Ministry of Public Works, Infrastructure and Utilities
Republic of Marshall Islands

Bidding Document of the Procurement of Works
Small Contracts (SBD Works - Small)

ENGINEERING DESIGN REPORT

PROJECT DESCRIPTION
AND
DESCRIPTION OF WORKS
(Section 6, Volume I)

Ebeye Solid Waste Management Project

Executing Agency	Funding Agency	Implementing Agency	Beneficiary Institution
Ministry of Finance, Banking and Postal Services	Asian Development Bank (ADB)	Ministry of Public Works, Infrastructure and Utilities	Kwajalein Atoll Local Government

Document Structure

Volume I	Project Description and description of works
Volume II_a	Specific Technical Specifications
Volume II_b	Technical Specification of mobile and semi-mobile Equipment
Volume III	Technical Designs (General Master Layouts, Architectural, Structural, MEP)
Volume IV	BOQ and Supporting Documents

Supporting Documents

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1 Introduction

1.1 Background

The Republic of the Marshall Islands (RMI), in the northern Pacific Ocean, comprises 29 coral atolls and 5 coral islands and has a population of about 53,000. The RMI is highly vulnerable to natural hazards and climate change impacts. It is classified as a fragile and conflict-affected situation. Unemployment is high and human development indicators are generally low.

The RMI is heavily dependent on external assistance, with annual grants averaging about 60% of gross domestic product, mostly from the United States. RMI citizens can live and work in the US without a visa under the RMI's Compact of Free Association with the US, and a significant portion of the working-age population leave the RMI to pursue opportunities in the US. As a result, the RMI has a younger population than the rest of the Pacific. Ebeye, on Kwajalein Atoll, is the second-largest urban center in the RMI and one of the most densely populated places in the world, with about 10,000 people living in 0.31 square kilometers, placing pressures on urban services, and creating social challenges. Because of substantial migration to the US, the population of Ebeye increased by only 0.4% per annum in 1999 – 2011. The island has no airport, and most visitors arrive through the US Army Garrison Kwajalein Atoll.

The US base is the major employer of Ebeye residents; other jobs are limited because of the lack of any industry. With the ongoing support of the Asian Development Bank (ADB), Ebeye residents receive improved water supply and sanitation services. Municipal Solid Waste Management (SWM), however, remains one of the most serious challenges.

At present the Kwajalein Atoll Local Government (KALGov) collects municipal solid waste (household, commercial, and institutional) 6 days a week. At least one garbage bin is provided to each household and waste from a household is collected 2–3 times a week. KALGov collects about 2,200 tonnes per year of municipal solid waste (MSW). Most waste is collected by KALGov's single compactor truck, whilst about one-third is delivered directly to the dumpsite by private citizens and businesses.

Since 2005 an old quarry has been operated by KALGov as a dumpsite at the north end of the atoll. The dumpsite is poorly operated, the collected waste is piled randomly within the site and not compacted. The dump site is a prime location for mosquito breeding, which led to a major outbreak of dengue fever in 2019. It is an environmental nuisance and leachate pollutes the lagoon. The dumpsite is in danger of being inundated because of rising sea-levels.

Waste collection and management equipment operated by KALGov is often deficient. The harsh marine environment and a lack of maintenance resources shortens its operating life. This project is located at the Ebeye dumpsite on Ebeye Island which is part of the Kwajalein Atoll which in turn is part of the Republic of the Marshall Islands.

1.2 Objective

The Republic of Marshall Islands (RMI) government has requested assistance from the Asian Development Bank for the proposed Ebeye Solid Waste Management Project. The project will upgrade the waste disposal site and recycling facility and improve the coverage and sustainability of the integrated solid waste management service delivery in Ebeye, thereby protecting public health and the environment.

The overall project has three outputs: (i) a waste disposal site upgraded; (ii) municipal solid waste collection, transportation, and disposal operations enhanced; and (iii) institutional capacity to sustain SWM services delivery and local engagement strengthened. The project is aligned with the following impact: efficient, effective, resilient, sustainable and affordable services and facilities that promote sustainable economic growth provided. The Project executive agency is the Ministry of Finance, Banking and Postal Services and the implementing agency is the Ministry of Works, Infrastructure and Utilities.

This specific bid document includes the component number 1, i.e. waste disposal site facility upgradation, with a provision for future recycling, and composting operations. The project at site will be constructed by a contractor on construction contract for small works.

1.3 Planned Infrastructure and the Design Horizon

With a design period of approximately 20 years, the project components/facilities were planned up to the year 2044, with initial construction focused on the period to 2025-26. The concept designs prepared during the feasibility study stage were updated and elaborated upon as the basis for preparing the detailed designs described herein.

1.4 Scope of Work

The small works construction contract is considered to develop the following components for the site:

- Prior to the major landfill construction activities, the Prefabricated building and entrance road will be constructed. The initial work associated with this work is the excavation of legacy waste beneath a 20-meter by 40-meter footprint. This work will require excavation of approximately 3,000 cubic meters of legacy waste. This waste will be disposed of at the temporary legacy waste stockpile, which is discussed below
- Excavation of approximately 24,221 cubic meters of legacy waste in a two-phase effort.
    - The Phase 1 effort will include preparing the peripheral road through removing approximately 1,150 cubic meters of legacy waste, excavating approximately 10,453 cubic meters of legacy waste on the south side of the landfill and hauling and placing 11,603 cubic meters of waste into a temporary stockpile on the north side of the landfill.
    - The south side of the landfill begins at a line 65 meters west and parallel to the property's northern boundary that is adjacent to the existing operations building. The temporary legacy waste stockpile will be placed on the north side the landfill site, except for a footprint of 30 meters by 75 meters to include the existing operations building and existing entrance road to allow for on-going operations. The estimated storage volume of the stockpile is 14,200 cubic meters for the south side legacy waste and 1,000 cubic meters for ongoing disposal operations. The temporary stockpile shall be made available for use for on-going disposal operations.
    - The phase 2 effort will include excavating the temporary legacy waste stockpile on the north side of the landfill and transporting it into the newly constructed lined landfill cell on the south side of the landfill. The capacity of the phase 1 liner construction will be approximately 39,250 cubic meters.
- Placement of 13,100 square meters of engineered reinforced fill over the legacy waste to remain in place (Global Bridge Design), with approximately 7,860 cubic meters of soil backfill material for the entire landfill footprint (for both Phase 1 and 2). The engineered reinforced fill will consist of the following:
    - Place 30 cm of soil and compact.
    - Install a reinforcing geogrid (Geogrid #2).
    - Place and compact an additional 30 cm thickness of soil to reach final grade of liner floor.
- Placement of 3,472 square meters of Soft Spot mitigation consisting of engineered reinforced fill over the saturate legacy waste to remain in place (Saturated Zone Bridging Design), with approximately 625 cubic meters of rock, approximately 3,472 sqm of nonwoven geotextile, 750 cubic meters of backfill soil material for the landfill "Soft Spot" footprint. The engineered reinforced fill will consist of the following:

  - Place and set 50 cm of rock over saturated legacy waste (Soft Spot), currently estimated to be 25 m by 50 m in area. Estimated volume of rock is 625 cum.
  - Place thick nonwoven geotextile (minimum 16–24 oz/yd²) over rock layer, to extend 3 m beyond rock footprint, currently estimated at 31m by 56 m or 3,472 sqm.
  - Install a reinforcing geogrid (Geogrid#0) over thick nonwoven geotextile layer covering approximately 3,472 sqm.
  - Place 30 cm of soil and compact, over Geogrid #0 to cover approximately 3,472 sqm. Estimated volume is 375 cum.
  - Install a reinforcing geogrid (Geogrid#1) over soil layer covering approximately 3,472 sqm.
  - Place an additional 30 cm of soil and compact, over Geogrid#1 to cover approximately 3,472 sqm. Estimated volume is 375 cum.
- Placement of approximately 7,905 cubic meters of engineered fill to bring the peripheral road to design grade.
- Placement of approximately 3,000 cubic meters of engineered fill beneath the building and entrance road area.
- Installation of approximately 13,100 square meters of a liner system, consisting of geosynthetic clay liner and 80mil high density polyethylene liner, with texture on both sides. This work will be completed in two phases in coordination with the legacy waste excavation. The first phase will install approximately 7,600 square meters on the south portion of the landfill and the second phase will install approximately 5,500 square meters on the north side of the landfill.
- Installation of approximately 11,413 square meters of drainage geo-composite on the liner floor, covering both phase 1 and 2 liner installations.
- Installation of approximately 900 feet of 6 inch diameter corrugated HDPE pipe, serving as the leachate collection headers. These headers will be directly plumbed to the drainage geo-composite (Draintube or equivalent).
- Placement of an operational layer over the liner systems, consisting of 16oz/yrd2 non-woven geotextile over the 13,100 m² lined landfill cell. As part of the installation of this nonwoven geotextile, special waste placement procedures will be utilized for the first lift over the geotextile.
- Installation of approximately 550 meters of drainage channel on the Peripheral Road.
- Demolition of existing 20 meters by 17-meters operations building, 4 meter by 4 meter incinerator and 8 meter by 5-meter building.
- Installation of a new 570-meter-long anti-climb security fence around the landfill property.

- Installation of a 16 meter by 26 meter sedimentation basin with associated inlet and outlet structures.
- Installation of approximately 260 linear meters of landfill gas interception trench and passive vent.
- Installation of a scale house and 20-ton pitless weight bridge.
- Installation of 17 solar powered area lighting.
- Design and construction of a prefabricated administration and maintenance building, with an area of a maximum of 200 square meters.
- Design and Installation of 75 gpm, TDH 15 feet, Submersible Leachate Pump Station.
- Design and Installation of 500-gallon Diesel Fuel Storage System.
- Design and Installation of 550 gpm, TDH 70 psi Seawater Fire Pump System.
- Installation of three (3) temporary small-diameter drive-point wells within saturated legacy waste at the base of the landfill excavation; development and stabilization of the sampling wells; collection of leachate samples from each well; preparation of one composite sample; measurement of specified field parameters; laboratory analysis of the composite sample using a California Title 27 groundwater-equivalent analytical suite including required QA/QC; abandonment of the wells following sampling; and preparation of a monitoring report summarizing field activities, analytical results, and observations.
- The **design, supply, installation, maintenance, and removal** of project information signage for an Asian Development Bank (ADB)-financed project.

1.5 Work Elements Requiring Engineering Design

There are four elements of the Works that will require engineering design. These elements will be bid so that engineering is included in the bid items, following the specifications for each of the items. The items requiring engineering design are as follows:

- Prefabricated Administrative and Maintenance Building. This item includes the design, supply, installation, and commissioning of a prefabricated administrative and maintenance building at a landfill site. Work includes turnkey architectural and engineering services, coordination with the building manufacturer, utility connections, foundation design and construction, interior fit-out, and final handover.

- Submersible Leachate Pump Station. This item covers the design, supply, installation, testing, and commissioning of a submersible leachate pump system rated at 75 gallons per minute (GPM) at 15 feet total dynamic head (TDH), including sump construction, pump system, control panel, and all associated civil and electrical works.

- Diesel Fuel Storage System. This item covers the supply, installation, testing, and commissioning of a 500-gallon double-walled diesel fuel storage tank system, including site preparation, fuel and electrical connections, interstitial monitoring, and regulatory compliance.

- Seawater Fire Pump System. This item covers the design, supply, installation, testing, and commissioning of a seawater-compatible fire pump system rated at 550 gallons per minute (GPM) at 70 psi. Scope includes pump procurement, electrical and civil works, control systems, installation, and final commissioning.

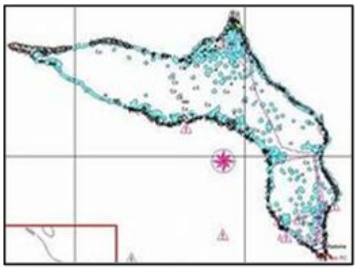
2 Baseline – Current Conditions

2.1 Geographical location and land use

Ebeye is an islet in the Kwajalein Atoll with a significantly altered terrestrial environment, consisting almost entirely of built environment. The current dump site is located at the northern end of the island and occupies an area of approximately 5.3 acres (2 ha). The coordinate of the site is (8°47'23.36"N, 167°44'5.57"E). The site is surrounded by lagoon at northerns and western side. On the eastern side there is a 10 m wide earthen road stretching from Ebeye to Gugeegue and the Ocean (beyond the road). On the southern side there is residential settlements.

The location of the project site is shown in the below figure.

Figure 1: Project Site



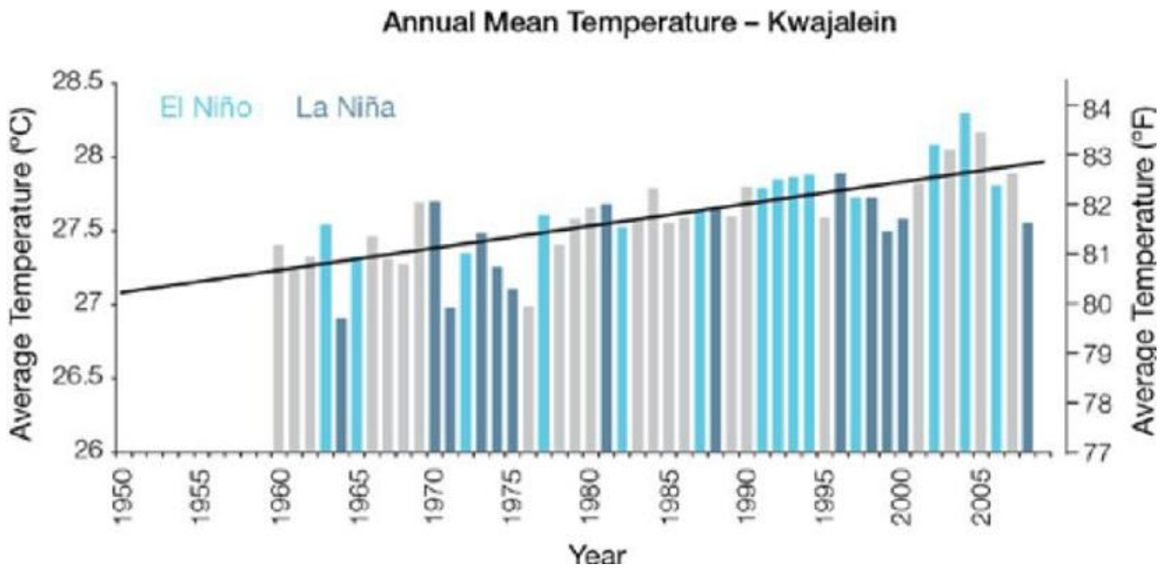
2.2 Terrestrial Environment

2.2.1 Climate

Located at latitude: 8^0 47' 33" north and longitude: 167^0 44' 56" east, Ebeye island is at the southern end of Kwajalein atoll, the world's largest atoll. The atoll has a total land area of 16 km2, with about 90 islands surrounding a 1,700 square kilometer lagoon. Ebeye is a small low-lying coral islet comprised of a land area of 32 hectares (80 acres), with a maximum elevation of about 3 meters (10 feet) above mean sea level. The climate is maritime tropical with slight seasonal and daily variations, with temperatures averaging about 27 degrees Celsius (Figure 8).

89. The rainfall of the RMI varies greatly from north to south. The atolls at $>10^0$ north receive less than 1250 mm (50 inches) of rain annually and are very dry in the dry season. Atolls $< 7^0$ north (closer to the equator) receive more than 2500 mm (100 inches) of rain annually. Both Majuro and Kwajalein have a dry season from around December to April and a wet season from May to November.

Figure 2: Average Temperature at Kwajalein



(Note: Light blue, dark blue and grey bars denote El Niño, La Niña and neutral years respectively.)

2.2.2 Climate Change

The International Panel on Climate Change (IPCC) recognizes that developing countries particularly small island developing states such as the RMI are particularly vulnerable to climate change. Projected sea level increases to the year 2100 are 0.35m to 0.70m, this rise, in combination with extreme sea level events, such as swell waves, storm surges, and El Niño-southern oscillation (ENSO) events, present severe sea inundation and erosion risks for low lying atoll islands. Locations currently experiencing adverse impacts such as coastal erosion and inundation will continue to be affected due to increasing sea levels. The contribution of mean sea level rise to increased coastal high-water levels, coupled with the likely increase in tropical cyclone maximum wind speed, is a specific issue for tropical small island states.

Based on the recent Technical Report (Pacific-Australia Climate Change Science Program, op cit.), for the period to 2100, the latest global climate model projections and climate science findings indicate:

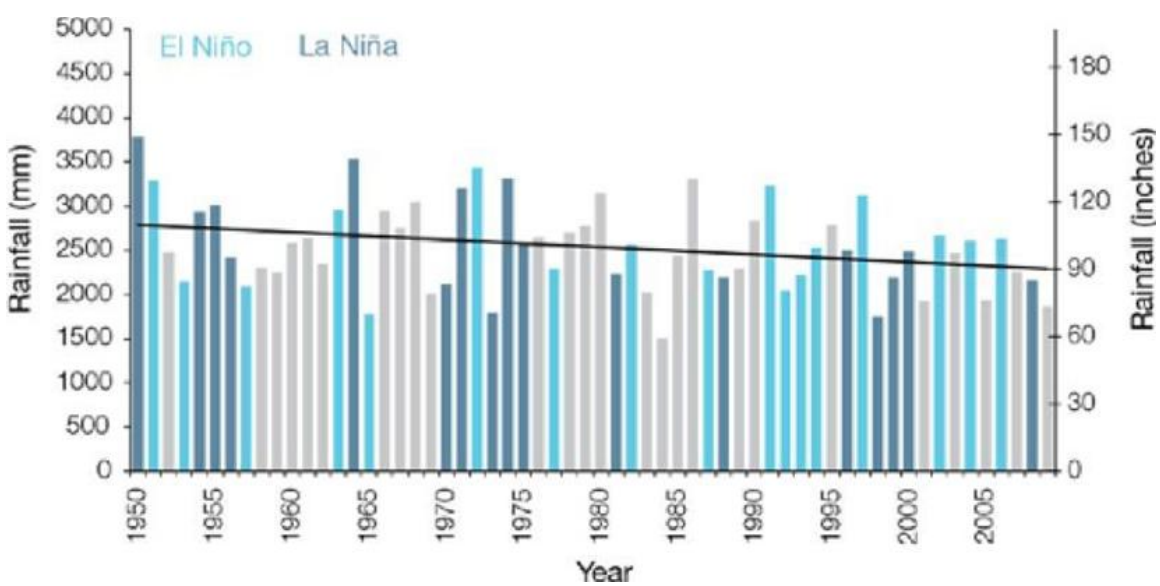
- El Niño and La Niña events will continue to occur in the future (very high confidence), but there is little consensus on whether these events will change in intensity or frequency;

- Annual mean temperatures and extremely high daily temperatures will continue to rise (very high confidence);
- Average rainfall is projected to increase (high confidence), along with more extreme rain events (high confidence);
- Droughts are projected to decline in frequency (medium confidence);
- Ocean acidification is expected to continue (very high confidence);
- The risk of coral bleaching will increase in the future (very high confidence);
- Sea level will continue to rise (very high confidence); and
- Wave height is projected to decrease in the dry season (low confidence) and wave direction may become more variable in the wet season (low confidence)

While relatively warm and cool years and decades will still occur due to natural variability, there is projected to be more warm years and decades on average in a warmer climate.

There will still be wet and dry years and decades due to natural variability, but most models show that the long-term average is expected to be wetter. The effect of climate change on average rainfall may not be obvious in the short or medium term due to natural variability.

Figure 3: Annual Rainfall Kwajalein



2.2.3 Drought

For both the northern and southern RMI the overall proportion of time spent in drought is expected to decrease under all global climate model scenarios.

2.2.4 Tropical Cyclone

There is a growing level of agreement among models that on a global basis the frequency of tropical cyclones is likely to decrease by the end of the 21st century. These projections are consistent with those of Australian Bureau of Meteorology and CSIRO (2011).

2.2.5 Sea Level Rise

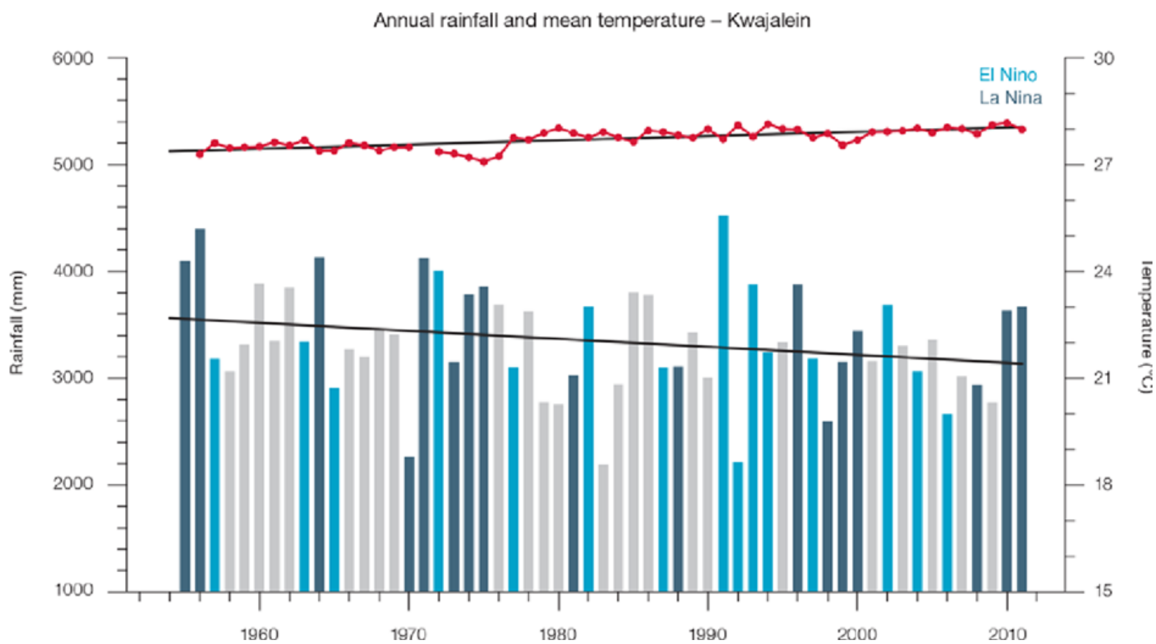
Mean sea level is projected to continue to rise over the course of the 21st century. There is very high confidence in the direction of change. Several global climate models (CMIP5, RCPs) simulate a rise of between approximately 3 to 7.5 inches (7–19 cm) by 2030. Inter-annual variability of sea level will lead to periods of lower and higher regional sea levels. In the past, this year-to-year variability has been about 8 inches (20 cm), and it is likely that a similar range will continue through the 21st century. The sea level rise near the Marshall Islands measured by satellite altimeters since 1993 is about 0.3 inches (7 mm) per year.

Sea level is also generally higher around the Marshall Islands during La Niña events, with three of the top 10 water levels recorded at Kwajalein occurring during La Niña and none during El Niño (Australian Bureau of Meteorology and CSIRO, 2011). Tide gauge data show the strong annual variability in tide heights and indicate that ENSO events are a significant component of high-water levels. The Weather Service Office has recorded that roads in both Majuro and Ebeye are affected by significant inundation on almost every equinox tide during La Niña conditions. During December 2008, a State of Emergency was declared following weeks of high seas which resulted from storm surges coinciding with high tides and two tropical depressions (UNOCHA, 2009). The populated areas of Majuro and Ebeye suffered damage to roads, houses, and other infrastructure on the low-lying atolls. A similar event occurred in June-July 2013, mainly affecting Majuro.

Tropical cyclones (typhoons) usually form between September and November but are often weak when they pass through the Marshall Islands' region. Nevertheless, RMI was affected by devastating cyclones several times in the last few decades. For example, typhoon Paka in 1997 caused severe damage to crops and damaged 70% of houses on Ailinglalap Atoll, with total damage estimated at US$80 million for the entire nation. Typhoons Zelda, Axel and Gay each caused significant damage and losses with the space of one year (1991-1992). Tropical Storm Roy impacted Kwajalein in 1988.

ENSO events also modulate temperature and rainfall in the western equatorial Pacific Ocean. Droughts generally occur in the first four to six months of the year following an El Niño. During severe El Niño events, rainfall can be suppressed by as much as 80%. The dry season begins earlier and ends much later than normal. Variability in temperature and rainfall, during ENSO events is shown in the below figure.

Figure 4: ENSO Events and Impacts on Rainfall and Temperature



(Note: Observed time series of annual average values of mean air temperature (red dots and line) and total rainfall (bars) at Kwajalein. Light blue, dark blue and grey bars denote El Niño, La Niña and neutral years respectively. Solid black trend lines indicate least squares fit)

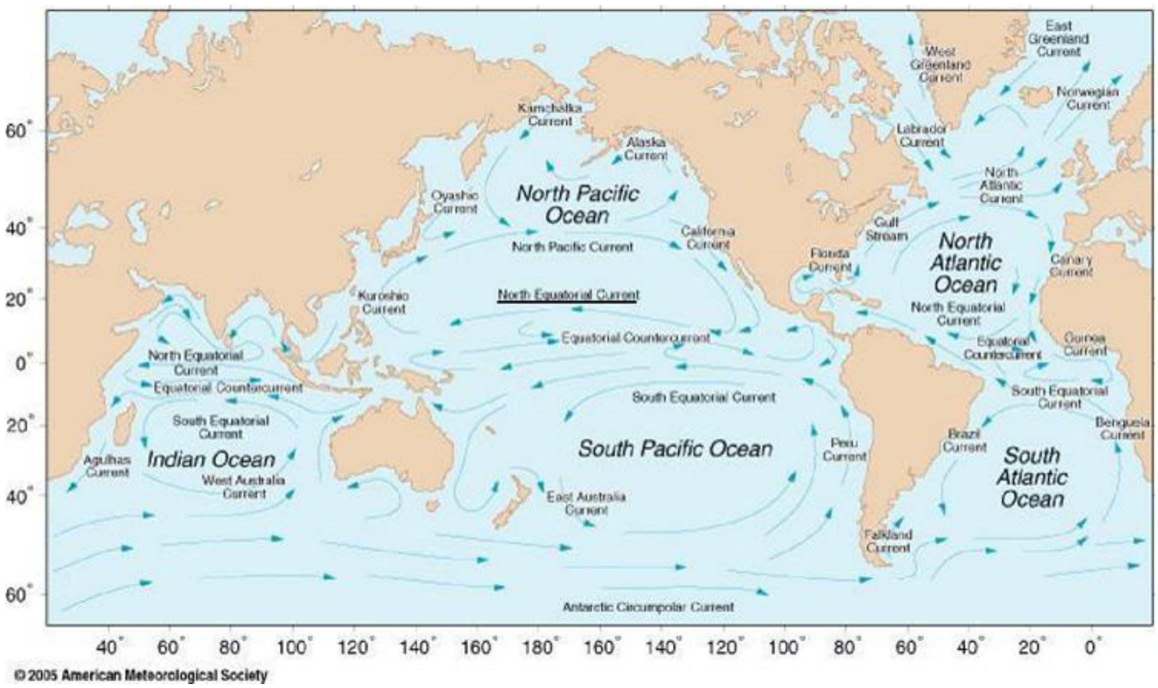
2.3 Physical Environment

2.3.1 Geology and Geomorphology

The atolls of the Marshall Islands are made up of calcareous remains of coral growth that have accumulated over millions of years on the peaks of submerged mid-oceanic volcanic islands. The atoll and islands lie in two parallel chains: Ratak (meaning sunrise) to the east, and Raliik (sunset) to the west. The two atoll chains are approximately 130 miles (209km) apart and are aligned diagonally northwest to southeast between 160o east-173o east and 04oN-15o north.

Most atolls of the Marshall Islands consist of an irregular shaped reef-rim with numerous islets encircling a lagoon with water depths that can reach 200 feet (60 m). The islets are more prevalent on the windward side. The atolls vary in size from Kwajalein, the largest Pacific atoll with 6.3 square miles (16.4 km2) of dry land and a lagoon of 840 square miles (2,174 km2). Ebeye Island is located at the lower, southeastern area of Kwajalein atoll.24 Ebeye lies at the southern edge of the Pacific North Equatorial Current (Latitude: 8° 47' 33" N, Longitude: 167° 44' 56" E); as such, ocean prevailing currents flow easterly, and towards the eastern shore of the island.

Figure 5: Pacific North Equatorial Current (NEC)



2.3.2 Soil

According to the US Department of Agriculture - Natural Resources Conservation Service, survey of soils in Majuro and several other islands in the Ratak chain, the main soil component in the atoll islands is classified as the Majuro series. With the climate, parent material, topography, vegetation, and age of soils being fairly uniform throughout the atoll islands, we can extrapolate that soils on Ebeye Island are similar.25 The Majuro series consists of very deep, somewhat excessively drained soils that formed in water deposited coral rubble and sand. Slope is 0-2%. These soils are sandy-skeletal, carbonate in composition. The water table (saltwater) is typically encountered at 1 to 1.8 meters depth.

2.3.3 Freshwater Resources

Groundwater exists as a basal aquifer, often called a freshwater lens—the Ghyben-Herzberg lens--on many atoll islands. Water quality varies from somewhat fresh to brackish. The lens is recharged by rainfall that percolates through the highly permeable coral soil. The groundwater level and salinity fluctuate with the sea tidal level. There are a few private wells in use in Ebeye, the water being brackish to mildly brackish, the well water is typically bailed by bucket. High groundwater salinity was found during the hydrology investigation in March 2014, despite high rainfall during the previous month. This indicates there is low potential for fresh groundwater use, and given the minimal lens formed under the narrow island, the width of which averages 250 meters across. There are no surface water resources existing on Ebeye.

2.3.4 Marine Water Resources

Marine water quality in Ebeye is monitored by the RMIEPA. Sample test results for period 2011 to 2014, at numerous sampling locations along the near shore reef of the western lagoon, greatly exceed the Class B water quality standard for microbiological pollution indicators (Enterococci). Coastal erosion is a serious concern in Ebeye, where construction of sea walls, coastal dredging, and beach sand mining has severely impacted the natural beach barrier.

2.3.5 Flora and Fauna

Well over 90% of the Ebeye community area is built environment. Vegetation primarily consists of plantings amongst residences and yards, such as: coconut, Terminalia catapp, tropical almond ('kotel'), Morinda citrafolia, noni, ('nin'), and ornamentals. Casuarina litorea, ironwood pines, are also common, planted as windbreaks, and along property boundaries. Scaevola taccada 'beach cabbage' or 'naupaka' dominates the shoreline north of the community, on the causeway to Gugeegue village. Observed fauna consisted mainly of introduced species such as dogs, cats, and rats. Resident and migratory shorebirds are common along the fringing reef.

2.3.6 Marine Flora and Fauna

Most coral reef ecosystems in the Marshall Islands are in excellent condition, with the outer atolls supporting healthy and diverse communities of marine life. Increasing threats from fisheries, including illegal fishing methods, climate change, and increasing urbanization, are impacting coastlines and coral reefs, especially near the population centers of Majuro and Ebeye.

A survey of the benthic morphology and marine life of the lagoon reef was conducted in 2015, for a proposed route for a new sewer outfall pipeline. The survey findings raised several ecological concerns including:

- non-coral invertebrates are largely absent from the reef, especially giant clams;

- Large (>20cm) and medium (10-20cm) fish are also largely absent from the reef;

- Coral cover varies from 5-50% across the survey sites. The high average is largely due to the particularly good coral in proximity to the middle part of the existing wastewater line. The area of primary concern for protection, however, is the shallow rise in the reef along the proposed wastewater route, where live corals are situated within a field of unconsolidated coral rubble. The deeper coral heads have already shifted to macroalgal dominance, with low coral biodiversity; and

- Upwards of 25% of the sandy substrate beyond the outfall is covered with cyanobacteria algae and fine silty sediment 2-3mm thick. This is a significant amount and is largely responsible for the supply of nutrients and silt to the deeper coral heads.

2.3.7 Threatened, Rare or Protected Species

No threatened, rare, or protected species (terrestrial or marine) were identified by the project. No conservation or protected areas have been established for Ebeye Island.

2.4 Social Environment

2.4.1 Socio-Economic Condition

Public sector spending and contributions from the United States, via the Compact of Free Association, largely drives the RMI's relatively small national economy. The government sector accounts for 41% of formal employment and 40% of GDP (including state owned enterprises). The US Test Site on Kwajalein also accounts for one-third of economic activity. The fragile nature of energy and food security was evident when a State of Economic Emergency was declared in 2008 following rising inflation which peaked at 30.1%. High food and fuel prices resulted, highlighting the vulnerability of the RMI to external market variations.

Some 94% of the employed Marshallese population worked in paid employment (11,932), with the private sector employing 41% of paid employees, ahead of the government sector at 35%. In all forms of employment males are more prevalent than females, at 65% male to 35% female. From 1999 to 2011, formal employment, in both the private and public sectors, increased by 1,848, with public sector growth (1,074) ahead of private sector job creation (772).

The 2011 Census reports that 15.2% of all Kwajalein households reported no income and another 7.8% reported less than $3,000 annual income. In total, 23% of all households thus reported incomes of less than $3,000 per year or less than $8.22 per day. With an Ebeye census average of 8.7 people per household (likely higher for poorer households), that means 23% of the Ebeye population is living on less than $0.94 per day with little or no subsistence income.

Vulnerabilities are linked to both physical and social characteristics of its islands and people, in addition to ongoing unsustainable development practices. Key drivers of the RMI's vulnerability include:

- Rapid population growth and over-population in urban centers.
- Low elevation and small atoll islands.
- Unsustainable development.
- Localized pollution (including contamination of water supply), poor waste management, sanitation, and environmental degradation.
- Climate change impacts including accelerated sea level rise, which may increase vulnerability and exposure to shocks and stresses, as well as increase intensity of extreme events.
- Limited resources (particularly food, water and fuel).
- Limited economic potential due to small size and remoteness.
- High exposure to external market shocks (demonstrated by the State of Economic Emergency declared in 2008 following unprecedented increases in costs of imported food and fuel).
- Sparse and scattered nature of islands and atolls, making communication and transportation to outer islands more difficult, with infrequent and unreliable transport links

2.4.2 Ethnographical Condition

The safeguards assessment for indigenous people, prepared for the project, found that "Ebeye people" do not constitute a distinct cultural group, "Ebeye people" are not dominated by another Marshallese cultural group or groups, and “Ebeye people” do not speak a language that is distinct from the Marshallese language spoken by other Marshallese. Thus, “Ebeye people” are not defined as Indigenous Peoples under the SPS.

2.4.3 Land Ownership and Use

Most land in the urban area of Ebeye is occupied with permission from the traditional chiefs (Iroji/Alap): 71% with permission from Iroji/Alap, 21% by family rights or closely related to title holder, 4% hold land title. The Public Lands Act 1966 declares that all marine areas below the high watermark belong to the national government. The owner of land abutting the ocean or lagoon shall have the right to fill in, erect, construct and maintain piers, buildings, or other construction on or over the water or reef abutting his land and shall have the ownership and control of such construction; provided, that said owner first obtains written permission of the Chief Secretary before beginning such construction.

2.4.4 Education

The 2011 Census shows 17% of the population six years and older have completed either high school (Grade 12) or GED, while another 12% have completed some college or higher. Almost one-fourth (24%) have completed grade 9–11, while those who have completed grade 8 comprise 14 percent. Over a quarter of the population (28%) six years and older have completed elementary grades 1–7, and 3 percent have competed pre-school. Only 2% were reported to have never been to school. More males than females were reported to have completed a higher level of education. While 13.1 percent of males have at least some college education as compared to 9.9% of females, there is very little difference in the percentage of those who have completed high school or GED by sex. However, more females than males were reported to have completed grade 8–11. The proportion of the Kwajalein population having completed at least a secondary level of education is 27.5%.

2.4.5 Poverty

As in most Pacific countries, cash or material poverty is a sensitive and often controversial topic. This stems from strong cultural beliefs and practices of ‘caring and sharing’ for those vulnerable and where no one gets hungry. Acknowledging the presence of poverty challenges the traditional foundation of the society and strength of its culture.

In a recent RMI national report, in preparation for the 2014 Small Island Developing States (SIDS) conference in Samoa, the issue of 'economic inclusiveness' was addressed, stating "Inclusive economic development is predicated upon eradicating income poverty and hunger, reducing inequalities, and ensuring decent work and productive employment.” In 2009, the RMI’s progress on Millennium Development Goal 1, Eradicate Extreme Poverty and Hunger, was mixed. While the RMI did not yet have abject or extreme poverty, the RMI was not on track to meeting the three targets under Millennium Development Goal 1. More recently, the 2010 Majuro and Kwajalein Household Water Survey concluded that poverty was a real and serious problem in urban areas of the RMI, with households facing problems such a no water, no electricity, high unemployment, stagnant wages, rising prices, a need for improved government services, and access to information.

2.5 Seismicity Condition of the Area

According to the GFDRR (Global Facility for Disaster Reduction and Recovery) of the World Bank the Republic of the Marshall Islands is located in a relatively quiet seismic area, right in the center of Pacific "ring of fire," which aligns with the boundaries of the tectonic plates. However, no significant earthquakes have been observed in recent history in the center portion of the ring except a historical record of tsunami in 1899 in the RMI, generated by a large earthquake in Papua New Guinea, but there is no important record of past major earthquakes in the islands. Therefore, RMI has a relatively low 40% chance in the next 50 years of experiencing (at least once), very weak levels of ground shaking which are not supposed to cause significant damages to well-engineered buildings.

2.6 Topographical investigation and features

2.6.1 Survey Objective

A topographical investigation was carried out with the following objectives:

- Complete topographical survey with spot levels and preparation of contour plan with 0.3 m interval.
- Level survey with spot level grid of 5 m x 5 m.
- Setting up temporary bench mark (TBM).
- Setting up a local coordinate system with respect to the magnetic North for future identification or reference frame.
- Actual Mean Sea Level of the Temporary bench mark to be established in the site

2.6.2 Output of the Topographical Survey

The topographical survey and the mapping have been carried using drone / fully automated Unmanned Aerial Vehicle (UAVs). Temporary Benchmark (BM) has been established and following key feature have been included in the map (As annexure of this bid document) :

- Topographical map - PDF Format showing main features of the Ebeye disposal site and adjoining areas.
- Key map.
- Total Site boundary and survey area boundary.
- Island coast line around all sides of the dumpsite .
- Surrounding features including the peripheral roads, boundary wall, waterbody drains, if any.
- Roads inside and outside of the site, access road.
- Electric poles & cables or any sort of utility items/lines etc.
- Permanent/temporary structure within the site.
- Nearby houses/ settlements/ permanent structures.
- Reduced level
- Northing-easting coordinate data

3 Waste Generation and Disposal Pathway

Around 10,375 people live on Ebeye island and adjoining smaller islands of Kwajalein atoll. As per the field study conducted in September 2023, on average the island generates around 8.17 tons of waste on daily basis.

KALGOV collects waste from residents on Ebeye, Guegeegue, Eboj, North Louj, South Louj and Coconut though its garbage collection vehicle. The vehicle collects and delivers 6.4 TPD of waste to the disposal site through two daily trips. Additionally, 0.7 TPD of waste is brought to the site directly by households and business entities.

4 Geotechnical Condition of the Site and Ground Improvements

4.1 Geotechnical Investigation Carried Out

4.1.1 Background of Investigation

The primary concern for the geotechnical investigation which was carried out in 2022, was to assess the subsurface condition in order to facilitate the geotechnical design of the foundations for the load bearing structures, such as - new incinerator, sheds and other civil structures. Five trial pits have been excavated on site. Five trail pits were made for the investigation. The final excavation depth was governed by the level of the coral rock.

No other laboratory tests or site investigation direct testing have been performed on site, since most of the extracted material is made by urban waste and it's very difficult and complex to characterize. Geophysical site investigation options have also proved to be difficult to perform, because of the same difficulties described above.

Penetrometric tests have also proved unfeasible for the same reasons and the Scala penetrometer, available in Ebeye, has been found too light for the purposes of the design.

The location of the pits is shown in the below figure.

Figure 6: Location of Geotechnical Investigation Pit

4.2 Observation and Findings from the Geotechnical Investigation

4.2.1 Stratigraphic Observations

The observation and finding from the geotechnical investigation are presented in the table below.

Table 1: Key Finding of Geotechnical Investigation

Pit No	Ground Water Depth (m bgl)	Stratigraphy
1	1.25 m bgl	• N 08degree 47.437' E 167degree 44.071' • Coarse sand with typical size aggregate from half (1/2) inch to three (3) inch sizes (1.2 to 3.6cm)

Pit No	Ground Water Depth (m bgl)	Stratigraphy
		• Fair amount of bigger rocks. No mud or clay • Reef to the final resting water level at 34 inches (~3ft) (0.85m) • Reef to ground level is about 84 inches (7ft) (2.1m) • Water flow estimated to be modest • Sample not collected
2	2.6 m bgl	• N 08degree 47.434' E 167degree 44.106' • 100% rubbish • No sand, no mud & no compost • Black water • Water flow estimated to be fast • Reef to final resting water level at 60 inches (5ft) (1.5m) • Reef to ground level at 162 inches (13.5ft) (4.1m) • Sample not collected due to no soil
3	1.8 m bgl	• N 08degree 47.397' E 167degree 44.107 • Coarse sand at upper level with lots of bigger rocks and debris couple feet below • Some compost • Black water • Reef to final resting water level at 36 inches (3ft) (0.9m) • Reef to ground level at 108 inches (9ft) (2.7m) • No soil sample collected due to 90% rubbish with larger debris & rocks
4	1.9 m bgl	• N 08degree 47.388' E 167degree 44.090' • No sand, no rock • 100% rubbish, debris and lots of plastics • Reef to final resting water level at 108 inches (9ft) (2.7m) • Reef to Ground level is 180 inches (15ft) (4.6m) • Water flow estimated to be fast • Black water • No soil sample collected due 100% rubbish
5	1.6 m bgl	• N 08degree 47.448' E 167degree 44.091' • Some coarse sand mixed with compost; ~5%-10% • 90% rubbish, black water • No clay or silt • Reef to final resting water level at 33 inches (2.75ft) (0.8m) • Reef to ground level at 96 inches (8ft) (2.4m) • Water flow estimated to be fast • No soil sample collected due 90% rubbish

4.2.2 Key Issues with the Subsurface Condition of the SIte

The key issues with the geotechnical condition of the site are highlighted below:

- The stratigraphic conditions found on site do not allow to simply lay down the new foundations on the existing soil, even in the presence of small loads. Waste is not capable of supporting any load and the coral rock beneath, even if a relatively shallow depth, cannot be easily reached.

- The waste, even when mixed with soil and gravel as found in some of the pits, has a very low strength and high deformability which are making it not suitable for sustaining a building.

- Both the corals and mixed layers of waste and natural soil are highly inhomogeneous in terms of depth and cannot provide a strong founding base (even for small incinerator).

- The presence of the marine groundwater makes also things more complicated: it would be impossible to excavate in the presence of such great amount of water.

- The design solution must then avoid the excavation of the area.

- There is a requirement of ground improvement with partial soil replacement and the formation of a new founding reinforced engineered fill which will support the incinerator and the ancillary buildings.

4.2.3 Appreciation of the Latest Geotechnical Investigation Report (March 2025)

An additional geophysical investigation was implemented to support a design effort for an incinerator building. The investigation consisted of ten excavation pits. The results of the investigation is presented below:

Figure 7: Location of Boreholes and Proposed Layout

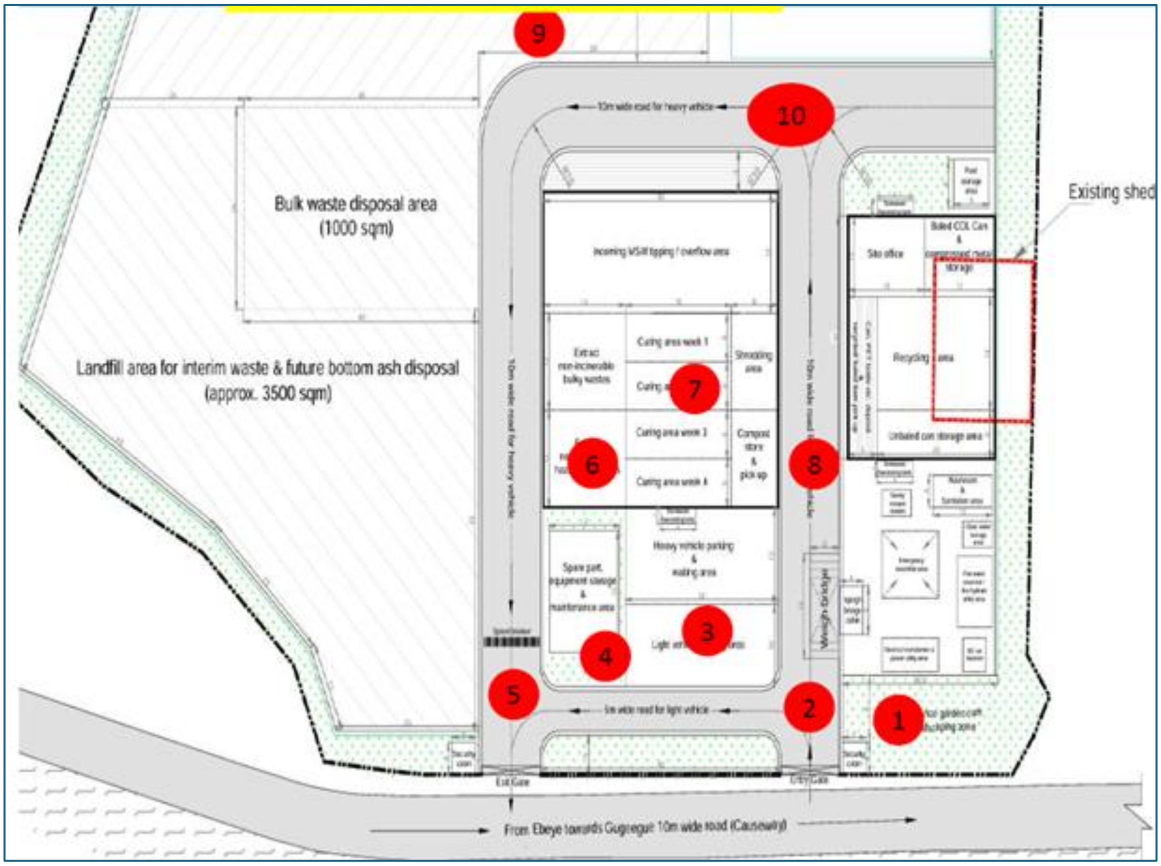


Table 2: Observations and Inferences

Bore holes	Observations and Findings of Geotechnical Investigation	Inference with regard to the proposed Layout in the Bid Document
BH 1	Excavation was performed to a depth of 1 to 1.5 feet, revealing a firm and compact soil layer. The material primarily consists of dense dirt.	Since the exploration exhibits form compacted soil layer, consisting of dense dirt, this area can provide good structural strength to the foundation of building etc. The borehole coincides with the area which has actually been considered to construct recycling area, office, finished recycled product storage, utility etc.
BH 2	Excavation was performed to a depth of 1.5 to 2 feet, revealing a firm and compact soil layer. The material primarily consists of dense dirt, with occasional debris and scattered waste materials present.	This area has been considered for road construction. As per the ground condition the suitable base preparation has been designed for this area, complying the ground treatment criteria in designing the site layout.

Bore holes	Observations and Findings of Geotechnical Investigation	Inference with regard to the proposed Layout in the Bid Document
BH 3	Excavation was carried out to a depth of 4-5 feet, at which compact layer was encountered. The soil primarily consists of dense dirt mixed with occasional debris and trash. During high tide, the water table was observed to rise to approximately 1 foot below the surface.	The associated area has been considered for the purpose of light and heavy vehicle parking. Hence no structural related concerns may be associated in this segment.
BH 4	Excavation was performed to a depth of 5-6 feet, at which point a hard, compact layer was encountered. The soil is predominantly composed of trash and debris, with minimal cohesive dirt present. During high tide, the water table was observed to rise to approximately 1.5 feet below the surface	This area is mostly open area and area for spare part equipment storage. Hence no heavy load is anticipated to encounter in this area
BH 5	Excavation was performed to a depth of 8 feet, at which point a hard, compact layer was encountered. The soil is predominantly composed of trash and debris, with minimal cohesive dirt present. During high tide, the water table was observed to rise to approximately 1.5 feet below the surface.	This area has been considered for road construction. As per the ground condition the suitable base preparation has been designed for this area, complying the ground treatment criteria in designing the site layout.
BH 6	Excavation was carried out to a depth of 10 feet, with no firm bottom layer encountered. The soil composition consists almost entirely of rubbish and debris, with minimal cohesive material present. During high tide, the water table was observed to rise to approximately 1 foot below the surface.	Borehole no 6 & 7 falls into the area with no firm bottom, but consists of rubbish and debris. In this section suitable ground improvement technic has been applied to strengthen the condition of subbase. The area has been proposed to be regenerated with stone inclusion, followed by high quality compacted fill material/aggregates. This will strengthen the ground condition on which reserving sorting section has been proposed.
BH 7	Excavation was carried out to a depth of 10 feet, with no firm bottom layer encountered. The soil composition consists almost entirely of rubbish and debris, with minimal cohesive	

Bore holes	Observations and Findings of Geotechnical Investigation	Inference with regard to the proposed Layout in the Bid Document
	material present. During high tide, the water table was observed to rise to approximately 1 foot below the surface.	
BH 8	Excavation was conducted to a depth of 10 feet, with no firm bottom layer identified. The material encountered primarily consists of trash and debris, mixed with small amounts of soil. During high tide, the water table was observed to rise to approximately 1 foot below the surface	This area has been considered for road construction. As per the ground condition the suitable base preparation has been designed for this area, complying the ground treatment criteria in designing the site layout.
BH 9	Excavation was conducted to a depth of 10 feet, with no firm bottom layer identified. The material encountered primarily consists of trash and debris, mixed with small amounts of soil. During high tide, the water table was observed to rise to approximately 1.5 feet below the surface	The borehole coincides with the area which is not recommended for construction of heavy structure. The indicated area is considered for no heavy structure or building construction. The area has been kept to accommodate the legacy waste and the future waste in form of a sanitary landfill.
BH 10	Excavation was conducted to a depth of 10 feet, with no firm bottom layer identified. The material encountered primarily consists of trash and debris, mixed with small amounts of soil. During high tide, the water table was observed to rise to approximately 1 foot below the surface.	This area has been considered for road construction. As per the ground condition the suitable base preparation has been designed for this area, complying the ground treatment criteria in designing the site layout

5 Design Approach

The intent of the design is to improve the Ebey Dump Site to create an engineered sanitary landfill that will enhance protection of the public and the environment. The remote location, low elevation of ground surface, scarcity of available land space and anticipated sea level rise makes designing a landfill very challenging. Consequently, there is a need to balance the various risks and optimize the protection of public health and environment.

Based on the information reviewed and further discussed in subsequent sections, the main objectives of the design are as follows:

- Remove the most active waste column in terms of landfill gas production and settlement from the site, which is waste ranging up to ten years old.
- Construct an engineered geosynthetic/soil bridge beneath the landfill liner footprint, above legacy waste left in place and abutting to native soil to attenuate differential settlement and facilitate more uniform settlement.
- Construct a second engineered geosynthetic/soil bridge specifically designed to cover an area within the landfill footprint that has water-saturated legacy waste that cannot safely support construction equipment or waste loads.
- Construct a landfill liner system with the lowest point being in a location of potential greatest settlement, with features to accommodate settlement through time.
- Construct a landfill liner system so that the floor slopes upwards towards the ocean, away from occupied homes.
- Construct passive landfill gas venting systems on the boundary of the liner system, as the waste left in place will generate gas that will migrate upwards to the liner and will emit at the liner boundaries.
- Construct the Administrative and Maintenance Building with proper engineering controls to prevent landfill gas accumulation in the building as well as a landfill gas monitoring system.
- Construct a properly sized stormwater drainage system and sedimentation control system.
- Construct a properly size leachate collection sump pump system to continuously remove leachate at the rate of generation. This minimizes the fluid head above the liner, which reduces leakage rates if the liner becomes compromised.
- Create multiple access points to the landfill liner and leachate collection system to allow for a range of response actions to potential issues in the future, such as “black Goo” accumulation, elevated temperature landfill conditions and differential settlement that could necessitate relocating the collection sump or adding additional leachate pumping systems.
- Provide space for future environmental controls, such as the closure cap and potential future landfill gas collection system.

- Provide space for future operational functions, such as recycling, container deposit and composting operation.
- Re-dispose the excavated legacy waste into the lined landfill.
- Provide ancillary facilities, including, diesel fuel storage and dispensing system and a properly sized fire pump system.

6 Design Considerations

6.1 Waste In Place Estimate

The Ebeye Dump site began operation in 2005, following the completion of a coral mining operation. Historical Aerial photographs from google earth, dated April 2003, revealed an apparent open excavation with water present at the bottom of the excavation pit. Interviews with current Ebeye Landfill staff confirms the use of the site as a coral mining operation.

The area of the dump site was measured via the measuring tools available in google earth and it was determined that the area bounded by the perimeter road was approximately 19,500 square meters. Also, the area of the apparent water surface was measured at approximately 3,560 square meters.

Based on observations made during the 2022 and 2025 geotechnical investigation of the site, the observed groundwater was greatly influenced by tidal action. Consequently, it is a reasonable assumption that the water surface observed in the historical aerial photograph is at sea level. There were no hourly time stamps on the historical aerial photograph, and thus no way to definitively determine the tide level during the time of the photograph. Shadows can be observed on margins of the apparent water surface on the west side, which suggests late morning to mid-day. Without certainty of the time of day, it is reasonable to assume the water level in the excavation is at mean sea level.

Survey monuments established for the project indicated the causeway road, near the entrance of the site, is 2.7 meters above mean sea level. In addition, the topographical survey completed for the project indicates that much of the property is lower than the reference point near the entrance of the dump site.

In regard to the depth below the observed water surface, certain assumptions can be made to estimate depth. The typical excavator in use on Ebeye Island during the early 2000's were reported to be medium-size excavator, with a maximum digging depth of 6 to 7 meters. Given the placement of the observed water surface, very shallow slopes were maintained on the ocean-side boundaries of the property.

Using this information, an estimate of the volume of waste in place was calculated, using the average end area method for the space between the water surface and road level. It was assumed that the entire dump site was at the same elevation as the causeway road near the Dump Site entrance, which is a conservative assumption. For the volume below the water surface, the average end area method was used to estimate volume, assuming 2:1 side slopes and a depth of 7 meters. Five equally spaced transects were measured across the water surface as part of the volume calculation. The areas were calculated based on the measured width, assumed depth and side slopes.

Table 3: Estimation of Waste Volume in Place

Dump Site Section	Volume, cubic meters
Above Water Surface	34,590
Below Water Surface	18,881
Total	53,471

This is a conservation estimate. However, this calculation can be utilized to consider the consumption rate of landfill space over time. Since disposal was initiated in early 2005 and survey work was completed in late 2024, the volume of waste in place was accumulated over approximately 19.5 years. This translates to an average of 2,745 cubic meters per year. Considering a typical landfilled waste density can range from 500 Kg/cubic meter for newly compacted waste to a final stabilized landfill density of 1,100 kg/cum, this volume can translate to 1,375 to 2,745 metric tonnes.

A study completed from October to November 2021 indicated that 2,200 metric tonnes per year is generated and disposed at the Ebeye Dump Site. Considering the assumption made for the estimate, particularly the assumption that the site is filled to the same elevation as the Causeway road at the main entrance of the Dump Site and the assumption of a constant disposal rate, this is a reasonable estimate and can serve as a basis for additional analysis if needed.

6.2 Waste Age Evaluation and Excavation Plan

The population on Ebeye Island has remained relatively stable since 2005, being approximately 15,000 people. Considering a relatively stable population size over the service life of the Ebeye Dump Site, it is reasonable to assume the disposal rate was relatively constant. Assuming a constant disposal rate, the estimated volume below the water surface, would have been filled in 6.9 years. So, the waste in this space was placed between 2005 and approximately 2011.

The current plan is to excavate to a maximum of 2.7 meter in depth to construct the sanitary landfill, with a leachate collection system. The estimate for the excavation volume is approximately 22,270 cubic yards. Assuming the disposal rate as estimated above was constant, this waste would have been disposed of between 2015 and 2025, with waste age being from zero to ten years.

The decision to excavate only a portion of the legacy waste in place was based on several factors and they include: (1) excavating all legacy waste would consume valuable landfill space needed for current and future use, (2) the actual depth of legacy waste is unknown (3) a large portion of the legacy waste is below groundwater, which makes excavation very problematic and (4) the more legacy waste excavated requires a like amount of imported fill, which is of limited supply and high in cost.

The current plan will remove a little less than half of the legacy waste currently in place. The decision to remove waste that is ten years old or younger is based on the behavior of decomposing waste over time, in addition to conserving landfill space. The two issues of importance for decomposing waste is landfill gas production and waste column settlement rates.

Typically, landfill gas production rates are highest in the first ten years following disposal. Consequently, eliminating the last ten years of waste would significantly reduce the methane production rate. Landfill gas production rates are highest after the first year of disposal, then will reduce with time.

Long term settlement of the waste column within a landfill will occur over a 30 to 40 year period, with settlement rates initially being as high as 10 to 25% over the first year. The total settlement rate of a waste column will typically range from 15 to 40% and will reach this level between 5 and 40 years. Through excavating legacy waste that is 10 years and younger, the settlement rate will be greatly attenuated beneath the lined landfill.

The geometry of the original coral mining pit will also serve to attenuate the settlement rate. Settlement rates are a function of waste column height. However, the original pit is essentially wedge shaped with a limited flat floor, which forces waste from the upper column to converge into a smaller cross section area with depth as it settles.

Regardless of attenuation, design features need to be included to address settlement. These features include measures to facilitate uniform, rather than differential, settlement and features that allow extension or re-position of systems to address potential settlement issues.

6.3 Depth of Liner

For landfills constructed in the United States, there is a requirement to have separation between the bottom of the landfill liner and groundwater. This is essentially the beginning of the liner design in determining the elevation of the bottom point of the liner, which is the leachate collection sump. The United States Environmental Protection Agency requires this separation distance to be 1.52 meter and the European Union Directive requires 1 to 2 meter separation.

In reviewing the survey data for the project, the reference monument near the entrance of the Ebeye Dump Site indicates that the ground level is 2.7 meters above mean seal level. Given this ground elevation, strict compliance with the separation requirement will be difficult. There are two challenges to keeping the bottom of the liner system 1.5 meters above the groundwater level.

First, the main leachate collection headers on the floor of the landfill liner require a minimum of 1% slope. Given the site geometry, the leachate collection headers will terminate above ground surface if the sump elevation is set 1.5 meters above mean sea level.

Second, groundwater beneath the landfill footprint is highly influenced by tidal action and changing sea level. The historic high tidal was recorded at 1.7 m above mean sea level, which further exasperates the challenge. If the historic high tide is considered, then the low point in the liner system would be 3.2 m above mean sea level or 0.5 meters above current ground surface. If the landfill were to be constructed above ground, there would be a significant loss in landfill space and service life.

Also, the anticipated seawater rise will range from 0.59 m to 1.45 m by 2050 at the Kwajalein Atoll. Consequently, it is impossible to design a workable sump elevation that will always have 1.5 m separation between groundwater and the liner floor.

There are four reasons why a separation between groundwater and the liner is desired and they are as follows:

- Prevent Uplift/Flotation: To ensure the liner does not bulge or detach due to hydrostatic pressure from below.
- Protect Liner Integrity: Groundwater contact can lead to chemical degradation or stress concentrations.
- Control Leachate Migration: Higher separation means more protective natural attenuation capacity in subsoils.

- Allow for Leak Detection and Leachate Collection: These systems function poorly when submerge.

In terms of the design, a depth of 1.7 m for the sump floor was selected. This places the liner 1 meter above current mean sea level and allows for the landfill floor to provide the required slopes for a functioning leachate collection header. There will still be a need to moderately build up the elevation of the landfill's peripheral road with this selected sump elevation, which will serve as the location for the liner anchoring system.

Considering that only legacy waste that is 10 years old or younger will be excavated, once the construction of the liner is complete, the lined cell will be immediately filled with legacy waste. This eliminates the concern of uplift or flotation by groundwater. The volume of legacy waste will fill the lined landfill to the peripheral road elevation and slightly above. Buoyancy force equals the weight of water that will be displaced by the liner. A liner system filled to ground surface level would weigh more than the weight of water displaced by the liner system by orders of magnitude.

The fact that legacy waste will remain in place at depth below the landfill and that the liner will contain waste above the liner system highlights the need to specify liner material with excellent chemical compatibility and offer high level of puncture resistance and other design features. The liner material selected for the Ebeye Landfill is an 80 mil high density polyethylene (HDPE). This material has excellent chemical compatibility, offers high level of puncture resistance and has a percent elongation at break of 700%.

In regard to leachate mitigation, the submerged portion of the legacy waste left in place will continue to produce leachate. While the legacy waste above sea level will be shielded by rain infiltration by the landfill liner, sea level rise will occur and generate leachate from previously unsubmerged layers of legacy waste. By 2100, sea level rise is estimated to be between 1.2 m to 7.8m.

Finally, when sea levels rise to the elevation of the sump, there are methods to determine if the liner system is compromised. If there is a leak, seawater will move into the landfill cell. This can be detected by volumetric and leachate quality monitoring.

Another important reason for selecting a depth of 1.7 m for the bottom of the landfill liner is related to constructability of the landfill liner. There will be a need to construct an engineered reinforced fill layer below the liner system. This layer needs to be placed during unsubmerged conditions. This is possible, but the construction will need to be highly coordinated with the tides. Placing the sump data point lower than 1.7 m above mean sea level will require engineered fill to be constructed in submerged conditions, which is not desirable.

6.4 Hydraulic Evaluation of Landfill Performance (HELP)

The U.S. EPA Hydrologic Evaluation of Landfill Performance (HELP) Model is a specialized computer simulation tool designed to estimate water movement and storage within landfill systems and other solid waste containment facilities. It was developed to assist engineers and regulators in understanding how precipitation, surface runoff, infiltration, percolation, evapotranspiration, and leachate generation interact within the layered structure of engineered waste containment systems.

HELP uses a quasi-two-dimensional, deterministic water balance approach. Users define site-specific parameters such as:

- Climate data (precipitation, temperature, solar radiation). Historical precipitation and temperature data from the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI) from three weather stations near the landfill site (Majuro, Kwajalein Atoll and Milli)
- Soil and liner layer characteristics (permeability, porosity, field capacity). Soil sieve analysis from the likely soil vender on Ebeye Island was reviewed to provide the appropriate model input.
- System design features (geomembranes, drainage layers, vegetation cover). This information was collected from the design.

The model then calculates daily or hourly water movement through each layer of the landfill or cover system, accounting for complex processes like:

- Surface runoff and infiltration.
- Evapotranspiration losses.
- Vertical percolation through unsaturated layers.
- Lateral drainage within drainage layers.
- Leachate generation rates.

The results of the model provided the following information:

- Peak Daily Leachate Production: 201 cubic meters or 53,098 gallons per day or 37 gallons per minute.
- Maximum head on liner: 0.6998 cm

- Location of maximum head on liner: 3.10 meters from sump
- Average head on liner: 0.3573 cm.
- Annual Total Leachate Production: 27,518.9 cubic meters.

A copy of the HELP model run is presented in Volume IV, Attachment 4.

6.5 Stormwater Modeling and Drainage Design (TR-55)

To provide perspective on the drainage improvements for Ebeye Landfill, the volume of storm water run-off was estimated using the WinTR-55 Small Watershed Hydrology Program developed by the National Resource Conservation Service, a division of the United States Department of Agriculture. WinTr-55 is a single event rainfall-runoff small watershed model.

The model applies to both urban and agricultural areas generating hydrographs from land areas and at selected points along the storm water conveyance system. This program can model multiple sub-areas, which is particularly useful in reviewing a drainage system for a landfill site. The condition requiring the watershed to be small is to minimize the effect of variation of rainfall distribution that occurs with each storm event. The size of the Ebeye Landfill property under analysis is not large enough to create a significant interference.

Technical Release 55 (TR-55) is a well-known method for estimating the volume of run-off and peak discharge rates from small watersheds. The method proceeds with evaluating the land use characteristics of the watershed under consideration, including soil type, cover complex and antecedent moisture condition of the watershed. TR-55 provides a comprehensive table that is used to characterize the land use. The table provides a "Run-off Curve Number" (CN) which is a function of hydrologic soil group, cover type/treatment and hydrologic condition.

The Run-off Curve Number was established through using both the TR-55 comprehensive table of land use and the soil data obtained from the likely vender on Ebeye Island. This same Run-off Curve Number was utilized in the HELP Model to model leachate production.

The storm data (25-, 50- and 100-year 24 hour storm event) was obtained from the US Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service at their website https://hdsc.nws.noaa.gov/pfds/. The storm data for the Kwajalein Missel Range, Lat 8.7279, Long 167.7374 is as follows:

Table 4: Design Storm Data

2 Yr, 24 hour	5 Yr, 24 hour	10 Yr, 24 Hour	25 Yr, 24 hour	50 Yr, 24 Hour	100 Yr, 24 Hour
4.89-inch	6.24-inch	7.37-inch	9.04-inch	10.4-inch	12.0-inch

The TR55 model output is presented in Volume IV, Attachment 4. The main conclusions of the TR55 model are as follows:

- Drainage Ditches require a slope of 0.02 to handle peak flows and to facilitate a cleaning velocity of 3 feet per second at lower flows. Independent calculations were completed to confirm flow capacity of ditch called out in design as well as to confirm cleaning velocity at low flows.
- Peak discharge flows for the 100-Year Storm Event are as follows:
  - LF Ditch: 28.01 cubic feet per second (cfs)
  - Fac Ditch; 6.01 cfs
  - Sedimentation Basin Inlet: 33.18 cfs
  - Sedimentation Basin Outlet: 32.90 cfs
- Peak discharge flows for the 10-Year Storm Event are as follows:
  - LF Ditch: 13.61 cfs
  - Fac Ditch; 3.51 cfs
  - Sedimentation Basin Inlet: 16.66 cfs
  - Sedimentation Basin Outlet: 16.51 cfs
- Peak Discharge occurs approximately 12 hours after the onset of storm, primarily due to Storm Type III.
- Sedimentation Basin has a capacity of 48.574 cfs at the 2.5-foot stage or 1.375 cubic meters per second at the 762 mm stage, which is more than adequate to handle peak flows.
- Note: the TR55 model was run with the assumption that all landfill runoff flow will follow a specific path for the purpose of estimate time of concentration. However, the drainage ditch design provides a high point in the LF ditch adjacent to the peripheral

road that essentially splits the peak flow in half, with two equal paths from the high point to the Sedimentation Basin.

6.6 Landfill Gas Emissions Model (LandGem)

To provide perspective on the issue of landfill gas production for legacy waste, the current conditions and post-excavation landfill gas production rates at the Ebeye Landfill were estimated using the Environmental Protection Agency's Landfill Gas Emissions Model (LandGEM), Version 3.1 (December 2024). The objective of using the LandGEM model is to estimate current and future landfill gas production rates is to adequately characterize the associated risks of the migration of landfill gas from legacy waste left in place to the boundaries of the lined landfill footprint and potentially into structures or nearby neighborhoods.

The LandGEM model is based on a first order decomposition rate equation and provides an estimate of total landfill gas, methane, carbon dioxide, non-methane organic compounds and individual air pollutants from solid waste landfills. The basic equation (Equation 8) is as follows:

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} k\, L_{\circ} \left[\frac{M_i}{10}\right] e^{-kt_{i,j}}$$

Where: QCH4 = Annual Methane Production Rate (m3/yr)

I	= one year time increment
n	= (year of calculation) – (initial waste acceptance year)
j	= 0.1 year time increment
K	= Methane Generation Rate (1/year)
Lo	= Potential Methane Production Capacity (m3/Mg)
Mi	= Mass of Waste Accepted in ith year
e	= Natural exponent
ti,j	= age of jth section of Mass Mi accepted in ith year

The model requires input of several parameters to calculate the landfill gas production rates. The primary input into the model is the mass of waste disposed per year at the landfill. The estimate of waste in place at Ebeye Landfill will be utilized, assuming the annual disposal rate was constant.

For the purposes of this estimate, the time constant, K, was estimated to be 0.10 $year^{-1}$. This value is based on studies for tropical island environment: UNEP IETC (2004), "Solid Waste Management in Pacific Island Countries: Regional Overview" and PCC 2006 "Guidelines for National Greenhouse Gas Inventories, Volume 5, Chapter 3: Waste.

In regards to the Methane Potential Production capacity, Lo, the USEPA LandGEM default value was utilized, as the is based on similar waste characteristics and the Ebeye waste study.

The model was run for all legacy waste in place from 2005 to 2025 and again with only legacy waste date before 2015 remaining in place. The results of the model runs are presented below:

Table 5: Landfill Methane Production Estimate

Case	Year	Annual Methane Volume, cum
Before Excavation	2025	405,500
	2045	61,560
After Excavation	2025	127,200
	2045	17,220

The production of methane gas is reduced by 68% through the excavation of waste aged between 0 and 10 years immediately after construction of the landfill and by 72% 20 years after construction. The LandGEM model run is presented in Volume IV, Attachment 4

6.7 Settlement Analysis

Long term settlement of the waste column within a landfill will occur over a 30 to 40 year period, with settlement rates typically ranging from 15 to 40%. Considering the results of the estimation of waste in place, the thickness of the waste column to be left in place is 8 meters; 7 meter below the water surface observed in the 2003 historical aerial photograph and an additional 1 meter above the water surface.

A trapezoid cross section was considered in the settlement analysis. The shortest length across the landfill is along the header reach Sump-L5, with a length of approximately 100 m. Two trapezoid cross sections, one with side slopes of 3.5:1 and the other with side slopes of 1:1, were evaluated.

The analysis proceeded with identifying the top boundary of the trapezoid cross section as the liner location and the side slopes represent native soil or engineered fill. To evaluate settlement, the height of the trapezoid cross sections was reduced by 40% and a new trapezoid cross section, with the top boundary being the original liner location and the bottom boundary being the new location of the liner on top of the waste column.

The length of the side slopes and bottom boundary were summed and compared to the original length of the liner. For a 100 meter liner length, the percent elongation for the two trapezoid cross section are as follows:

- Side Slopes of 3.5:1 - 0.9% Elongation
- Side Slopes of 1:1 – 2.6% Elongation

When the waste column settles vertically, lateral dimensions (side slope lengths) do not necessarily increase linearly, as was assumed in the above analysis. If the landfill has steep side slopes, those slopes may flatten slightly as settlement occurs, which would modify the results of the analysis.

However, the above analysis does highlight the fact that design needs to consider settlement. The waste left in place is between 10 and 19.5 years old and the side slopes are likely shallower than 1:1. The 40% settlement serves as a conservative design basis, since 40% settlement is an upper range and the fact that about 25% settlement takes place in the first ten years after disposal and this waste will be removed as part of the project. Materials and the construction of the landfill liner and leachate collection system will need to include measures to address likely strain. Although the analysis suggests elongation up to 2.6%, it is important to note that the shorter the span of the liner, the larger the percentage elongation will be. Shorter span across settlement is possible through differential settlement.

To address differential settlement, a literature review was conducted and identified a paper presented at the 2015 Geosynthetics Conference in Portland Oregon entitled "*State-Of-The-Art of Piggy-Back Landfills Worldwide: Comparison of Containment Barrier Technical Designs and Performance Analysis In Terms of Geosynthetics Stability*", written by F. Tino, F. Olivier, I. Touze-Foltz and L. Dias. This paper documented the best practice for designing landfills that will overlay old landfill cells. The model recommendation for such arrangements is to place engineered reinforced fill separating legacy waste and new overlying landfill cell. The engineered reinforced fill component consisted of 30 cm granular material over legacy waste, followed by placement of a geogrid reinforcement (high tensile strength), followed by a 30 cm layer of granular materials (high friction). This design will be utilized in the project. Calculations supporting the specifications for the geogrid is presented in Volume IV Attachment 4.

The engineering response to settlement will need to include the following:

- Specify materials that can handle strain is the 2 to 4% range to incorporate a factor of safety.
- Incorporate an engineered fill beneath the liner to enhance the potential for uniform settlement.
- Include design featured to allow for extension of riser pipes, introduce slip planes where needed and provide additional access to the landfill floor to accommodate new leachate extraction zones if necessary.

6.8 Ebeye Dump Site Soft Spot Mitigation

6.8.1 Site Observations

Based on a review of historical aerial photographs of the Ebeye Dump Site and interviews with operators and contractors familiar with the site's operational history, the area was previously used as a quarry, resulting in an excavation with a depth of potentially up to approximately 6 meters in a portion of the site. This excavation contained water that was directly influenced by tidal fluctuations. When the site was subsequently converted to a dump site, waste was placed within the quarry pit, including waste pushed directly into standing water. The site is now entirely filled with waste, with no persistent standing body of water.

The current site topography slopes downward toward a low point near the mid-southern boundary of the site. Notably, this low point does not directly correspond to the deepest portion of the former quarry excavation. This low point area is locally referred to by dump site operators and contractors as the "soft spot". Under repeated equipment traffic, the surface in this area exhibits pronounced pumping behavior, which has in the past resulted in a localized vehicle sinkage incident in which a vehicle was pressed down below the waste surface by equipment to complete the submergence. Based on site observations, the soft spot appears to be at an elevation near mean sea level, as operators report that this area consistently collects water after heavy rain and, when water is present in the area, appears to be influenced by tidal conditions.

Based on these observations, the Dump site's soft spot consists of water-saturated legacy waste that cannot safely support construction equipment or waste loads.

6.8.2 Mitigation Strategy

Generally, there are three ways to deal with the "Soft Spot" issue: (1) over-excavate and backfill with structural soil fill, (2) avoid constructing over the area, or (3) construct a bridging platform. Due to constraints on materials and space as well as the need to maximize disposal capacity at the site, the project will use a reinforced soil bridging system that acts like a flexible raft to provide basal reinforcement and a stable working platform for landfill operations.

The bridging platform works by developing tension in a geogrid membrane as it deflects downward by a specified amount, allowing it to span localized weak zones in the waste below. This mechanism is similar to how a hammock carries weight: loads are resisted through lateral tension rather than rigid support from beneath.

In addition to providing void-spanning capacity, the geogrid layer serves to stabilize the general soft-spot area by redistributing loads to the underlaying waste, confining the engineered fill, and limiting the lateral growth of localized zones of weakness within saturated legacy waste. While long-term settlement of the underlying waste mass is expected, the reinforced platform controls localized differential settlement and prevents progressive failure, thereby maintaining a stable working surface and protecting the overlying liner system.

6.8.3 Bridging Design

Two distinct but complementary bridging systems are incorporated into the landfill design:

- Saturated Zone Bridge Design

  This system is used only in designated soft-spot or saturated waste areas. It consists of a seated rock layer placed over saturated legacy waste, a heavy-duty nonwoven geotextile filter, and two layers of high-strength geogrid separated by engineered fill. The rock layer provides a stable working surface without aggressive compaction, while the geogrids provide primary tensile resistance and load redistribution.

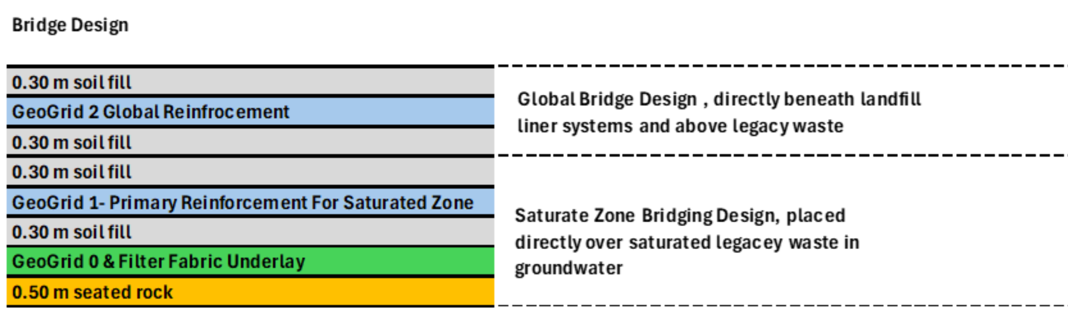
This system is conservatively designed to resist all anticipated live and dead loads independently, without reliance on overlying systems.

- Global Bridge Design

  This system is installed beneath the landfill liner system in all areas where legacy waste remains in place, including soft-spot areas. It consists of engineered fill layers and a geogrid reinforcement layer designed to promote uniform settlement and provide secondary control of differential settlement beneath the liner system.

  In soft-spot areas, the Global Bridge Design is installed above the Saturated Zone Bridge Design. In areas of native soil, the liner system is installed directly on prepared subgrade without bridging.

An illustration showing the two bridging designs stacked directly on top of one another is presented below:



6.8.4 Design Methodology

The design of the bridging systems is based on established tensioned-membrane theory for geosynthetic reinforcement spanning localized unsupported zones. This approach is consistent with international best practice and is documented in German geosynthetics design guideline, *Empfehlungen für den Entwurf und die Berechnung von Erdkörpern mit Bewehrungen aus Geokunststoffen (EBGEO)*. EBGEO provides a modern, mechanics-based design standard that explicitly models geosynthetics spanning cavities, sinkholes, or subsidence zones using tensioned membrane action. A detailed description of the design calculations is presented in Volume IV, Attachment 4.

The design method evaluates the relationship between applied vertical loads, the characteristic width of a localized unsupported zone, and allowable membrane deflection. Rather than assuming uniform failure across the entire soft-spot area, the design focuses on credible localized failure mechanisms, such as punch-through beneath construction equipment.

Based on site observations and operator experience, a representative localized void width was selected to reflect realistic failure scenarios. Allowable deflection was chosen to mobilize tensile resistance while maintaining acceptable settlement for construction operations and liner support.

Design loading includes both live loads from construction and landfill equipment and dead loads from engineered fill and overlying waste. Conservative assumptions were used, including analysis of heavy landfill compactors and dozers. Load dispersion through the fill was evaluated using established conservative methods to estimate stresses acting on the geogrid layers.

For design conservatism, load reductions attributable to overlying or underlying bridging systems were not credited in sizing the primary soft-spot reinforcement.

6.9 Friction Angle Consideration

In landfill design, slope failure refers to the sliding or slumping of waste material or other elements of the landfill system, such as the liner or cover, along a failure plane. The failure can occur within the waste itself, at the interface between different materials, or between the waste and the underlying liner.

A slope of 3.5:1, which is a 3.5 meter horizontal distance to achieve 1 meter in elevation, has been selected to ensure adequate stability while accounting for the specific properties of the materials involved, including the waste and the liner system. This slope ratio is a common choice for landfills because it provides a balance between stability and the required capacity. The Factor of Safety (FoS) for the slope, calculated using typical values for shear strength and shear stress, demonstrates a stable configuration for the proposed conditions.

Friction Angle: The friction angle of the waste material and liner system has been assumed to be within the typical range of 25° to 35°, depending on the degree of compaction and moisture content of the waste. For a smooth geomembrane liner, the friction angle between the waste and liner is typically around 10° to 15°, while for a textured liner, this can be increased to 20° to 30°. The higher the friction angle, the steeper the slope can be without compromising stability. An HDPE liner with texture on both sides will be used in the project. A slope of 3.5:1 is 15.9°.

Shear Strength: The shear strength of the waste and the interface between the waste and liner has been considered, using typical cohesion values of 5 kPa to 25 kPa for municipal solid waste, and considering the normal stress due to overburden pressure. The calculated

Factor of Safety (FoS) for the 3.5:1 slope is above the minimum required value of 1.5, ensuring that the slope will remain stable under expected loading conditions.

The selection of a 3.5:1 slope is further supported by the nature of the waste material expected to be deposited in the landfill. The municipal solid waste (MSW), typically consisting of compacted and decomposed materials, has a moderate friction angle, ensuring that the slope remains stable.

The design also considers the type of liner system in place. Whether a geomembrane liner (e.g., HDPE) or a geosynthetic clay liner (GCL) is used, the 3.5:1 slope ensures that the interface between the waste and liner remains stable.

For textured geomembrane liners, the friction angle is higher, allowing for a slightly steeper slope without compromising stability. The 3.5:1 slope ensures a stable design even with smoother liner surfaces.

Also, a 3.5:1 slope offers a good compromise between stability and erosion control. It is not so steep that it increases the risk of erosion or soil loss under rain events, while still being steep enough to allow for efficient water drainage from the landfill surface. The slope can be easily vegetated or equipped with erosion control measures (e.g., geotextiles, mulch) to minimize the impact of stormwater runoff.

Given the expected settlement of the waste material over time, the 3.5:1 slope is designed to accommodate settlement-related adjustments without significantly compromising the slope's integrity. As the waste decomposes and compacts, the slope angle may become slightly steeper due to material settlement. The selected slope provides a sufficient margin for this process while maintaining a stable structure throughout the landfill's operational and post-closure periods.

6.10 Geosynthetic Fabric as Operations Layer

Due to concerns of preserving landfill space for waste disposal needs and the limited aggregate resources on Ebeye Island, a heavy ≥16oz/yd^2 needle-punched nonwoven geotextile will be utilized as a protection layer over the planned liner system for Ebeye Landfill (GCL + HDPE geomembrane + drainage composite). The geotextile will replace the 30 cm soil operations layer typically installed over landfill liner systems. The use of a geotextile to protect HDPE liner systems is consistent with EPA Technical Guidance (EPA/600/R-93/182 September 1993).

While compacted soil can provide some cushioning, it is less effective than geotextiles because it may contain sharp particles (e.g., stones) that could puncture the liner. Soil's effectiveness depends on its composition, compaction, and lack of sharp objects, making it less reliable and less consistent than geotextile. Also, a soil operations layer is not designed for puncture protection but does provide a separation distance between waste and the liner system.

Non-woven or woven geotextiles are specifically designed to protect HDPE liners in applications like landfills, ponds, or containment systems. They offer high puncture resistance, uniform coverage, more effective distribution of loads and cushioning against sharp objects (e.g., rocks or debris). Non-woven geotextile provides equivalent or superior puncture resistance and strain accommodation compared to a traditional 300 mm soil operations layer. The technical basis for the substitution is as follows:

- High Strain Capacity and Puncture Resistance

  Thick nonwoven geotextiles (≥16 oz/yd^2) typically exhibit elongation at break of 50–100%, depending on polymer and manufacturing process (ASTM D4632). The tensile strain capacity enables the geotextile to absorb localized pressures and strains from waste settlement and traffic without tearing.

  The mass per unit area (≥540–814 g/m^2) and thickness (typically 6–8 mm) provide excellent cushioning against sharp objects or irregularities during initial waste placement.

- Superior Puncture Protection

  Unlike soil, geotextiles are uniform, do not contain aggregate or inclusions, and maintain consistent coverage over the entire liner surface. This improves liner system survivability, particularly during initial waste loading, where traditional soil layers may rut, shift, or thin out under equipment traffic.

- Construction Advantages

  Eliminates need to import, haul, and place 300 mm of clean soil, which is an expensive material Ebeye Island. An additional advantage is that using geosynthetic fabric as an operations layer will accelerate construction and reduces environmental footprint by minimizing soil borrow requirements.

To ensure adequate protection of the liner system during initial placement of waste, the specifications for the project will include specialized waste management procedures to remove large objects or sharp objects that have the potential to damage the liner system. Since legacy waste will be excavated and redisposed in the new lined landfill, there will be a choice of materials placed in the first lift, and the placement of waste will be under close observation by construction inspectors.

6.11 Potential Future Issues

There are a range of potential future issues that should be anticipated, and it would be prudent to include design features that will assist with the management of these potential future issues. These potential future issues include the following

6.11.1 Landfill Gas Migration From Legacy Waste

Landfill gas, primarily methane and carbon dioxide, can migrate from a landfill into surrounding areas. Gas can migrate both into onsite buildings and offsite properties if not properly controlled. This occurs because landfill gas moves along pressure gradients and through porous soils, utility trenches, or cracks in foundations.

The legacy waste older than ten years old will remain in place and will be a source of landfill gas production. Also, since landfill gas is typically in the 120 F range, it will migrate upward through the soil due to thermal buoyancy force. In the current design, the landfill liner will cover the footprint of the legacy waste left in place. Consequently, the landfill gas will flow towards the liner and emit at the boundary of the liner. Landfill gas may also migrate along other pathways that offer the least resistance to flow.

Buildings constructed on or near landfill areas are at risk if gas control systems are inadequate. Methane can accumulate in confined spaces, creating fire or explosion hazards, especially in basements, utility rooms, or crawl spaces.

The mitigation included in the project to address this risk includes the following:

- Removal of about half of the legacy waste on the property. This resulted in an estimate 68% reduction of landfill gas production on the site.
- The landfill liner floor is sloped towards the ocean and away from neighboring properties. The slope toward the sump for leachate, provide the slope needed to guide landfill gas migrating to the liner to move towards the ocean.
- Passive landfill gas vents at the non-ocean boundary of the landfill. These passive vents could be incorporated into a landfill gas extraction system in the future if needed.

- For the planned buildings on the landfill site, legacy waste will be completely removed from beneath the foundation and a methane barrier and monitoring system will be installed for the buildings.
- Space has been allocated for a future landfill gas blower and flare system if it is needed in the future.

6.11.2 "Black Goo"

In the context of landfill operations, "black goo" is a term used to describe a viscous, nearly rubber-like, dark-colored leachate or semi-solid material that emerges within landfill cells. This phenomenon is typically associated with aging landfills, landfills in areas of high precipitation or those experiencing poor leachate drainage. Black goo has been encountered in Gaum.

The current theory of its origin is the accumulation of hydrophilic polymers, accompanied by intense anaerobic decomposition processes. The material poses operational and environmental challenges due to its physical characteristics and chemical composition, which may include high concentrations of ammonia, sulfides, organic acids, and volatile compounds. Its sticky, odorous, and often corrosive nature can compromise the performance of leachate collection systems and landfill containment infrastructure.

The presence of black goo within a landfill presents several operational and environmental risks. One of the most immediate concerns is the clogging of leachate collection pipes, as the viscous material can adhere to perforations and pipe walls, reducing flow capacity. Over time, this can lead to the accumulation of leachate and increased hydraulic pressure on the liner system. Sump pumps are particularly vulnerable, as they may experience cavitation or overheating due to the high viscosity of the material. If not managed properly, black goo can also increase the potential for liner damage or breach, leading to the contamination of underlying groundwater.

Antidotal observations suggest sections of the leachate collection system that allows quiescence will typically generate black goo under the right circumstances. So, one strategy is to ensure that collected leachate is conveyed or moved continuously.

The mitigation included in the project to address this risk includes the following:

- Size the leachate sump pump to operate near continuously, with the aim of operating at the rate of generation.

- Include two separate sump risers to allow for sump pump replacement if needed due to Black Goo issues.
- Include multiple access risers for the leachate collection headers. This will allow additional points to operate leachate collection pumps if needed.

6.11.3 Elevated Temperature Landfill Mitigation Measures

An elevated temperature landfill (ETLF) is a landfill where internal waste temperatures significantly exceed typical biological decomposition levels—often rising above 60°C (140°F). While conventional landfills experience some heat from microbial activity, ETLFs involve abnormal heat generation that can affect landfill stability, gas generation, and liner system performance.

The characteristics of an ETLF include the following:

- Excessive Heat Generation: Driven by rapid chemical reactions, accelerated biodegradation, or exothermic processes involving certain waste materials.
- Increased Leachate Production: Higher temperatures lead to more moisture release and potential changes in leachate composition.
- Elevated Landfill Gas Pressure: Heat increases gas generation rates, often beyond design expectations, impacting gas collection systems.
- Structural Concerns: Elevated temperatures can soften or degrade geosynthetic liners, piping, and other system components.

The two main concerns are increased landfill gas production and damaging the liner system. To address these concerns, multiple access risers to the leachate collection headers ar provided for in the design. This will allow additional points to potentially introduce cooling fluids or utilize as an element for gas collection.