collection pipes have been oriented such that only one low-point is required near the landfill gas management area in the proposed infrastructure. An in-line condensate knockout with an interior baffle plate and sump will be installed prior to the enclosed flare system. Condensate from the knockout may then be pumped or drained by gravity to a condensate storage tank.

The condensate knock-out will be connected to the underground condensate holding tank via 110mm SDR 17 PE piping. The tank will have at least 2500 mm (2.5 m) of native soil cover over the crest. The tank will be double-walled steel construction in accordance to the USEPA Act 100 specifications or other similar specifications. It will be selected to operate under earth loads with a minimum of 150% safety factor. All the pipe connections on the tank shall be flanged and piping shall be PE unless otherwise noted and exposed metallic piping and metallic piping in the tanks shall be primed and coal tar epoxy painted. The holding tank will to be emptied by manual pumping through a suction pipe via a vacuum truck. The specified tank is 37,850 liters (10,000 gallons), making the actual storage capacity approximately 79 days based on anticipated condensate production of 482 L/day.

12.3.4 Blower and Flare System

The extracted LFG will be transferred via the header pipe to a Blower/Flare station which will be located within the infrastructure area adjacent to the leachate lagoon as indicated and detailed within the Design Drawings. The flare stack will rest on a concrete foundation and will include a flame arrester, a condensate drain port and an orifice plate between the blower and flare to measure the flow rate. The operational vacuum is to be a minimum of 0.254 m (10 inches) of water column at each well. The blower/flare capacity is to be 600 scfm with step down/turndown capability for lower flows. The blower calculation is the sum of the required minimum vacuum at the furthest well, the pressure losses in the LFG piping and pressure losses through the flare and flame arrestor. For the proposed system, this adds up to the minimum approximate blower vacuum of 0.508 m (20 inches) of water column.

12.3.5 Conveying Gas to offsite energy recovery

If a third party is identified and contracted with, the LFG will be extracted from the landfill and delivered to a pipeline with a standard commercial blower system. The landfill gas delivered to the pipeline system will be initially passed through a filtering system to remove any filterable impurities, which could damage equipment. The filtered landfill gas will be directed to a single stage blower where its pressure will be raised to approximately 15 psig. The compressed landfill gas will be directed into a knockout tank where a large portion of the entrained water will be removed. The knockout tank has no vents; therefore, it has no air pollution potential. At this point in the fuel gas compressor process, the landfill gas will have a temperature of approximately 230°F and will be directed to a cooler (air to air) to reduce its temperature. The temperature reduction will force the condensation of water vapor in the gas. After the cooler, the gas will pass through a second coalescent filter to remove the condensed water vapor.

A dehydration system is then used to further remove entrained liquids. The condensate will be directed to a storage tank and then discharged to the facility’s on-site leachate storage facility.

Once the landfill gas is compressed in the gas compression system and the condensate is removed, the landfill gas will be moved into the pipeline system. This pipeline will be constructed of 16-inch diameter, HDPE pipe. It will be placed underground in a trench that is three feet wide. The top of the pipe will be three feet below the ground surface. The pipeline will begin on the west side of the landfill, at the gas compressor area next to the enclosed flare. The pipeline will be located along the north side of the facility and the gas will move in an easterly direction within the pipeline system.

This option is generally limited to a user facility within approximately 8 km of the Aqaba landfill facility. Although not practical to convey LFG to the City of Aqaba itself, there remains the opportunity to possibly forward LFG to a facility along the coastal communities southeast of the main city.

13 Monitoring

13.1 Design Strategy

In the United States, environmental monitoring in the vicinity of landfill is required by law as part of EPA regulations for landfill design, construction, and operation. The final set of monitoring requirements is site specific and depends on the risk of contamination. Landfill gas detection monitoring and groundwater monitoring are discussed below for further consideration prior to implementation of the project.

13.2 Landfill Gas Detection Monitoring

A LFG monitoring system typically consists of gas probes installed around the site perimeter that measure the gas concentrations at regular intervals. Probes are constructed to a minimum diameter of 100 mm with threaded pipe connections. A minimum of 3000 mm (3m) of the 32 mm diameter PN16 PVC-U is perforated with 5mm diameter holes. The borehole depths will vary and must be field verified prior to drilling.

13.3 Groundwater Monitoring

At a minimum, a groundwater monitoring network consists of one upgradient and two groundwater monitoring wells. If wells are installed, general parameters that should be obtained during a monitoring event consist of:

- Static water level (field parameter)
- Specific conductivity (field parameter)
- pH (field parameter)
- Dissolved oxygen (field parameter)
- Turbidity (field parameter)
- Temperature (field parameter)
- Color and sheens (by observation)

USEPA Subtitle D recommendations for groundwater monitoring recommend at a minimum the sampling and analysis of the following Constituents for Detection Monitoring:

From Appendix I to Part 258—Constituents for Detection Monitoring

	Common name	CAS RN2
Inorganic Constituents:		
(1)	Antimony	(Total)
(2)	Arsenic	(Total)
(3)	Barium	(Total)
(4)	Beryllium	(Total)
(5)	Cadmium	(Total)
(6)	Chromium	(Total)
(7)	Cobalt	(Total)
(8)	Copper	(Total)
(9)	Lead	(Total)
(10)	Nickel	(Total)
(11)	Selenium	(Total)
(12)	Silver	(Total)
(13)	Thallium	(Total)
(14)	Vanadium	(Total)
(15)	Zinc	(Total)

Organic Constituents:

(16)	Acetone	67–64–1
(17)	Acrylonitrile	107–13–1
(18)	Benzene	71–43–2
(19)	Bromochloromethane	74–97–5
(20)	Bromodichloromethane	75–27–4
(21)	Bromoform; Tribromomethane	75–25–2
(22)	Carbon disulfide	75–15–0
(23)	Carbon tetrachloride	56–23–5
(24)	Chlorobenzene	108–90–7
(25)	Chloroethane; Ethyl chloride	75–00–3
(26)	Chloroform; Trichloromethane	67–66–3
(27)	Dibromochloromethane; Chlorodibromomethane	124–48–1
(28)	1,2-Dibromo-3-chloropropane; DBCP	96–12–8
(29)	1,2-Dibromoethane; Ethylene dibromide; EDB	106–93–4
(30)	o-Dichlorobenzene; 1,2-Dichlorobenzene	95–50–1
(31)	p-Dichlorobenzene; 1,4-Dichlorobenzene	106–46–7
(32)	trans-1, 4-Dichloro-2-butene	110–57–6
(33)	1,1-Dichlorethane; Ethylidene chloride	75–34–3
(34)	1,2-Dichlorethane; Ethylene dichloride	107–06–2
(35)	1,1-Dichloroethylene; 1,1-Dichloroethene; Vinylidene chloride	75–35–4
(36)	cis-1,2-Dichloroethylene; cis-1,2-Dichloroethene	156–59–2
(37)	trans-1, 2-Dichloroethylene; trans-1,2-Dichloroethene	156–60–5
(38)	1,2-Dichloropropane; Propylene dichloride	78–87–5
(39)	cis-1,3-Dichloropropene	10061–01–5
(40)	trans-1,3-Dichloropropene	10061–02–6
(41)	Ethylbenzene	100–41–4
(42)	2-Hexanone; Methyl butyl ketone	591–78–6
(43)	Methyl bromide; Bromomethane	74–83–9
(44)	Methyl chloride; Chloromethane	74–87–3
(45)	Methylene bromide; Dibromomethane	74–95–3
(46)	Methylene chloride; Dichloromethane	75–09–2
(47)	Methyl ethyl ketone; MEK; 2-Butanone	78–93–3
(48)	Methyl iodide; Idomethane	74–88–4
(49)	4-Methyl-2-pentanone; Methyl isobutyl ketone	108–10–1
(50)	Styrene	100–42–5
(51)	1,1,1,2-Tetrachloroethane	630–20–6
(52)	1,1,2,2-Tetrachloroethane	79–34–5
(53)	Tetrachloroethylene; Tetrachloroethene; Perchloroethylene	127–18–4
(54)	Toluene	108–88–3
(55)	1,1,1-Trichloroethane; Methylchloroform	71–55–6
(56)	1,1,2-Trichloroethane	79–00–5
(57)	Trichloroethylene; Trichloroethene	79–01–6
(58)	Trichlorofluoromethane; CFC–11	75–69–4
(59)	1,2,3-Trichloropropane	96–18–4
(60)	Vinyl acetate	108–05–4
(61)	Vinyl chloride	75–01–4
(62)	Xylenes	1330–20–7

It is worth noting here that as per the USEPA regulations these monitoring requirements should be site-specific and may be suspended if the owner/operator of the landfill demonstrates that there is no potential migration of hazardous constituents from that landfill to the uppermost aquifer during the active life of the landfill and the post-closure care period. For the proposed Aqaba project, the ground water table is deep under the landfill (more than 100 m deep) and anticipated rain fall is low (average yearly 16 mm with a range of 1 to 33 mm). Therefore, it may be possible to waive some of these monitoring requirements.

14 Quantity Estimates

This section includes the quantity estimates for infrastructure needed at the landfill, phased cell construction, and phased closure and gas management installation. Operations & Maintenance (O&M) and post-closure care have not been evaluated.

14.1 Infrastructure

As discussed above, landfill infrastructure and other facilities will be required in support of security, access, operations, management, and monitoring functions. These facilities will be constructed in advance of, or in conjunction with the initial cell and are included within the quantity estimates for the first cell.

- Perimeter security fencing with a lockable access gate(s)
- Crushed stone surfaced access roads
- Site office/maintenance building
- Fuel dispensary
- Lined leachate evaporation lagoon
- Landfill gas generation facility with a backup utility/enclosed flare station
- Stormwater management basin
- Three groundwater monitoring wells
- Utility extensions/improvements

Conceptual quantity estimates are included within Table 1.a in Appendix H.

14.2 Cell Construction

The landfill will be designed with four cells, each draining to its own sump from which collected leachate will be pumped to the leachate evaporation lagoon. Each cell will be segregated from adjacent cells with a 1.5 meter (minimum height) lined interim/intercell berm. Quantity elements included in the construction of each of the four cells include:

- Subgrade excavation
- Subgrade fill
- Perimeter access road and concrete or stone lined stormwater channel
- Liner cushion layer (150 mm thick)
- Geosynthetic Clay Liner (GCL)
- 60 mil HDPE liner layer
- Nonwoven geotextile cushion layer
- Protective cover/leachate collection layer (450 mm thick)
- PVC leachate collection piping system
- Leachate sump/risers/pumping system
- Perimeter utilities (leachate forcemain, gas header and electrical)
- Quality assurance during construction

Major cell construction quantities are summarized in Table 14-1. Quantity estimates are included within Tables 1.a through 1.d in Appendix H.

Table 14-1: Major Construction Quantities

Cell I.D.	Subgrade Cut (m^3)	Subgrade Fill (m^3)	Liner Area (m^2)	PVC Piping (m)	Perimeter Forcemain (m)	Perimeter Electric (m)	Perimeter Gas (m)
Infrastructure	93,642	29,379	NA	NA	NA	NA	NA
Cell 1	247,902	47,926	29,790	265	475	375	475
Cell 2	291,324	59,353	30,485	250	345	345	345
Cell 3	163,353	24,037	23,245	195	25	25	295
Cell 4	187,622	5,250	29,335	185	25	25	310
Totals	**983,843**	**165,945**	**112,855**	**895**	**870**	**770**	**1,425**

14.3 Phased Closure and Landfill Gas Management System

The landfill will be closed in phases with an ET cover to minimize potential infiltration of stormwater into the waste mass, to control odors and limit other nuisances such as mosquitos and vermin, and to allow for earlier and more efficient gas collection/utilization. Quantity elements included in closure and gas management system estimates include:

- 1.35 m (maximum thickness) ET soil cover
- 0.15 m (minimum) gravel layer for erosion control
- Permanent landfill gas extraction wells
- Permanent landfill gas piping

Minimum phased closure and gas management system quantities are summarized in Table 14-2 as quantities constructed by the end of filling in each phase as indicated on the design drawings. Quantity estimates are included within Table 2 in Appendix H.

Table 14-2: Closure Cap and Landfill Gas Management Quantities

Cell I.D.	Capping Area (m^2)	Permanent Wellheads (each)	Drilling Depth (meters)	Gas Piping (meters)
1	8,657	2	22	103
2	11,551	3	50	141
3	9,285	3	39	116
4	87,462	20	423	1,165
Totals	116,915	28	534	1,525

It is noted that temporary wells, trench wellheads and perforated gas collection trenches may also be installed at any time during development of the cell depending on the need for active gas management prior to phased installation of the ET cover. These are not included in the quantity estimate.

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