Greening Uganda's Urbanization and Industrialization

Development of Green Industrial Masterplans, Infrastructure plans and project concept notes for Entebbe, Pakwach and Soroti

Water and Sanitation Assessment
(Storm water, Water supply, Wastewater and Solid waste management plans)

Final Report for Entebbe Free Zone

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1. Introduction

1.1 Background

Based in Seoul, the Global Green Growth Institute (GGGI) is an intergovernmental organization founded to support and promote green growth. It targets key aspects of economic performance such as poverty reduction, job creation, social inclusion, and environmental sustainability. GGGI works with countries around the world, building their capacity and working collaboratively on green growth policies that can impact the lives of millions. The organization partners with countries, multilateral institutions, government bodies and the private sector. This is to help build economies that grow more economically and efficiently. Ultimately, they become more effective and sustainable in the use of natural resources, less carbon intensive, and more resilient to climate change. GGGI is partnered with the European Union (EU) as part of the EU inclusive green economy uptake programme (GreenUP). At present, it delivers a project entitled "greening Uganda's urbanization and industrialization" (2020-2023). The programme is aligned with the government of Uganda's vision 2040, the third National Development Plan (NDP III), and the Uganda green growth development strategy (UGGDS). The project promotes sustainable development and inclusive green growth in Uganda. It focuses on green city development, green industrialization, efficient waste management and green growth integration into planning and budgeting.

1.2 Project Objective

The main objective of the project is to develop green masterplans, symbiotic infrastructure plans and infrastructure project concept notes for the 3 locations. The project hopes to support the development of 3 industrial locations at Entebbe, Soroti and Packwach to support Uganda in becoming mid-income status via industrialization. Therefore, the overall goal is to design the infrastructure to allow the industrial park and its contextual city to thrive, as an economic system. The current status of delivery of the specific objectives of the water and sanitation assessment is presented below.

Table 1-1: Assignment objectives and current status of delivery of outputs

#	Specific objective	Current status
1	Preparation of draft inception report	Completed, **29th July 2023**
2	Preparation of final inception report	Completed, **29th July 2023**
3	Site visits, detailed field data collection, and stakeholder engagements	July – August 2023 Additional stakeholder engagements in Entebbe are currently ongoing
3	Preparation of detailed methodologies for water and sanitation data collection and analysis (or modelling) Preparation of outline designs and master plans for water supply, wastewater collection and treatment, stormwater, and solid waste management for each of the three sites.	Completed on **18th August 2023**
4a	Preparation of the proposed water and sanitation infrastructure lay outs/plans	Draft Report for Entebbe Free Zone completed, **13th September 2023**
4b	Preparation of the proposed water and sanitation infrastructure lay outs/plans	Draft Report for Soroti Industrial Park – ongoing. To be submitted on **14th September 2023**
4c	Preparation of the proposed water and sanitation infrastructure lay outs/plans	Draft Report for Pakwach Industrial Park – ongoing. To be submitted on **25th September 2023**
5	Preparation of brief environmental impact assessment of the plans	Green infrastructure plans included in final revised water and sanitation assessment report, submitted on **19th December 2023**
6	Development of project concept notes for water and sanitation infrastructure	Draft concept notes submitted on **15th November 2023.** Revised final concept notes submitted on **19th December 2023**

1.3 Water and Sanitation Assessment for Entebbe Airport Free zone

This report presents the draft findings of the water and sanitation assessment for Entebbe Airport Free Zone. The Free Zone is Uganda's 1st Port Free Zone and has been established at Entebbe International Airport, following acquisition of 5 acres of land from the Uganda Civil Aviation Authority (UCAA) in 2018. The free zone is located near Entebbe Airport Cargo terminal (Figure 1-1). The construction of the Free Zone commenced in 2021, with the National Enterprise Corporation (NEC), which serves as the commercial arm of the Uganda People's Defence Force (UPDF).

Figure 1-1: Location of the Entebbe International Airport Free Zone

One of UFZA's primary responsibilities is to ensure that designated areas for Free Zones are officially developed. UFZA plays a central role in overseeing the operations of the Free Zone, and its main responsibilities include the following:

1) Establishment, development, and management of Free Zones
2) Promoting and marketing Free Zones
3) Supervising, maintaining, and controlling Free Zones
4) Licensing and regulating Free Zone activities

1.4 Stakeholder identification and engagement

Stakeholder identification and engagement was undertaken to identify and understand the needs, priorities, and concerns of the relevant stakeholders. The relevant stakeholders are categorized into National, Local (District) and Private Sector levels.

1.4.1 National level stakeholders (Ministries, Departments and Agencies)

- Uganda Investment Authority (UIA)
- Uganda Free Zone Authority (UFZA)
- Uganda Civil Aviation Authority (UCAA)
- National Water and Sewerage Corporation (NWSC) Entebbe offices
- National Enterprise Corporation (NEC)
- Directorate of Water Resources Management (DWRM), Ministry of Water and Environment

- Directorate of Water Development (DWD), Ministry of Water and Environment
- National Environment Management Authority (NEMA)
- Uganda National Meteorological Authority (UNMA)

1.4.2 Local government stakeholders
- City Engineer – Entebbe City Council
- Water Officer – Entebbe City Council
- Environment Officer – Entebbe City Council

1.4.3 Private sector stakeholders
i) Horti fresh Association Uganda Limited
ii) Uganda Free Zone Authority (UFZA)
iii) Jambo Roses Officials

Field visits were undertaken to the project site from 18th – 19th July 2023. During the field visits, stakeholder engagements were undertaken by the Consultant in line with the terms of reference and in consultation with the GGGI. The following were the key findings of the field visits and stakeholder engagements. The sectors under consideration are listed below and the detailed in the subsequent chapter. Free Zone:

i. Meat sector:
ii. Fish sector:
iii. Fruits and Vegetables:
iv. Dairy sector:
v. Floriculture

The final selection of the sectors that will finally be accommodated at the Free Zone is still ongoing. This will be informed the results of multi-criteria analysis that will be undertaken based on the overall findings of the assignment. The multi-criteria analysis will also be informed by the findings of the water and sanitation assessment.

2. Potential Sectors

2.1 Introduction

The Entebbe International Airport Free Zone has identified key sectors for development based on extensive discussions, site assessments, socio-economic and environmental analyses. The proposed sectors include; fruits and vegetables, meat, floriculture, and diary. The water supply requirements, wastewater generation and treatment, and solid waste management assessment are described in detail based on the findings of the team sectoral analysis.

2.2 Meat sector

The following processes were considered for the meat sector:

i.   Packaging steaks: The packaging of steaks would require trimming of the cuts and packing of steaks. The trimming of the cuts results in wastewater requiring pre-treatment before treatment off-site. In addition, the analysis by the project team identified a bottleneck in the transportation of carcasses to the Free Zone.
ii. Cold storage of packed steaks. The storage of packed steaks requires cold chain facilities with only domestic wastewater generated.

The selected process for the meat sector at the Free Zone is cold storage of processed meat products.

The meat sector aims to have cold storage of processed products within the limited space of the Free Zone. Infrastructure requirements include cold chain facilities (tailored to differing storage temperatures for fish and meat), export logistics, sanitation, security, and water supply. The core processes within the Free Zone will encompass a range of activities, including cleaning, weighing, preservation, transportation, and exportation.

The quantity of meat to be stored has been determined from the team sectoral analysis and quantification. This report has been prepared based on storage of 13,300 kg processed meat per day (Nur Atikah et al., 2019). The wastewater characterisation has been determined from previous studies and is detailed in Chapter 4 of this report.

2.3 Dairy Sector – Cheese Production

The dairy sector will potentially benefit from the Free Zone, with the expected processes under consideration at the site including quality testing, pasteurization, curd manufacture, packaging, transportation, and export.

The processing of milk at the Free Zone would result in wastewater requiring pre-treatment before treatment off-site. The project team discussions have not yet identified a potential company for cheese production at the Free Zone. This report has provided for cold storage of cheese.

The quantity of milk to be processed has been determined from the team sectoral analysis and quantification and this report has been prepared based on processing of 134 kg of cheese per day. Choosing cold storage of milk within the Free Zone offers a favourable balance of environmental sustainability and economic viability. Cheese production typically involves lower resource use and waste generation, along with a longer shelf life, reducing food waste. The wastewater characterisation is described in detail in Chapter 4 of this report.

2.4   Fruits and Vegetables – Sorting, Washing and Packaging

The value chain of fruit and vegetable production involves various stages, including sorting, cleaning, grading, packaging, stacking, inspection, storage, and export. The stakeholder engagement with Hortifresh Association Uganda Limited provided estimation of the quantity of fruits and vegetables. The quantity of fruits and vegetables to be packaged were determined from the team sector selection and analysis. The quantity of fruits and vegetables to be packaged have been determined as 20,000 kg.

The sector will rely heavily on adequate water supply for cleaning the fruits and vegetables before packing. Additionally, the sector must tackle solid waste generated during the sorting, cleaning, and packaging processes; therefore, segregation, proper disposal and recycling methods for waste materials should be established to prevent land and water pollution. Similarly, treatment of wastewater generated from washing and processing of fruits and vegetables is vital to minimise discharge of pollutants (fertilizers and herbicides etc.) to Lake Victoria

2.5   Floriculture sector – Packaging and export

The floriculture sector at the Entebbe International Airport Free Zone represents a promising economic venture centred around the processing and export of flowers for the fresh handling facility. The sector's vitality relies heavily on efficient water resource management, post-harvest processing, necessitating a dependable supply of clean water for cleaning of the flowers. The quantity of lowers processed, and materials used will be based on a per hectare basis as stated by (Hawera, Tefera and Sahu, 2021).

In terms of waste management, this sector generates a diverse array of solid waste materials, including leaves, stems, cut flower remnants, paper, cardboard, and plastic which will be further explained in the following chapters. To promote sustainability, it is crucial to explore options such as composting, recycling, and responsible disposal for these waste products.

Furthermore, wastewater produced in floriculture operations exhibits distinct characteristics, typically containing organic matter, residual fertilizers, and possibly traces of pesticides or herbicides from the cleaning processes. A comprehensive understanding and characterization of this wastewater is essential for designing an effective treatment system, ensuring compliance with environmental regulations, and mitigating the sector's environmental footprint as will be dealt with in the processing sectors.

3. Water Supply

3.1   Introduction

The potential sectors identified for the Free Zone will require varying amounts of water for industrial processes, cleaning, domestic use, etc. This chapter will detail the estimation of the water demand and the water supply options. The opportunities for integrating the existing water supply infrastructure in Entebbe municipality are also explored.

3.2   Existing Infrastructure

National Water and Sewerage Corporation supplies water to Entebbe Municipality. The water supply system relies on only a surface water source, namely, Lake Victoria. There are two water treatment plants in Entebbe, both located in the same area in Kakeeka Parish on the shores of Lake Victoria. The old water treatment plant has a capacity of 3000 m^3/day, while the new water treatment plant as a capacity of 33,000 m^3/day. According to the municipal officials, the design capacity of the water treatment plant is not being utilized fully.

Figure 3-1: Location of the NWSC Water Treatment Plant

The Entebbe International Airport Free Zone lies within the Uganda Civil Aviation Authority (UCAA) complex. The pipeline supplying the UCAA complex is a DN200 mm pipeline. It is estimated that UCAA consumes about 5% of the water supplied in Entebbe City. There are no reported challenges with water pressure within the water mains that supply water to the homes, institutions and businesses. The challenges experienced are caused by power outages and machinery breakdown at the water treatment plant.

3.3   Water Demand Categories

The water demand categories at the Free Zone comprise of:

i.   Domestic demand: Water consumed by employees and workers at the Free Zone
ii.   Industrial demand: Water required to support the sectors and processing plants in the Free Zone. This demand includes firefighting and cleaning water requirements.

3.4   Design Criteria

3.4.1   Domestic Demand

The per capita water consumption has been determined based on the Directorate of Water Development (DWD) Water Supply Design Manual 2nd Edition (Environment, 2013). The selected per capita water consumption is 100 litres per capita per day.

3.4.2   Industrial Demand

The industrial demand for different potential sectors at the Free Zone has been assessed for a given scalable quantity of raw materials since the total quantity of raw materials is not yet determined to obtain the total daily demand. When all the quantities of raw materials for each sector have been established and the quantity that can be processed daily obtained, a detailed analysis of the daily demand and the design requirements for different infrastructure shall be established. The water requirement presented in this section for each sector has been established basing on the scalable value of raw materials as follows; 1000L of milk for the dairy sector, 1000kg of meat, fish, fruits and vegetables and floriculture for respective sectors. This amount of water includes water for production processes, cleaning, and water required during storage of the products.

3.4.2.1   Dairy Sector – Cheese Production

Each step during cheese production requires a certain amount of water for different purposes such as cleaning, heating, cooling, diluting, washing and storage of cheese. The quantity of water required depends on whether the hard or soft cheese is to be produced. The water demand for cheese production was estimated based on a study carried out to review the environmental life cycles for cheese production. (Finnegan, Yan, Holden, & Goggins, 2017). The computed water demand for processing 1600 litres of milk to hard and soft cheese is 1.76 to 4.34 m^3. and 1.07 to 2.98 m^3 respectively. The water demand during production of cheese is higher and has been considered in determining the water supply infrastructure.

3.4.2.2   Meat Sector – Cold Storage

The volume of water required in the meat processing is mainly required for processes cleaning equipment. This water demand was estimated to be 2.5m^3 to 40m^3 per tonne of raw meat processed basing on a study carried out to assess the characteristics of effluent water from small and medium meat factories (Latiffi et al., 2019). Due to the high-water requirement and the required infrastructure for the waste management in a meat industry, only cold storage of meat will be done at the Free Zone, and the water requirement for this sector is included in the domestic water demand at the Free Zone.

3.4.2.3   Fruits and Vegetables – Sorting, Washing and Packaging

The amount and quality of water required in the process of fruit and vegetable sorting, washing and packaging depend on several factors, such as the type and condition of the raw material, the processing method and equipment, the hygiene standards and regulations, and the environmental conditions. The amount of water required to process one ton of fruits and vegetables was determined basing on the study carried out on water consumption in fresh-cut fruit and vegetable production as 2.4m^3 to 11m^3 and 5m^3 to 16m^3

respectively (Lehto et al., 2014a). The quantity of water required for the fruit sector has been estimated for 10 tons of fruits and vegetables expected at the freezone as 24m^3 to 110m^3 and 50m^3 to 160m^3

3.4.2.4   *Floriculture – Packaging and Export*

Water assumes a critical role in maintaining the freshness and quality of harvested flowers. Water is utilized for hydrating the flowers immediately after harvest, in storage and transportation to maintaining proper humidity levels through water vapor or misting systems and prevent desiccation. Water consumed in processing floriculture was estimated based on the study carried out on storage for cut flowers and plant material at the Kansas State University. The amount of water consumed in preserving 52 tons of flowers has been estimated as 197 m^3.

3.4.3   Peak Factors

The average day demand is determined from the summation of the domestic demand and industrial demand. The average day demand is subject to variations in the water demand such as seasonal availability of the quantity of raw materials. The maximum day demand factor of 1.3 is applied to the average day demand. The maximum day demand is used in the design of the storage reservoirs.

There are hourly fluctuations in demand over the duration of the day. The fluctuations are catered for by peak hour factors which are applied to the maximum day demand. The peak hour factor of 2.0 is adopted for the design of the distribution main supplying the Free Zone.

3.5   Water Demand Estimation

3.5.1   Domestic Demand

The per capita water consumption is estimated within the range of 50 to 100 litres per capita per day. The number of people expected at the Free Zone has been estimated as 450 people.   Using the upper limit, the computed domestic water demand for the free zone is 38.5 m^3/d. Table 3-1 shows the estimated domestic water demand at the Entebbe Freezone.

Table 3-1: Estimated domestic water demand at the Free Zone

Sector	Water Requirement	Percentage Development of Freezone		
		35%	75%	100%
Domestic water demand	Minimum Water Requirement	7.9	16.9	22.5
	Mean Water Requirement	11.8	25.3	33.8
	Maximum Water Requirement	15.8	33.8	45.0

3.5.2   Industrial Demand

The realistic time frames for the gradual development of an industry must be considered when determining the industry's water demand. In this study, progressive development has been considered as a percentage of full capacity for each potential sector. The water demand has been estimated at the 35%, 75% and 100% of full capacity of each sector. Industrial water demand at the Free Zone has been quantified for the cheese production, floriculture, fruit, and vegetable sectors. Since only storage is considered for the meat sectors,

its water requirement has been captured in the domestic water demand for the people expected to work in the sector at the Free Zone. The industrial water demand is summarized in Table 3-2.

Table 3-2: Industrial Demand

Sector	Water Requirement (m³/day)	Percentage Development of Freezone		
		35%	75%	100%
Fruit Sector	Minimum Water Requirement	8.40	18.00	24.00
	Mean Water Requirement	23.45	50.25	67.00
	Maximum Water Requirement	38.50	82.50	110.00
Vegetable Sector	Minimum Water Requirement	17.50	37.50	50.00
	Mean Water Requirement	36.75	78.75	105.00
	Maximum Water Requirement	56.00	120.00	160.00
Floriculture	Minimum Water Requirement	68.98	147.81	197.08
	Mean Water Requirement	68.98	147.81	197.08
	Maximum Water Requirement	68.98	147.81	197.08
Dairy Sector - Cheese	Minimum Water Requirement	0.62	1.32	1.76
	Mean Water Requirement	1.07	2.29	3.05
	Maximum Water Requirement	1.52	3.25	4.34
Total Industrial Water Demand	Minimum Water Requirement	95.5	204.6	272.8
	Mean Water Requirement	130.2	279.1	372.1
	Maximum Water Requirement	165.0	353.6	471.4

The industrial water demand considering 100% development of the Free Zone ranges from 272.8 m³/day to 471.4 m³/day.

3.5.3   Average Day Demand at the Free Zone

The average day demand at the Free Zone, inclusive of the domestic and industrial water demand is shown in Table 3-3.

Table 3-3: Average Day Demand

Sector	Water Requirement (m³/day)	Percentage Development of Free Zone		
		35%	75%	100%
Total (Industrial + Domestic)	Minimum Water Requirement	103.4	221.5	295.3
	Mean Water Requirement	142.1	304.4	405.9
	Maximum Water Requirement	180.7	387.3	516.4

The maximum day demand at the Free Zone has been obtained as 671.3 m³/day by increasing the maximum water requirement at 100% development of the Free Zone by 30%. According to the Water Supply Design Manual 2nd Edition by the Ministry of Water and Environment, the industrial water demand is estimated based on the area occupied by the industry. This results into a maximum day demand of 104 m3/day at 100% development capacity based on 5 acres of the freezone. However, the sectoral approach that was used in this study takes into consideration the intensity of the industries and the varying water

requirements for the different industrial processes. This presents the worst-case scenario due to the specificity in water demand estimation for each sector considered for the freezone.

3.5.4 Firefighting water demand

The Entebbe Free Zone covers an area of 5 acres. According to the Water Supply Manual MWE (2013), the firefighting water demand has been estimated at a rate of 324 m^3/d for two hours for this type of industry. A fire hydrant shall be connected to a DN300 mm transmission line. The DN 300 mm pipeline shall supply water to both the storage tank for use within the Free Zone and the hydrant for use during firefighting operations.

3.6 Current water situation

The previous section has investigated the water demand for different sectors and the people expected at the Free Zone. The maximum water requirement has been estimated at different capacities of the Free Zone, i.e., 35%, 75% and 100% of the full capacity of the Free Zone as 180.7 m^3/day to 516.4 m^3/day. The consideration of the level of development of the Free Zone has also taken into consideration of the population expected at the Free Zone at different capacities. According to the stakeholder engagement with the municipality officials, the available source of water in the area is from the National water and sewerage Cooperation (NWSC), whose combined current capacity is 36,000 m^3/day. It was argued that this capacity is being underutilized and can supply the water required at the Free Zone.

3.7 Water Supply Options

3.7.1 Borehole

The Free Zone is located near the shores of Lake Victoria. The water table within the vicinity of the Free Zone is high. A shallow well can be drilled and motorised to meet the water demand requirement. The Free Zone is located in the Lake Victoria Basin (LVB). According the Tanzanian Ministry of Water, the estimated groundwater recharge in the entire catchment is 1,327Mm^3/year. The estimated groundwater recharge in the Free Zone is 6.07 m^3/day (based on 0.02 km^2 acreage).

The water demand estimation for the Free Zone is a minimum of 180.7 m^3/day. The available groundwater can meet 3% of the estimated water demand. This option cannot mee the water demand at the Free Zone. In addition, the water quality is expected to have similar properties to Lake Victoria, hence conventional water treatment will be required. The recommended treatment option for the estimated water demand is a packaged water treatment plant. However, this would require high capital investment costs. In addition, the design life of the system is limited to 15 years. Hence this option is not considered feasible for water supply at the Free Zone.

3.7.2 Surface Water Supply

The Consultant explored the possibility of constructing an independent water system for supply to the Free Zone only. The surface water supply option would require construction of an intake, water treatment plant and storage reservoir. This option provides a long-term solution for water supply, however, due to the high capital investment costs and land requirements, it will not be explored further.

3.7.3 Extension of Existing Water Supply System

The existing Entebbe Municipality piped water supply system has reserve capacity to meet the water demand at the Free Zone. The Free Zone will be served by existing DN200 mm pipeline serving the UCAA complex. However, the water demand at the Free Zone is expected to grow over time from an estimated demand of 103.2 – 180.7 m^3/d to 295.3 – 516.4 m^3/d when the Free Zone is fully operational. Therefore, a new large diameter water distribution pipeline of at least DN 300 mm is required. Connection of the freezone to the existing water supply system is the best option for water supply at the park since the available capacity of the system is being underutilized. Furthermore, based on discussions with NWSC, it was confirmed that the existing water treatment plant capacity can meet the estimated water requirements for the Free Zone.

3.8 Water Storage

3.8.1   Design Criteria

A storage reservoir is required to provide for fluctuations in water demand during the day (e.g., the hourly peak flow) and minimize disruptions in flow during periods of maintenance. Furthermore, the storage provides for a constant residual pressure and flow for smooth operations at the Free Zone.

The DWD Water Supply Design Manual recommends 30% of the maximum day demand has been adopted for storage. The calculated storage for the Free Zone is shown in Table 3 4.

3.8.2   Calculated Storage

The storage requirement has been estimated based on the maximum day demand for 100% production capacity at the Free Zone. The calculated storage is shown in Table 3-4.

Table 3-4: Calculated Water Storage

Water Requirement	Maximum Day Demand (m^3/day)	Calculated Storage Capacity (m^3/day)	Adopted Storage Capacity (m^3/day)
Minimum Water Requirement	383.9	115	120
Mean Water Requirement	527.6	158	160
Maximum Water Requirement	671.3	201	210

The adopted storage reservoirs at 100% capacity of the Free Zone range in capacity from 120m^3 to 210m^3. If a margin error of 10% is used to cater for inaccuracies in estimations for 100% development of the Free Zone and other uncertainties, the storage requirement ranges from 135 m^3 to 235 m^3. The duration of the storage provided by the proposed reservoir tanks over the development of the Free Zone are shown in Table 3-5.

Table 3-5: Duration of Storage

Parameters	Percentage Development of Free Zone			
	35%	75%	100%	110%
Minimum Water Requirement (m^3/day)	103.4	221.5	295.3	324.9
Adopted Storage Capacity (m^3)	120	120	120	132
Storage Capacity (%)	116%	54%	41%	41%
Hours of Storage (hr)	**28**	**13**	**10**	**10**
Mean Water Requirement (m^3/day)	142.1	304.4	405.9	446.5

Parameters	Percentage Development of Free Zone			
	35%	75%	100%	110%
Adopted Storage Capacity (m³)	160	160	160	176
Storage Capacity (%)	113%	53%	39%	39%
Hours of Storage (hr)	**27**	**13**	**9**	**9**
Maximum Water Requirement (m³/day)	180.7	387.3	516.4	568.1
Adopted Storage Capacity (m³)	210	210	210	231
Storage Capacity (%)	116%	54%	41%	41%
Hours of Storage (hr)	**28**	**13**	**10**	**10**

The duration of storage provided at 100% development of the Free Zone ranges between 9 to 10 hours. This is deemed sufficient storage to cater for disruption in supply due to maintenance works. In order to cater for any inaccuracies and uncertainties in the water storage and requirements, the duration of storage has also been estimated at 110% development of the Free Zone between 9 to 10 hours.

3.8.3   Storage Reservoirs

The storage reservoirs proposed are of capacities of 135m³, 180m³ and 235m³. The storage reservoir can be of the following types:

i.   Polyethylene (PE Tanks): The tanks are manufactured in capacity ranging from 0.5m³ to 10m³. The tanks can be erected on masonry ground support or steel towers.
ii.   Pressed Steel Reservoir Tanks: The tanks are configured to provide storage from 1.5m³. The tanks can be erected on reinforced concrete dwarf walls or steel towers

The pressed steel reservoir tanks provide long-term durability coupled with a lower storage to area ratio. However, these tanks have higher capital investment costs compared to PE tanks.

Given the required storage capacity and durability of the infrastructure at the Free Zone, we recommend use of the pressed steel reservoir tanks. The design capacity of the pressed steel tanks is 135 – 235 m³. This capacity shall be confirmed during feasibility and detailed design stage of the water and sanitation infrastructure. According to the ongoing construction works at the Free Zone, there are 5 rainwater harvesting tanks each of 5000 litres capacity to correct rainwater. Rain water is seasonal and therefore, not a reliable source of water for the Free Zone. However, this water source can be utilized during the rainy seasons.

During the detailed engineering design, the pressure required at the water consumption ends shall be analysed. Pumps are proposed to boost the water pressure supplied to the park. The consultant proposes that these pumps be operated by hydroelectric power, and a standby source of power from solar energy is proposed as opposed to diesel generators. This is intended to reduce the carbon dioxide emission from diesel generators. The total quantity of carbon dioxide emission will be determined during the detailed engineering design when the pump specifications and power requirements have been computed. However, it can be noted that for every litre of fuel, 2.62kg of carbon dioxide are produced[1]. The water pumps will also provide the required water pressure for the fire hydrants.

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[1] How To Calculate Emissions from Diesel Generator? - UtilitySmarts

3.8.4   Operation and Maintenance

The operation and maintenance of the water supply infrastructure at Free Zone will comprise of the following:

i. Payment of water bills. NWSC will provide water bills based on the water consumed per month. The water bills will be paid monthly
ii. Desilting of the storage reservoirs. The accumulation of silt is dependent on the water quality from the supply main. The desilting can be carried out every two years
iii. Routine maintenance works. The routine maintenance works will be determined based on a visual assessment of the infrastructure. This includes works such as replacement of valves, painting of steel tower and repair of leakages of pipes and/or tanks.

4. Wastewater Management

The potential sectors identified for the Free Zone will require varying amounts of water for industrial processes, cleaning, domestic use, etc. This chapter will detail the estimation of the wastewater flows and pollution load. The opportunities for integrating the existing wastewater supply infrastructure in Entebbe municipality are also explored.

The design criteria for wastewater management includes determining flow rates and wastewater characteristics, selecting treatment processes, designing layout and infrastructure, managing sludge, ensuring regulatory compliance, and considering energy efficiency and future expansion.

4.1 Existing Infrastructure

There are two existing Waste Stabilization Ponds (WSP)), the Lunyo WSP (0°4'10''N, 32°28'23''E) and the Kitoro WSP (0°3'14''N, 32°27'21''E) near the Free Zone independently managed by UCAA and NWSC.

Figure 4-1: Location of the NWSC WSPs

The NWSC WSPs located in Kitooro have a design treatment capacity of 16,000 m^3/day. (The design capacity is 500 m^3/d but the capacity being utilised is 300 – 380 m^3/d). The entire geographical area downstream of the WSPs is not served by the existing sewer network. This catchment includes residential properties and commercial institutions such as hotels and beaches. The institutions rely on onsite wastewater management technology, which can lead to pollution of the lake if not well maintained or undersized.

The UCAA WSPs are located southwest of the NWSC ponds and treat the wastewater from the UCAA complex. The Consultant will conduct an inspection of the Kitoro and Lunyo ponds to assess their functionality and treatment efficiency.

The ponds will have an impact on the groundwater in Entebbe both positively and negatively. Positively, the ponds can serve as a source of groundwater recharge and improve water quality by removing contaminants. Additionally, these ponds can help manage the water table and prevent flooding when designed correctly. However, there are also potential negative effects, including groundwater contamination risks if the ponds overflow or poorly treat water. Nutrient loading and sediment accumulation can further affect water quality and storage capacity. Proper design, maintenance, and water treatment processes are essential to maximize the benefits of treatment ponds while minimizing their adverse impacts on groundwater. Regular monitoring and consideration of local hydrogeological conditions are crucial for their effective implementation.

4.2   Design Criteria

4.2.1   Domestic Wastewater

The domestic wastewater comprises of wastewater from toilets, bathrooms and kitchens as well as the trucks turnover to account for the drivers that come in and out of the Free Zone. The domestic wastewater was estimated based on an 80% water consumption return rate. A peak hour factor of 1.5 is applied to the estimated wastewater flow to cater for hourly fluctuations.

The domestic wastewater characterisation is shown in Table 4-1.

Table 4-1: Domestic Wastewater Characterization

Parameter	Lower Limit	Upper Limit
BOD (mg/L)	155	286
TSS (mg/L)	155	330
TN (mg/L)	26	75
TP (mg/L)	6	12
NH3 (mg/L)	4	13
Coliform Bacteria	10	100
Faecal Coliforms	10	100

4.2.1.1   Industrial Wastewater

4.2.1.2   Dairy Sector – Cheese Production and Storage

Wastewater from the cheese production contains high levels of organic matter, nutrients, salts, and pathogens that can pollute water resources and pose health risks while the wastewater from storage may have minimal contamination with the contamination originating from cleaning of the storage rooms after emptying. Wastewater from cheese production comes from various sources, such as washing of the equipment, milk losses, staff activities, and whey separation. The cheese production process results in the liquid waste in the form of whey and wastewater. The whey that is generated at the factory is collected in the storage tank and sold to animal farmers as feed. According to Hanková et al., 2020, the volume of wastewater generated during the production of cheese from 1000 litres of milk is $1.8m^3$ but following discussion with Santos Foods limited the volume of wastewater generated during the production of cheese from 1000 litres of milk is $0.75 – 3.5m^3$. The wastewater produced in storage primarily originates from the personnel working in the storage facility and is included in calculations for domestic wastewater. Table 4-2 shows the characterisation of wastewater from the dairy industry during production of soft and hard cheese in $0.75 – 3.5m^3$ of wastewater.

Table 4-2: Dairy Sector Wastewater Characterization

Parameter	Lower Limit	Upper Limit
BOD (mg/L)	590	6,000
COD (mg/L)	1,000	63,300
FOG (mg/L)	330	2,600
TSS (mg/L)	190	2,500
TN (mg/L)	18	830
TP (mg/L)	5	280
TS (mg/L)	1,920	53,200

Table 4-3: Dairy Sector Wastewater Characterization for soft cheese

Parameter	Limit
BOD (mg/L)	26.77
COD (mg/L)	59
FOG (mg/L)	0.49
TSS (mg/L)	8.31

Table 4-4: Dairy Sector Wastewater Characterization for hard cheese

Parameter	Limit
BOD (mg/L)	9.48
COD (mg/L)	73
FOG (mg/L)	0.99
TSS (mg/L)	7.15

Due to the wastewater characteristics as well as the volumes of wastewater generated from the processes involving the processing of cheese, only cold storage of cheese and production of hard cheese shall be considered at the Free Zone.

4.2.1.3   Meat Sector – Packaging Steaks & Cold storage

The meat packaging and storage industry produces minimal amounts of wastewater The wastewater is generated from various sources such as cleaning, washing, cooling, rendering and packaging of meat products (Costa, Amorim, Duque, Reis, & Castro, 2022) as well as cleaning of equipment and the storage room. The volume of wastewater generated for the packaging process is minimal. It should also be noted that the wastewater produced in storage primarily originates from the personnel working in the storage facility and is included in calculations for domestic wastewater. The summary of the characterisation is shown in Table 4-5.

Table 4-5: Meat Sector Wastewater Characterization

Parameter	Lower Limit	Upper Limit
BOD (mg/L)	500	4,000
COD (mg/L)	1000	15,000
FOG (mg/L)	300	2,000
TSS (mg/L)	300	6,000
TN (mg/L)	50	800
Cl (mg/L)	300	800

Due to the wastewater characteristics and the volume of wastewater generated from the processing of meat, only cold storage shall be done at the Free Zone.

4.2.1.4   Fruits and Vegetables – Sorting, Washing and Packaging

The fruit and vegetable cleaning, sorting, washing and packaging and temporary storage industry (FVSPI) produces wastewater that contains high levels of organic matter, suspended solids, sugars, starches, acids, salts, pesticides and pathogens. The amount of wastewater generated in the fruit and vegetable cleaning, sorting, washing and packaging and temporary storage process is equivalent to the volume of water utilized in the process (Lehto et al., 2014b). According to Lehto et al., 2014, the characterisation of wastewater from a fruit and vegetable cleaning, sorting, washing, and packaging and temporary storage industry is as shown in Table 4-6.

Table 4-6: Fruits and Vegetables Sector Wastewater Characterization

Parameter	Lower Limit	Upper Limit
BOD (mg/L)	400	1,700
COD (mg/L)	4,400	5,900
TSS (mg/L)	300	6,000
TN (mg/L)	68	92
TP (mg/L)	13	19
TS (mg/L)	4,600	18,900
E. coli	3.1	3.7
Coliform Bacteria	4.6	6.9
Faecal Coliforms	2.3	5.5

4.2.1.5   Floriculture processing

The characteristics of wastewater generated are typically influenced by activities such as trimming, packaging and cold storage. This wastewater commonly contains organic matter, including plant debris and residues generated from cleaning and trying to keep the flowers fresh, as well as traces of fertilizers, pesticides, and cleaning agents. Suspended solids, including flower stems and petal fragments, can also

be present. Additionally, the pH levels of the wastewater may vary, and it may have a slightly elevated temperature due to the cooling process. The concentrations of specific pollutants, such as nutrients and potential contaminants, may depend on the flower varieties grown, cultivation practices, and the type of cleaning agents or disinfectants used.

Table 4-7: Floriculture Sector Wastewater Characterization

Parameter	Lower Limit	Upper Limit
TSS (mg/l)	265.3	247
TDS (mg/l)	237	391.67
TP (mg/l)	3.7	6.27
COD (mg/l)	325.33	688.27
TN (mg/l)	28.33	94

4.3 Wastewater Estimation

Wastewater quantities were estimated considering that at the start of the industry, all sectors will not be occupied to full capacity. The occupancy levels considered are 35%, 75% and 100% of the full occupancy for all the sectors. Table 4-8 shows the lower, mean, and upper limit values of characterisation of wastewater from each sector at different percentages of occupancy.

Table 4-8: Wastewater Quantification for Free Zone

Sector	Wastewater Volume (m³)	Percentage Development of Freezone		
		35%	75%	100%
Fruit Sector	Minimum Wastewater Volume	4.8	10.3	13.7
	Mean Wastewater Volume	13.4	28.6	38.2
	Maximum Wastewater Volume	21.9	47.0	62.7
Vegetable Sector	Minimum Wastewater Volume	10.0	21.4	28.5
	Mean Wastewater Volume	20.9	44.9	59.9
	Maximum Wastewater Volume	31.9	68.4	91.2
Floriculture	Minimum Wastewater Volume	51.7	110.9	147.8
	Mean Wastewater Volume	51.7	110.9	147.8
	Maximum Wastewater Volume	51.7	110.9	147.8
Dairy Sector - Cheese	Minimum Wastewater Volume	0.5	1.0	1.4
	Mean Wastewater Volume	0.8	1.8	2.4
	Maximum Wastewater Volume	1.2	2.5	3.4
Domestic	Minimum Wastewater Volume	5.5	11.8	15.8
	Mean Wastewater Volume	8.9	19.0	25.3
	Maximum Wastewater Volume	12.6	27.0	36.0
Total Industrial Water Demand	**Minimum Water Requirement**	**67.0**	**143.5**	**191.4**
	Mean Water Requirement	**86.9**	**186.2**	**248.2**
	Maximum Water Requirement	**106.8**	**228.8**	**305.1**
Total (Industrial + Domestic)	**Minimum Wastewater Volume**	**72.5**	**155.3**	**207.1**
	Mean Wastewater Volume	**95.7**	**205.2**	**273.5**
	Maximum Wastewater Volume	**119.4**	**255.8**	**341.1**
Peak Flow	**Minimum Wastewater Volume**	**108.7**	**233.0**	**310.7**
	Mean Wastewater Volume	**143.6**	**307.7**	**410.3**
	Maximum Wastewater Volume	**179.1**	**383.7**	**511.6**

The summary of the wastewater characterisation for 100% development of the Free Zone is shown in Table 4-9.

Table 4-9: Wastewater Characterization for Free Zone (100% Development)

Parameters (kg)	Low Limit	Mean Limit	High Limit
BOD	103.7	340.7	438.3
COD	1,092.9	1,362.4	1,683.1
FOG	1.7	8.5	13.2
TSS	133.4	747.1	1,415.6
TDS	52.5	0.0	0.0
TN	17.2	23.3	29.5
TP	4.2	4.9	6.5
Cl	0.0	0.0	72.1
Zn	0.0	0.0	0.0
Fe	0.0	0.0	54.8

Parameters (kg)	Low Limit	Mean Limit	High Limit
NH3	0.2	0.5	53.2
TIC	0.0	152.8	0.0
TS	1,071.7	2,911.1	4,633.0
E.Coli	715.6	87,697.2	854.1
Coliform Bacteria	113,508.0	22,168.6	1,592.9
Faecal Coliforms	531.0	2,290.5	1,269.7

4.4 Wastewater Management Options

The wastewater management options include the following:

i.   Construction of a packaged wastewater treatment plant
ii.   Utilization of the existing wastewater management facilities in the Lunyo and Kitoro waste stabilisation ponds.

Packaged wastewater treatment plants are pre-designed and modular systems used for wastewater treatment. They offer several advantages, including space-saving, easy installation, low maintenance, portability, and environmental friendliness. These plants operate in a series of stages: pre-treatment to remove large debris, biological treatment using microorganisms to break down organic matter, clarification to separate treated wastewater from solids, and disinfection to neutralize remaining pathogens (WSI, 2023). These plants can provide a practical and efficient solution for treating wastewater in various settings, ensuring responsible and effective wastewater management while minimizing operational complexities

The construction of the packaged wastewater treatment plant is not considered due to the limited space within the Free Zone, the high capital investment costs and long-term durability of the treatment plant. Redirecting wastewater from the park to public infrastructure may offer some advantages. Firstly, it may preserve the natural environment of the park by avoiding potential contamination and harm to ecosystems (Kesari *et al.*, 2021). Secondly, it will prioritize public health and safety by ensuring proper treatment of wastewater, reducing the risk of waterborne diseases, and safeguarding the water supply for nearby communities(Kesari *et al.*, 2021). Thirdly, this redirection of wastewater will make efficient use of resource-intensive wastewater treatment technologies already in place in public infrastructure, potentially reducing costs for the organization responsible for the park. Additionally, this approach fosters a collaborative effort among different entities, promoting coordination and cooperation in wastewater management(Gamache, 2021). While not the primary goal, redirecting wastewater can lead to long-term cost savings by leveraging existing treatment facilities and avoiding substantial upfront investments in independent wastewater treatment infrastructure like the packaged wastewater treatment plants.

Hence the wastewater management option will focus on integrating the treatment requirements at the Free Zone with the existing wastewater management infrastructure.

4.4.1   Wastewater Treatment Processes

The wastewater generated from the processes within the Free Zone shall be combined and treated. Given that most of the processes at the Free Zone shall be cold storage of processed products, the wastewater generated from the Free Zone can be combined and transported to the treatment unit.

The wastewater treatment processes required are:

- Primary treatment: Free ZoneThis treatment process includes the screening of the wastewater and grease and oil separation.
- Secondary Treatment: This treatment comprises of anaerobic treatment in wastewater stabilization ponds. The wastewater will undergo treatment in the anaerobic, maturation and facultative ponds
- Tertiary Treatment: The effluent from the ponds will undergo further treatment in the existing swamp before discharge into the lake.

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┌─────────────────────────────┐
│   Domestic, Vegetables,     │
│     Fruits and Dairy        │
└─────────────────────────────┘
              ▼
┌─────────────────────────────┐
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│     Screen and Grit Trap    │
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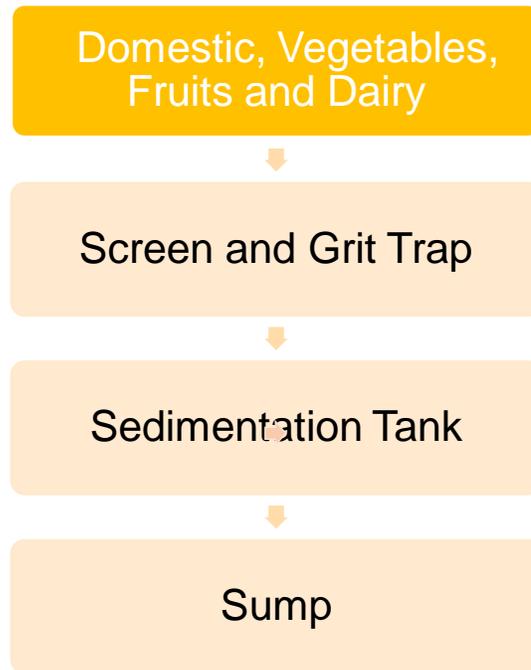
Figure 4-2: Treatment Processes at Free Zone

The sizing of the structures assumes that the sector processes will operate for at least 8 hours in a day. The hydraulic design of the structures is not covered under this scope of works. The primary treatment structures will be reinforced concrete and masonry structures and will comprise of the following:

i. Two inlet channels. The channels will have a grit trap, a course screen and a fine screen. During the cleaning of the floors and machinery, it is expected that some solid waste will be carried into the wastewater. The screen will trap the solid waste for removal.

ii. Sedimentation Tank. The wastewater from the domestic, fruits, vegetables and dairy will flow into the sedimentation tank. This will allow for the settling of fine particles within the wastewater. The wastewater will spill into the sump. This chamber will receive a maximum volume of 511.6 m^3/day. The capacity of the sedimentation tank will be 520m^3.

iii. Sump. The sump will be a subsurface structure that will provide suction for the pumping of the wastewater. The sump will provide storage for at least two hours and will have a capacity of 40m^3.

Additional infrastructure for the operation of the treatment processes includes:

i. Pump house. This will house the pumps at the site. Mechanical and electrical installations will be done in the pump house.

ii.   Pump Attendant house. The house will be occupied by the attendant at the pump station. The structure will comprise of a store for reagents, electrical mechanical spares and a sanitation facility for the attendant.

iii. Drying shed. This will provide drying storage for the solid waste trapped under the primary treatment. The solid waste will be disposed of off-site at the dumping site for Entebbe Municipality.

4.4.2   Integration with Existing Infrastructure

The existing infrastructure includes independent wastewater stabilization ponds under the management of NWSC and UCAA.
The opportunities for integration with the existing infrastructure includes:

i.   Pumping of wastewater from the Free Zone to the existing UCAA WSPs. The Consultant will carry out an assessment of the existing ponds and determine the design capacity and treatment efficiency

ii.   Pumping of wastewater from the Free Zone to the existing NWSC WSPs. The Consultant will carry out an assessment of the existing ponds and determine the design capacity and treatment efficiency.

iii. Pumping of wastewater from the Free Zone and adjacent properties to the existing WSPs. The existing commercial properties along the lake shoreline rely on on-site sanitation technologies. The functionality of these technologies impacts the pollution of the lake.

4.4.3   Operation and Maintenance

The selection of the WSPs to receive the wastewater will determine the operation and maintenance modalities, as explained below:

- UCAA WSPs. Currently, there is no technical operator at the WSPs, as the wastewater flows from one pond to the next. Hence a private operator would be required to man the lifting station. The operator of this system would be a tendered private operator. The operator will be responsible for the day to day running of the treatment units and will be paid an agreed amount for the services rendered. However, the Free Zone will incur expenditures towards purchase of reagents and repair works at the treatment unit.

- NWSC WSPs. The operator of the system will be NWSC. NWSC will be responsible for assigning qualified personnel to operate the facility, purchase of reagents and spares and payment of utility bills. It should be noted that the connection to the NWSC ponds will results in 100% surcharge to the water utility bill to cater for the sewerage services.

The pump station will be connected to the national grid. A standby power source is required, and this can take the form of solar power or diesel generator. Solar power can be harnessed by mounting solar panels on top of the warehouse roofing sheets. Approximately 100 square feet of shade-free rooftop space can provide 4 kWh of solar power per day, on average[2]. The detailed assessment of the viability of using solar power will be further assessed in the feasibility studies.

4.4.4   Greening Options
To promote cost-effective and eco-friendly wastewater treatment across various sectors, a range of strategies has been considered

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[2]https://www.solarmango.com/sector/warehouses.

4.4.4.1 Constructed Wetlands

To enhance the sustainability of wastewater treatment processes, it is essential to incorporate cost-effective greening measures. These include the implementation of vegetated buffer strips with native vegetation to reduce nutrient runoff and filter contaminants. Constructed wetlands can be established to facilitate eco-friendly wastewater purification, and rain gardens with native plantings can be used to capture and treat stormwater runoff. The constructed wetlands cannot be implemented at the lake shores, as the area is a swamp.

4.4.4.2 Energy Recovery for wastewater

The recovery of energy from wastewater can be an environmentally beneficial practice. Biogas generation, for instance, can be employed to harness the energy potential of organic matter in the wastewater. Anaerobic digestion processes can break down organic compounds, producing biogas as a by-product which can be utilized as an energy source for heating or electricity generation. The captured biogas contributes to energy recovery and helps offset operational costs. Furthermore, the installation of solar panels on suitable areas, such as warehouse roofing sheets, can harness solar energy, which is a sustainable source of power for various facility needs. By integrating these energy recovery methods with the aforementioned greening measures, wastewater treatment processes can become more resource-efficient and environmentally responsible. The construction of a dome for the recovery of biogas would be capital intensive and require biogas bottling facilities at the WSPs.

Treatment of wastewater to effluent discharge standards will ensure protection of the nearby wetland and downstream users where the effluent will be discharged. The wastewater treatment using this facility will result in a Biological Oxygen Demand (BOD5) removal of at least 70% and a Chemical Oxygen Demand (COD3) removal of at least 75% as per (United nations, 2016). Despite the promising outcomes, precise percentage reductions in water pollution will require a comprehensive study, considering factors such as wastewater quality and operating conditions.

5. Solid Waste Management

5.1 Solid Waste Characterization

5.1.1 Introduction

The solid waste in Entebbe Free Zone is majorly composed of organic waste and the total quantity of solid waste projected will be about 6789kg per day without valorization from all the potential sectors considered. The potential solid waste streams include organic waste, plastics, paper and cardboard. The estimated quantities are shown in Table 5-1.

Table 5-1: Estimated quantities of solid waste generated in Entebbe Free Zone

Sector	Characterization of solid waste	Level of Development		
		35%	75%	100%
Fruits wash and Packaging	Organic waste	147.0	315.0	420.0
	Plastics	63.0	135.0	180.0
	Paper and cardboards	0.0	0.0	0.0
	Others	0.0	0.0	0.0
Vegetables Wash and Packaging	Organic waste	147.0	315.0	420.0
	Plastics	63.0	135.0	180.0
	Paper and cardboards	0.0	0.0	0.0
	Others	0.0	0.0	0.0
Domestic	Organic waste	82.7	177.2	236.3
	Plastics	11.8	25.3	33.8
	Paper and cardboards	23.6	50.6	67.5
	Others	0.0	0.0	0.0
Floriculture	Organic waste	1836.5	3935.5	5247.3
	Plastics	0.4	0.9	1.3
	Paper and cardboards	1.0	2.2	2.9
	Others	0.0	0.0	0.0
Total	**Organic waste**	**2213.2**	**4742.6**	**6323.5**
	Plastics	**138.3**	**296.3**	**395.0**
	Paper and cardboards	**24.7**	**52.8**	**70.4**
	Others	**0.0**	**0.0**	**0.0**

5.1.2 Fruit Sector

Only washing and packaging of fruits will take place at the Free Zone therefore the solid waste from the fruit sector will comprise of organic chippings, fruits that cannot be sold and plastics generated during packaging of these fruits. The organic waste from chippings and for bad fruits will total up to 42 kg and this can be used in biodigester to produce biogas and fertilizer. The waste from packaging materials will be approximately 18 kg.

5.1.3   Vegetable Sector

The solid waste from washing and packaging vegetables will comprise of organic chippings, vegetables that cannot be sold and waste packaging materials. The organic waste from chippings and for bad vegetables will total up to 42 kg and this can be used in biodigester to produce biogas and fertilizer. The waste from packaging materials will be approximately 18 kg.

5.1.4   Dairy Sector

The waste from the dairy sector is whey. The whey obtained can be dried and valorized into animal feeds, however drying whey would be costly for small cheese plants (Schingoethe, 1976). A more feasible option will be selling this whey to nearby cattle farmers to feed the liquid whey to their animals as this has been noted to boost milk production in lactating cows (Schingoethe, 1976).

5.1.5   Floriculture Sector

In the processing of flowers for packaging and export within the floriculture industry, the generation of solid waste will be a significant concern. The solid waste quantification sector focuses on meticulously measuring and assessing the volume and types of solid waste produced during various stages of flower processing. This includes waste generated during sorting, trimming, packaging, and other related activities. Understanding the composition and quantity of solid waste will be critical for devising effective waste management strategies. These wastes will be generated based on incoming inputs and per hectare generations per day. Some of the solid waste that will be generated includes leaves and flower stems, cut flower wastes, plastics and paper.

5.1.6   Meat Sector

Only cold storage of meat will be carried out at the Free Zone and no processing takes place here. The solid waste will hence very minimal from this sector.

5.1.7   Domestic Waste

Waste from the domestic sector will be generated by workers, visitors, truck drivers and other people at the Free Zone. The waste will include food wastes, plastics from beverages and paper.

5.2   Components of Solid Waste Management

5.2.1   Generation

Solid waste generation is the initial step in the waste management process. It encompasses the creation of solid waste materials through various activities at the Free Zone including fruit and vegetable wash, floriculture, domestic waste, cheese processing and cold storage of meat. The quantity and composition of waste generated are closely linked to the production patterns and methods.

5.2.2 Storage

The storage of solid waste at the Free Zone will involve the use of storage facilities such as waste bins, containers, communal depots, or designated areas for larger waste items preventing littering. A waste banker of about $48.7m^3$ is proposed to be constructed at the site.

5.2.3 Collection

Various collection methods will be employed at Free Zone and these include the following;
- **Source Separation:** Businesses separate recyclables and, in some cases, organic waste at the source to facilitate recycling and reduce landfill waste.
- **On-Site Collection:** This will involve collection of waste directly into on-site bins or containers provided around the Free Zone. Compactors may also be used to reduce waste volume.
- **Centralized Collection:** Private waste collection services will be employed to pick up waste from centralized points within the Free Zone. Private waste collection services are assumed to be more cost effective as opposed to a service managed by the park due to costs of hiring trucks, workers and other associated transportation costs. In addition, the solid waste collection within the Municipality has been tendered to private operators and this service is provided at a low cost.
- **Waste Collection Schedule**: Regular and on-demand pickup schedules will be established to meet waste generation needs.

5.2.4 Transportation

After waste materials are collected, they need to be transported to their final destination, which can include recycling facilities, incineration plants, landfill sites, or specialized treatment centers. The inorganic solid waste will be transported to Nkumba dumpsite, a 13-acre piece of land located around 14 km from the Free Zone.
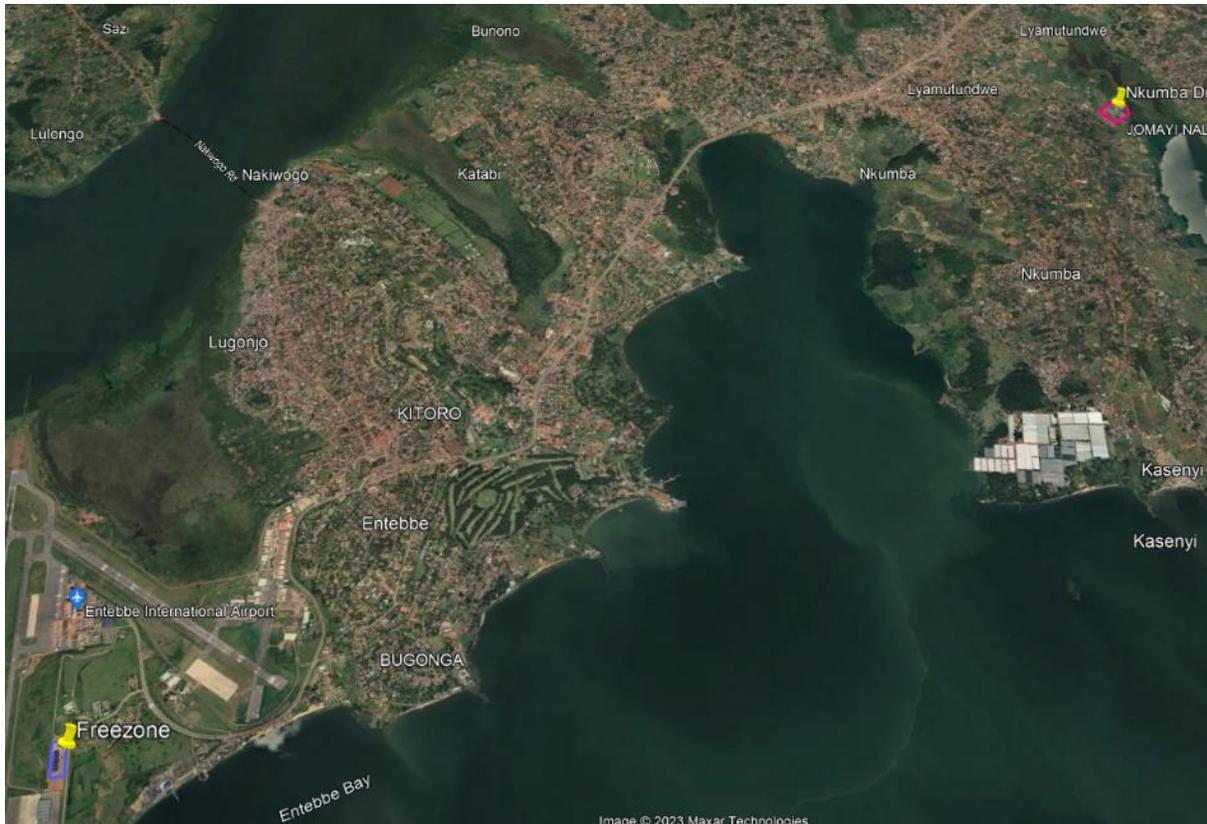
Figure 5-1: Aerial View of the location of Nkumba Dumpsite from the Free Zone

5.2.5 Disposal

The final stage of solid waste management is disposal, which involves the responsible and safe management of waste to minimize environmental and health risks. Several disposal methods will be looked into including composting, landfilling, incineration, anaerobic digestion, and innovative techniques like hog feeding, where waste is utilized as animal feed depending on the type of waste.

5.3 Solid waste management options

The various available options for solid waste management for the Free Zone include composting, landfilling, incineration and anaerobic digestion. Composting involves controlled biological processes in which microbial bacteria converts organic waste into biologically stable products. Compositing involves processes of sorting, shredding, composting, curing and screening. Landfilling is one of the most widely used waste disposal methods and this method mainly involves deposition and compaction of the solid waste at designated dumpsites. Incineration is a high temperature process that reduces waste volume by thermal decomposition, it also offers energy recovery and safe disposal of hazardous waste. This process involves preparation of waste, combustion, air pollution control and handling of residue generated by the process. Anaerobic Digestion involves the conversion of organic waste into energy (biogas) and digestate which can be used for manure purposes. The following subsections describe in detail the key processes entailed in recycling, anaerobic digestion, composting, incineration and landfilling.

5.3.1 Recycling

Paper, plastics, cardboard and other recyclable materials will be sorted out on reaching the Nkumba landfill. These items will be sold to recycling companies to facilitate the production of new materials and products.

5.3.2   Anaerobic Digestion

The type of digester that is recommended will be fixed dome plant because of its relatively low cost and a high lifespan (20 years). The digester will consist of an underground pit lined with concrete or brick, with an inlet pipe that will be used to add feed to the digester and an outlet pipe to let out digested slurry. It will also be painted with polymer paint on the inside to ensure gas-tightness and prevent gas leaks which could cause explosions. The volume of the digester computed at a loading rate of 8324 kg/day of organics is 554.9m^3. For safe use of the anaerobic digester, at least 1/5 of the volume of the reactor will be allocated for storage of gas generated (Laurel Rowse *et al.*, 2011).

This plant will be operated by feeding through the inlet pipe with organics mixed with water at a ratio of 1:1 (8324 kg of water and organics per day). This mixture flows to the bottom of the digester by gravity where anaerobic microbial processes take place to release methane and carbon dioxide. The biogas produced will be stored under the dome at the top of the digester. Increase in pressure beyond equilibrium point in the plant forces the digested slurry out from the outlet pipe into the collection tank. The digested slurry obtained from the collection tank can be used for agricultural purposes as fertilizer which is estimated at about USD 0.04 per kilogram. The biogas obtained can also be utilized for cooking or heating.
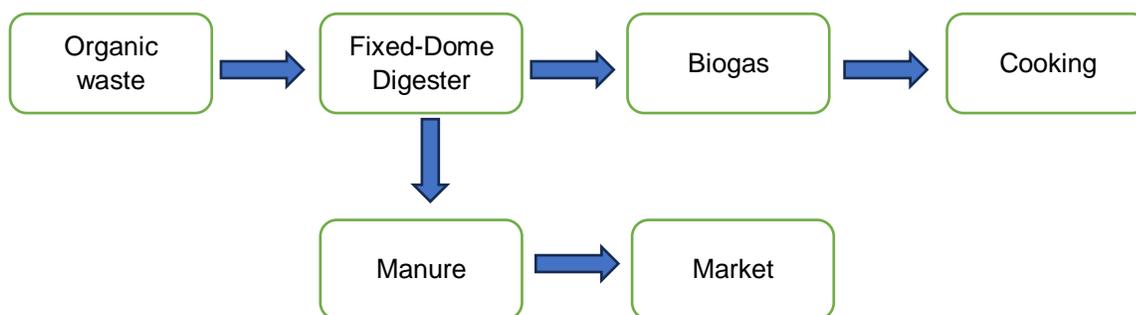
Figure 5-2: Anaerobic digestion process

The Table 5-2 shows the estimated capital investment costs for the construction of an anaerobic digester fully made of burnt bricks (Rakotojaona,2013).

Table 5-2: Estimated capital cost of Anaerobic digester construction

Parameter	Level of Development		
	35%	75%	100%
Volume (m^3)	280.88	449.51	554.90
Amount (USD)	11,115.83	17,614.44	21,676.07

5.3.3   Landfilling

In landfilling, the trucks delivering waste to the landfill will be weighed on the weigh bridge to accurately determine the waste received to come up with the different rates and for invoicing purposes. The waste footprint area will be divided into individual cells, each cell will be lined at the base with liner material to prevent soil and groundwater contamination and to facilitate leachate collection and removal which will be

produced by the waste. One cell will be constructed and filled at a time, which helps reduce initial investment costs, minimizes soil stockpile expenses, reduces leachate generation, limits exposed waste areas, and controls litter, birds, and pests. Leachate management will involve conveying the leachate via gravity from the active cell through pipes to a leachate holding tank for temporary storage before transportation to the nearest wastewater treatment plant.

The anaerobic decomposition of the organic matter generates gases, primarily methane (40-60%), carbon dioxide (35-45%), and trace amounts of non-methane organic compounds. These gases will be extracted using an active gas extraction system comprising crush-resistant pipes laid on a 3-4% slope. Temporary caps on the active cell will prevent the release of landfill gas into the atmosphere. The collected gas, known as biogas, will be harnessed for lighting and powering various processes at the landfill.

After waste disposal, mechanical compaction will be performed, followed by the daily covering of the waste surface and side slopes with a soil layer of at least twelve (12) centimeters. Trucks exiting the landfill will be washed or their tyres will be sprayed to prevent waste mud and contaminants from being transported onto public roads.

Landfills pose some threats to the environment which include contamination of ground and surface water by the leachate generated, emission of greenhouse gases (Methane and carbon dioxide). These will be minimized through the use of Leachate collection systems and gas collection systems respectively. Other environmental impacts include odor, dust, noise and air pollution from trucks. The Nkumba dumpsite is the location suggested for these processes to take place. Figure 5-3 illustrates the process involved during landfilling.
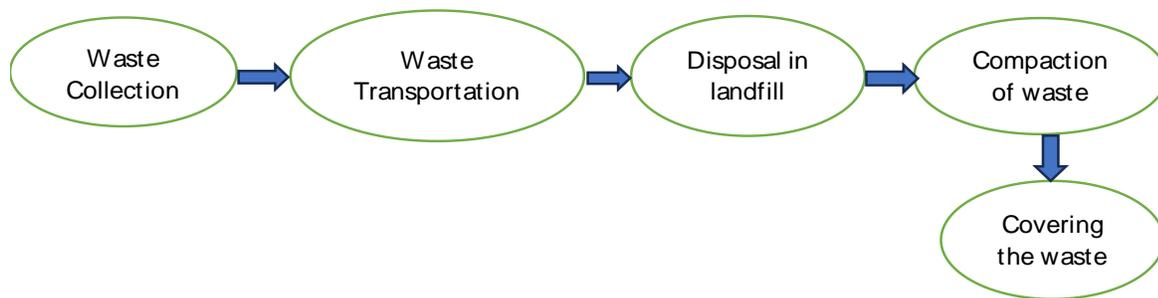

Figure 5-3: Flow chart showing the process of landfilling

An estimate of the total area required for the disposal of the annual waste generated in the Entebbe International Airport Free Zone is shown in Table 5-3.

Table 5-3: Estimation of area required for landfilling the annual solid waste generated at the Free Zone

Parameters	Level of Development		
	35%	75%	100%
Projected Annual Waste Generation (tons)	59.46	127.42	169.89
Volume of the waste (m^3)	69.95	149.90	199.87
Total Volume of annual Daily Cover (m^3)	7.00	14.99	19.99
Total volume for liner system and caps (m^3)	17.49	37.48	49.97
Volume due to settlement in (m^3)	7.00	14.99	19.99
Capacity of landfill (m^3)	87.44	187.38	249.84
Average landfill height (m)	5.00	5.00	5.00
Area for landfilling (m^2)	17.49	37.48	49.97
Area of Nkumba landfill (m^2)	52609	52609	52609

5.3.4 Composting

The organic waste will be subjected to composting using the windrow method and this will be done within the landfill site area. The composting pad will be made of up of concrete flooring and roofed at the top, this will prevent rain from penetrating into the waste. The windrows will be designed with a gentle slope to allow for leachate gravity flow to the leachate tank and they will also be arranged in order of reducing size from active to maturation stages since the compost will be expected to reduce size with time. The organic waste in the active stage where decomposition initially takes place will be moisturized with recycled leachate and water in order to increase the moisture content of the waste. After the active stage which will be about 3-4 weeks, the compost will be shifted to the next windrow for the curing stage which will take 6-8 weeks. When maturation is attained, the compost will be sieved to separate the larger particles from the fine compost. The larger particles will be taken back for re-composting or can be landfilled while the fine compost will be sold to the farmers with a kilogram of compost estimated at USD 0.04. The composting processes is suggested to take place at the Nkumba dumpsite and the processes to be followed are shown in Figure 5-4 below.
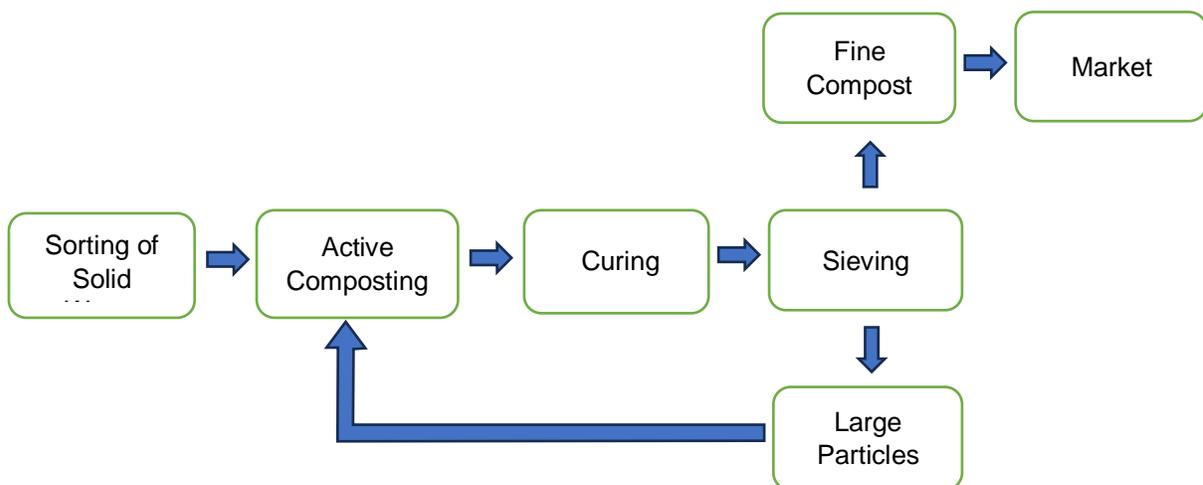

Figure 5-4: A flow chart showing the composting process

An estimate of the area required, dimensions of windrows and dimensions of the footprint area required for composting the monthly organic matter generated in the Entebbe International Airport Free Zone is shown in Table 5-4 below.

Table 5-4: Calculation of the estimated footprint area required for composting

Parameter	Units	Level of Development		
		35%	75%	100%
Height of Windrow	m	1.5	1.5	1.5
Length of Windrow	m	10.0	10.0	10.0
Width of windrow	m	3.0	3.0	3.0
Width of aisle	m	1.0	1.0	1.0
Volume of each windrow	m^3	29.7	29.7	29.7
Feedstock generated in 4 weeks	Kg	66,396.9	142,279.1	189,705.5
Volume of feedstock generated in 4 weeks	m^3	110.7	237.1	316.2
Number of windrows required	No	3.7	8.0	10.6
width of all windrows	m	11.2	24.0	31.9
Width of all aisles	m	3.7	8.0	10.6
Combined width of aisles, buffer area and windrows	m	16.9	33.9	44.6
Combined length buffer area and windrows	m	12.0	12.0	12.0
Required Pad footprint Area	m^2	202.8	407.2	535.0
Length of Pad	m	15.0	15.0	15.0
Width of Pad	m	13.5	27.1	35.7

The capital cost for the setting up the composting process was also estimated based on the estimated cost for the Mbale composting plant (Niwagaba et al., 2015.) as shown in Table 5-5 below.

Table 5-5: Estimated capital cost for setting up the composting process

Parameter	Level of Development		
	35%	75%	100%
Land Occupied (m^2)	202.85	407.24	534.99
Land Occupied (acres)	0.05	0.10	0.13
Amount (USD)	6,265.57	12,579.01	16,524.90

5.3.5 Incineration

The incineration process involves the preparation of the solid waste collected depending on the physical characteristics of the waste, storage facilities are provided for temporary storage of the waste before combustion. The waste will then be put in the combustion chamber where carbon dioxide, water vapor and ash residue will be generated. Air pollution will be the main environmental threat from incineration, and this could be controlled by employing air control equipment such as quench, venturi scrubber, Wet scrubber and other equipment (Oppelt, 1987). The ash residue generated will be taken to the nearest landfill area. The estimated retail price of an incinerator for an organization which produces substantial waste is about USD 12,300. **Error! Reference source not found.** shows the process followed for incineration of solid waste.
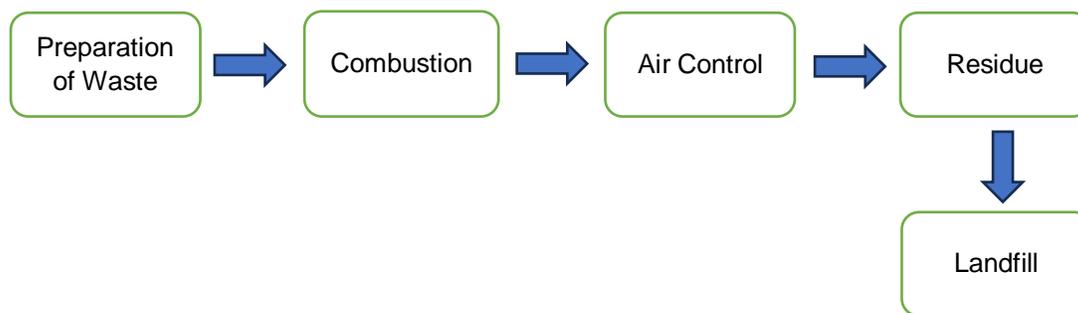
```
┌──────────────┐     ┌──────────────┐     ┌──────────────┐     ┌──────────────┐
│ Preparation  │ ──▶ │  Combustion  │ ──▶ │ Air Control  │ ──▶ │   Residue    │
│  of Waste    │     │              │     │              │     │              │
└──────────────┘     └──────────────┘     └──────────────┘     └──────────────┘
                                                                        │
                                                                        ▼
                                                                ┌──────────────┐
                                                                │   Landfill   │
                                                                └──────────────┘
```

Figure 5-6: Incineration Process

5.3.6   Environmental Concerns

Table 5-6 below shows some of the environmental concerns associated with the various solid waste management options assessed.

Table 5-6: Potential environmental concerns of the different solid waste management options

Landfilling	Incineration	Composting	Anaerobic Digestion
• Dust • Release of greenhouse gases • Odor • Groundwater contamination • Surface water contamination	• Air pollution	• Surface water contamination • Odor • Groundwater contamination	• Gas Leaks which may lead to explosions

5.3.7   Criteria for choosing the suitable option for the Free Zone

The criteria shown in Table 5-7 was followed for choosing the best option for management of solid waste disposal at the Entebbe Free Zone. The feasibility criterion was based on the following;

- **Landfilling:** The Nkumba dumpsite is located quite far (about 14km) from the Free Zone. Solid waste from the Free Zone could be collected by private garbage collection companies and taken to this dumpsite for disposal. Landfills are suitable for various kinds of solid waste except for hazardous waste which could lead to massive environmental pollution.
- **Composting:** Composting is suitable for dry waste (Jördening & Winter, 2005). The solid waste majorly generated at the Free Zone will be dry for example trimmings, leaves, stems. The proposed location for the composting plant (Nkumba dumpsite) is however quite far from the Free Zone location (about 14km).
- **Incineration:** Incineration is generally adopted for disposal of hazardous waste and readily combustible waste materials. At the Free Zone, 93% of the waste generated will be organic which will not be readily combustible and will consume a lot of fuel and produce high emissions.
- **Anaerobic Digestion:** 93% of waste generated at the Free Zone will be organic however this waste includes majorly trimmings from flowers which have very low moisture content and contain high lignin, these will need additives and a lot of water for them to be utilized for this purpose. Co-digestion of the solid waste generated at the Free Zone with other more suitable organics like food wastes and animal waste would make this option more feasible.

Table 5-7: multi-criteria analysis for identification of suitable solid waste management option

Criteria	Composting	Landfilling	Incineration	Anaerobic digestion
Capital cost	+	+	x	x
O & M costs	+	+	x	++
Material and energy recovery	x	+	×	++
Environmental impact	+	×	×	+
Acceptance	x	×	+	++
Local Labour Experience	+	++	+	+
Feasibility	+	+	×	+

Key: ++ Good +Fair x Bad

From above, we recommend consideration of co-digestion of the organic waste generated at the Free Zone with the food waste generated at the Entebbe International Airport Cargo Terminal canteens. The organic waste from the Free zone is about 6324kg per day whereas the food waste from the canteens is about 2000kg per day. The volume of the digester required at maximum capacity will be about 554.9m^3 with a height of about 5.61m and diameter of about 11.22m. The consultant further proposes the construction of the digester offsite on UCAA premises adjacent to the cargo terminal canteens. This will enable the canteens to utilise the biogas produced (about 4120m^3 from 6324kg of organics) for cooking.

5.4 Solid Waste Management Strategy

The strategy will be centred towards creating a green solid waste management process. The strategy will involve the digestion of the organic waste generated at the Free Zone as opposed to dumping it at Nkumba dumpsite. Taking this into consideration, the methane emissions are expected to reduce by about 5.58Gg over a period of 30 years. These estimates were generated using the IPCC Waste Model and Guidelines (IPCC, 2007). Furthermore, the gas collected from digestion will be harnessed for cooking at the Entebbe International Airport Cargo terminal canteens. This will replace the use of other types of fuels that give off carbon dioxide hence indirectly contributing to the greening strategy.

6. Stormwater Management

6.1 Hydrological Studies

Comprehensive hydrological studies were carried out to identify and determine the catchment area and estimate the design flows for the appropriate return periods for the Entebbe Free Zone.

6.1.1 Design Return Period

The choice of the re-occurrence of the flood magnitude was guided by the following factors:
  i)   Amount of traffic and expected level of service
  ii) Potential flood hazard to property
  iii) Magnitude and risk associated with damages from larger flood events
  iv) Conditions for practical detour during probable failure

In addition, other factors like; potential upstream land use for the anticipated life of the possible drainage structures and construction cost were also considered in selection of the design return periods.
The design return periods shown in Table 6-1, based on geometric design criteria, were used for planning, design and analysis (MoWT, 2010).

Table 6-1: Design Return Period for Structure Types by Geometric Design Criteria

Structure Type	Geometric Design Standard			
	PIa, PIb	PIII Gravel A	PIII, Gravel B	Gravel C
Gutters and Inlets*	10/5	2	2	-
Side Ditches	10	10	5	5
Ford/Low-Water Bridge	-	-	-	5
Culvert, pipe (See Note) Span < 2m	25	10	5	5
Culvert, 2m < span < 6m	50	25	10	10
Short Span Bridges 6m < span < 15m	50	25	25	25
Medium Span Bridges 15m < span < 50m	100	50	50	50
Long Span Bridges spans > 50m	100	100	100	100
Check/Review Flood	200	200	100	100
PIa = Paved Ia PIb = Paved Ib PII = Paved II PIII = Paved III				

Note: The span in the above table is the total clear opening length of the structure. For example, the span of a double 1.2 m diameter pipe is 2.4 m.

6.1.2 Extreme Rainfall Frequency Analysis

6.1.2.1 Rainfall Intensity Duration Relationships

In this study, the 2 yr 24-hour rainfall data was obtained from storm rainfall map of East Africa specified in the TRRL Laboratory Report 623. In this report, the rainfall for Entebbe was extracted as **70 mm**. This rainfall was used for further analysis.

6.1.2.2 Impact of Climate Change on Daily Maximum Rainfall

According to the 4th Intergovernmental Panel on Climate Change Assessment Report, the global climate change models project an increase in average temperatures in Uganda by up to 1.5ºC in the next 20 years and by up to 4.3ºC by the 2080's. In addition, the report predicts an increase in rainfall and corresponding run-off volumes of 10 – 20% over most of the country (UN-Habitat, 2009).

In this study, all hydrological studies and hydraulics designs for the project took into consideration a climate change factor of 1.2 (Mugume et al., 2013). This climate change factor was applied to the 2 yr 24-hour rainfall to account for the effect of climate change on rainfall extremes. The 24-hour rainfall depths estimated for higher return periods are shown in

Table 6-2.

Table 6-2: 24-hour Rainfall Depths at Entebbe

Rainfall Return Period, T	10	25	50	100	200
Flood Factor	1.21	1.52	1.81	1.90	2.09
Index 'n'	0.96	0.96	0.96	0.96	0.96
24 hr Rainfall Depth (mm)	101.64	127.68	152.04	159.60	175.56

6.1.3 Catchment Delineation

Catchment delineation refers to the process of creating a boundary that represents the contributing area for a particular control point or outlet. The process of catchment delineation is used to define boundaries of the study area and/or to divide the study area into sub-areas. In this work, the Digital Elevation Model (DEM) based automatic catchment delineation was undertaken in ArcGIS software, using the ArcHYDRO Extension. The input data into ArcGIS was a SRTM DEM. The DEM has a horizontal resolution of 30 m and was downloaded from United States Geological Survey (USGS) data.

The delineated catchment for Entebbe Free Zone covers an area of 0.041km² with an average slope of 8.9%. Figure 6-1 below shows the delineated catchment for Entebbe Free Zone.
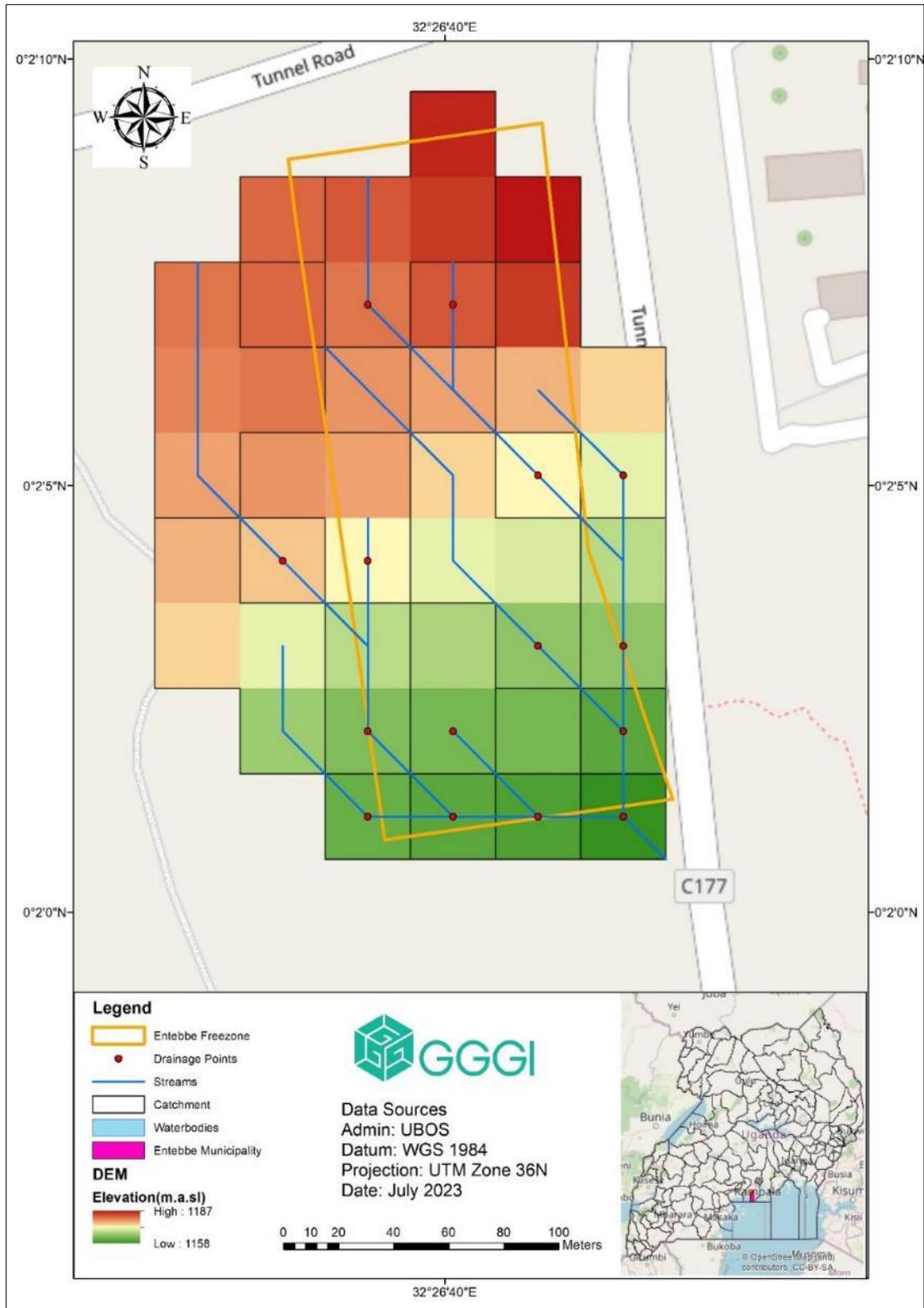
Figure 6-1: Delineated Catchment for Entebbe Free Zone

6.1.4 Estimation of Design Peak Flows

6.1.4.1 Choice of flood flow estimation methods

Having chosen the design return periods, peak design flows were estimated using hydrologic parameters of the catchment area using the most appropriate methods for flood flow estimation for an ungauged catchment. Various methods for flood flow estimation were evaluated in detail and the most context appropriate ones chosen. The table below shows the comparison of the various methods for flow estimation.

Table 6-3: Comparison of various design flood flow estimation methods

Pros	Cons
TRRL East African Flood Model	
• Provides a simple and straightforward method for predicting design storms for flood estimation in East Africa. • Based on extensive field and desktop analytical studies in East Africa	• Suitable for catchments < 200 km^2
Modified Rational Method	
• Simple and straight forward rainfall intensity-based run-off estimation method • Suitable for catchments with limited data • Provides an estimation of the maximum flows from a catchment • Accounts for the effect of storage on flood wave attenuation for large catchments	• Uses a constant rainfall intensity which is not appropriate for long duration time series • Inaccuracies in estimation of the composite run-off coefficient which is dependent on various factors e.g., soil moisture content, rainfall intensity and duration, degree of soil compaction, vegetation etc.
Soil Conservation Service (SCS) Method	
• Widely used dimensionless Unit Hydrograph method • Simple and straight forward method	• Key parameter such as the ratio of time to peak to the base time not satisfactorily applicable to East African Catchments • Applicable to small ungauged urban catchments

In this study, the TRRL Method and the Modified Rational Method were chosen and applied for the flood estimation.

6.1.4.2 Estimation of design peak flows using the TRRL Method

The Transport and Road Research Laboratory (TRRL) method that was developed for Uganda, Kenya and Tanzania made use of limited data for flood estimation for highway bridges and culverts. The model is used for estimating flows for catchments less than 200 km^2.

The TRRL method combines catchment parameters such as catchment area and slope, length of the main stream, land cover and channel slope together with other parameters such as Standard Contributing area

coefficient, Catchment wetness factor, catchment lag time and contributing area coefficient to predict the peak flow and base time of design hydrographs for catchments.

The TRRL Method (Fiddes et al., 1974) involves the following main steps
  i)   Determination of time of concentration
  ii) Design rainfall estimation
  iii) Estimation of rainfall excess
  iv) Estimation of run-off

The detailed description of the TRRL method is found in section 5.3 of the Ministry of Works and Transport (MoWT) Drainage Design Manual (2010), Volume 2 and Chapter 4 of the TRRL Laboratory report 706 (Fiddes et al, 1976). The results in Table 6-4 below indicates the design peak flow for the Entebbe Free Zone catchment for the estimated return periods.

Table 6-4: Design Flood Estimates obtained using the TRRL Method

Parameter	T = 50 yrs	T = 100 yrs	T = 200 yrs	Remarks
Catchment Area, A (m^2)	40811.483	40811.483	40811.483	
Catchment Area, A (km^2)	0.041	0.041	0.041	
Land Slope, S_L (-)	0.089	0.089	0.089	
Length of main stream (km)	0.322	0.322	0.322	
Channel Slope (-)	0.074	0.074	0.074	
Initial retention, Y (mm)	0.0	0.0	0.0	
Standard Contributing Area Coefficient, C_s	0.45	0.45	0.45	Rolling (Catchment slope 4-10%), Slightly Impeded drained soil type
Catchment Wetness Factor, C_W	1.0	1.0	1.0	Wet Zone: Perennial Streams
Land Use Factor, C_L	1.3	1.3	1.3	Grass Cover, Bare soil
Contributing Area Coefficient, C_A (km^2)	0.563	0.563	0.563	
Catchment Lag Time, K (hrs)	1.500	1.500	1.500	Good Pasture
Rainfall Time, T_P (hrs)	0.750	0.750	0.750	
Initial Flood Wave Attenuation Time, T_A (hrs)	0.000	0.000	0.000	
Base Time, T_B (hrs)	4.200	4.200	4.200	
T yr 24 hr rainfall for Entebbe (mm)	152.0	159.6	175.6	Climate Change factor of 1.2 applied to the 2 yr rainfall
Rainfall during base time, R_{TB}	133.6	140.3	154.3	
Areal Reduction Factor	1.000	1.000	1.000	
Average Rainfall, P (mm)	133.6	140.3	154.3	
Total Volume of Runoff, RO (m^3)	3067.2	3219.7	3541.6	
Average flow, Q_{avg} (m^3/s)	**0.2**	**0.2**	**0.2**	
2nd Iteration				
Flood Wave Attenuation Time, T_{A1} (hrs)	0.00374	0.00369	0.00360	
Base Time, T_B (hrs)	4.204	4.204	4.204	
Rainfall during base time, R_{TB}	133.623	140.267	154.293	
Average Rainfall, P (mm)	133.6	140.3	154.3	
Total Volume of Runoff, RO (m^3)	3,067	3,220	3,542	
Average flow, Q_{avg} (m^3/s)	**0.2**	**0.2**	**0.2**	
3rd Iteration				
Flood Wave Attenuation Time, T_{A1} (hrs)	0.00374	0.00369	0.00360	
Base Time, T_B (hrs)	4.204	4.204	4.204	
Rainfall during base time, R_{TB}	133.623	140.267	154.293	
Average Rainfall, P (mm)	133.6	140.3	154.3	
Total Volume of Runoff, RO (m^3)	3,067	3,220	3,542	
Average flow, Q_{avg} (m^3/s)	0.2	0.2	0.2	
Peak flow, Q_T	**0.43**	**0.46**	**0.50**	**For K > 1 hr, F = 2.3**

The results indicated that the total 50-year, 100-year and 200-year design peak flows are **0.43 m³/s, 0.46 m³/s** and **0.50 m³/s** respectively.

The rational method is a simple technique developed by Kuichling (1889) for estimating design peak runoff for areas up to 640 acres (Ohio Department of Transportation, 2014). The rational method is based on a formula that relates runoff-producing potential of the watershed, the average intensity of rainfall for a particular length of time (time of concentration) and the catchment area (Thompson, 2006).
This method is mainly based on the following assumptions:

- Peak flow occurs when the entire catchment is contributing
- Rainfall intensity is uniform over the entire catchment area
- Rainfall intensity is uniform over a duration of time equal to or greater than the time of concentration
- Rational coefficients are independent of the intensity of the rainfall
- The return period of the run-off is assumed to match with the return period of the rainfall

The rational equation is expressed as follows:

$$Q = C_f \times \frac{CiA}{360} \hspace{3cm} \text{Equation 1}$$

Where:
Q is the peak discharge (m³s⁻¹)
C is the runoff coefficient (dimensionless)
i is the design rainfall intensity (mm/hr)
A is the catchment area (ha)
C_f is the multiplier of higher recurrence intervals (dimensionless)

Runoff coefficient, C

The runoff coefficient, *C*, is a dimensionless ratio of rainfall excess to total rainfall and it varies with the topography, land use and surface characteristics of the drainage area. Table 6-5 shows typical values of runoff coefficients, C for urban areas.

Table 6-5: Typical values of runoff coefficients for urban areas

Land Use	Condition	Range of C values
Lawns	Sandy soil, flat <2%	0.05-0.10
	Sandy soil, steep >7%	0.15-0.20
	Heavy soil, steep <2%	0.13-0.17
	Heavy soil, steep >7%	0.25-0.35
Residential	Single Family areas	0.30-0.50
	Apartment dwelling areas	0.50-0.70
Industrial	Light areas	0.50-0.80
	Heavy areas	0.60-0.90
Business	Downtown areas	0.70-0.95
	Neighbourhood areas	0.50-0.70
Streets	Asphaltic	0.70-0.95
	Concrete	0.80-0.95
	Bricks	0.70-0.85
Roofs		0.75-0.95

A higher value of **0.9** has been adopted so as to take into consideration the post development run-off resulting from anticipated future land use and land cover changes in the catchment area.

Time of concentration

The time of concentration is the time required for water to flow from the most remote point on the watershed boundary to the point of interest. When using the rational method, the designer assumes that peak flow occurs because of surface runoff accumulating over a duration equal to the time of concentration.
The time of concentration was estimated using the SCS overland sheet flow equation:

Design rainfall intensity, i

The design rainfall intensity, *i*, is the average rate of rainfall (mm/hr) for a duration equal to the time of concentration. One of the main assumptions of the rational method is that the return period of a computed peak flow is the same as that of the rainfall intensity.

The relation between rainfall duration, rainfall intensity and the return periods is represented by Intensity-Duration-Frequency (IDF) curves. The IDF curves are determined by analysis of rainfall data for a particular site or by the use of standard meteorological atlases (Thompson, 2006). Once the return period has been selected for the design and a time of concentration calculated for the catchment, the rainfall intensity can be determined from the IDF curves approximated using the standard formula below;

$$i = \frac{a}{(t_c + b)^c}$$
Equation 2

Where:
i is the design rainfall intensity (mm/h)
t_c is the time of concentration (h)
a, *b* and *c* are constants depending on the region/location of the catchment.

Flows for different return periods were computed using the Modified Rational Method for the Entebbe Free Zone catchment to determine the design flows as shown in Table 6-6.

Table 6-6: Design Flood Estimations obtained using the Modified Rational Method

Parameter	T = 50 yr	T = 100 yr	T = 200 yr
Catchment Area (km²)	0.041	0.041	0.041
Catchment Area (ha)	4.0811	4.0811	4.0811
Length of mainstream (m)	322.20	322.20	322.20
Length of mainstream (km)	0.32	0.32	0.32
Average slope of Catchment (%)	8.94	8.94	8.94
Time of concentration, Tc (hrs)	0.07	0.07	0.07
Rainfall Intensity (mm/hr)	326.73	342.97	377.27
Average slope factor, C_s	0.08	0.08	0.08
Permeability of soil factor, $C_к$	0.26	0.26	0.26
Vegetation factor, C_v	0.28	0.28	0.28
Rational Coefficient, C	0.9	0.9	0.9
Peak Reduction Factor	1.00	1.00	1.00
Chosen Design Flow, Q (m³/s)	**3.3**	**3.5**	**3.8**

The results indicate that the 50-year, 100-year and 200-year design peak flows are **3.3 m³/s, 3.5 m³/s** and **3.8 m³/s** respectively.

6.1.4.4   Comparison of design flows

The design flood flow values for the 50-year, 100-year and 200-year return periods computed using the Modified Rational Method are higher than corresponding values obtained using the TRRL Method as shown in Table 6-7.

Table 6-7: Comparison of the Design Peak Flows

Method	Q_{50} (m³/s)	Q_{100} (m³/s)	Q_{200} (m³/s)
TRRL Method	0.43	0.46	0.50
Modified Rational Method	3.3	3.5	3.8
Chosen Design Flood	**3.3**	**3.5**	**3.8**

Based on the results, the Modified Rational Method yielded higher design flow values than the TRRL Method. Therefore, the selected 50-year, 100-year and 200-year design flows were **3.3 m³/s, 3.5 m³/s** and **3.8 m³/s**.

6.1.5   Stormwater Drainage System Layout

A layout of the stormwater drainage system was produced with the outfall located at latitude 0° 2'1.27"N and longitude 32°26'42.58"E as shown in Figure 6-2 and Figure 6-3.

The channels on site are stone-pitched with dimensions of approximately 1 m top width and 0.6 m depth.

There is an outfall channel directs runoff from the site downstream to near the UCAA terminal. The channel has been eroded by runoff from the site. The consultant undertook hydrological studies in order to determine the catchment properties of the site as well as the peak flows.

Figure 6-2: Stormwater Drainage System Layout around Entebbe Free Zone overlain a Google earth image

6.1.6   Hydrological Design of Drainage Channels

In this study, the peak discharges were estimated using the Modified Rational Method as shown in Equation 1 above, considering 5-yr and 10-yr return periods.

Figure 6-3 shows the stormwater drainage layout around Entebbe Free Zone overlain a satellite image showing the various drainage channels.

Figure 6-3: Stormwater Drainage System Layout around Entebbe Free Zone overlain a satellite image

Hydrological studies were undertaken for the drainage system in order to compute the design flows capacities of each drainage channel as shown in Table 6-8.

Table 6-8: Computed Design Flows for the drainage channels using the Modified Rational Method

Channel	Catchment Area (km²)	Catchment Area (ha)	Length of main stream (km)	Average slope of Catchment (%)	Time of concentration, T_c (hrs)	Rainfall Intensity (mm/hr) 5 yr	Rainfall Intensity (mm/hr) 10 yr	Rational Coefficient	Peak Reduction Factor	Design Flow, Q (m³/s)	
										5 yr	10 yr
1	0.012	1.20	0.155	8.94	0.04	212.21	235.6	0.90	1.00	**0.64**	**0.71**
2	0.002	0.20	0.031	8.94	0.01	229.09	254.3	0.90	1.00	**0.11**	**0.12**
3	0.001	0.08	0.012	8.94	0.01	232.99	258.6	0.90	1.00	**0.05**	**0.05**
4	0.001	0.06	0.012	8.94	0.01	232.99	258.6	0.90	1.00	**0.03**	**0.04**
5	0.000	0.02	0.012	8.94	0.01	232.99	258.6	0.90	1.00	**0.01**	**0.01**
6	0.003	0.29	0.049	8.94	0.02	225.92	250.8	0.90	1.00	**0.16**	**0.18**
7	0.004	0.40	0.070	8.94	0.02	222.76	247.3	0.90	1.00	**0.22**	**0.24**
8	0.001	0.10	0.012	8.94	0.01	232.99	258.6	0.90	1.00	**0.06**	**0.07**
9	0.005	0.49	0.103	8.94	0.03	218.31	242.3	0.90	1.00	**0.27**	**0.30**
10	0.001	0.12	0.010	8.94	0.00	233.52	259.2	0.90	1.00	**0.07**	**0.07**
11	0.011	1.07	0.107	8.94	0.03	217.80	241.8	0.90	1.00	**0.58**	**0.64**

6.1.7 Blue Green Infrastructure for Stormwater Management

6.1.7.1 Rainwater Harvesting Tanks

Rainwater harvesting involves the gathering and retention of stormwater for on-site reuse, typically through the capture of runoff from building rooftops. These collection structures come in diverse forms and can be installed either above ground or below the surface. Depending on its source and treatment, harvested rainwater can serve various purposes, including industrial cooling processes. There are presently five existing rainwater harvesting tanks, each boasting a 5000-litre capacity, designed for the collection and storage of rainwater.

Given the paved nature of the Entebbe Free Zone, substantial runoff is generated following storm events, estimated at 3.8m³/s. The Consultant undertook preliminary studies to determine the capacity of rainwater tanks required for the freezone as shown in the proceeding section.

6.1.7.1.1 Estimation of rainwater harvesting tanks

The computation of the approximate volume of rainwater tanks was done using BS 8515:2009 – the British Standard for designing rainwater harvesting tanks. The intermediate approach was followed in the design and this method takes the lower of 5% of the annual rainwater yield or 5% of the annual non-potable water demand.
The annual average rainfall for Entebbe was determined from literature and input into the equation shown below.

$$Y_R = A \times e \times AAR \times \text{ŋ} \times 0.05$$

Where
Y_R is 5% of the annual rainwater yield
A is the collecting area (m²)
e is the yield coefficient (%)
AAR is the depth of the annual average rainfall for the location (mm)
ŋ is the hydraulic filter efficiency

Table 6-9: Computation of the rainwater harvesting volume

Description	Value
Average Annual Rainfall (mm)	1866.0
Roof Plan Area (m²)	4046.9
Yield Coefficient (%)	90
Hydraulic Filter efficiency (%)	90
Rainwater yield (l)	**305,833.0**
Rainwater yield (m³)	**305.8**

The annual non-domestic demand was estimated from Chapter 3 of the report as 471.4 m³/d.

Table 6-10: Annual Industrial Demand

Description	Value
Industrial Demand at 100% development (m³/d)	471.4
Annual Water Demand (m³)	172,061
5% of annual demand (l)	8,603,050

The required volume of rainwater tanks was estimated to be 305.8 m^3. This volume is less than 5% of the annual non-domestic demand and was therefore adopted as the final volume of the rainwater tanks. Based on this, it is recommended to provide 5 No. rainwater harvesting tanks each with a capacity of 62 m^3.

The runoff collected in the rainwater harvesting tanks shall be used for industrial processes such as cooling of machinery at the site. The required volume of rainwater tanks will lead to a reduction in annual water bills of 3.55% which corresponds to approximately UGX 430,152,500 savings annually. This consequently lowers the energy demand for pumping by 1.56% since this demand is met by the rainwater tanks. Additionally, rainwater tanks will reduce peak runoff generated from the catchment by 11%.

6.1.7.2   Bioswales

Bioswales are gently sloping, vegetated landscape depressions designed to capture, treat, and allow the infiltration of stormwater runoff. These are essentially vegetated channels that channel and convey runoff; during periods of heavy rainfall, these channels temporarily store water before its gradual discharge.

At the Entebbe Free Zone, when runoff is directed to the outfall, it is conveyed away from the site through an earth channel. The consultant is suggesting the construction of a vegetated channel downstream from the outfall to safely divert water away from the site, thus protecting the channel that is currently suffering erosion due to high water velocity. Furthermore, there is a need to assess the capacity and condition of the downstream culvert near the UCAA Cargo Terminal. If necessary, upgrades should be considered to accommodate the expected stormwater flows, preventing downstream flooding events.

7. Multi-Criteria Analysis

7.1 Introduction

The proposed water and sanitation infrastructure at the Free Zone have been detailed in the previous chapters. This section explores criteria for consideration in the selection of the sectors at the Free Zone.

7.2 Multi-Criteria Analysis

A simple multi-criteria analysis was undertaken by considering the following key factors: Water requirements, Capital and Operation and Maintenance (O&M) costs for wastewater treatment and solid waste management, Wastewater generation rates, Waste water composition, Solid waste generation and Acceptance of the proposed facilities. The aim of the multiple criteria analysis was to identify the most suitable sector to be accommodated within the Free Zone. The results of the simple multi-criteria assessment are presented in the table below.

Table 7-1: Multi-criteria analysis for identification of suitable sectors for the Free Zone

Sector	Meat (Cold Storage)	Fish (Cold Storage)	Diary (Cold Storage)	Fruits and vegetables	Floriculture
Water requirements	++	++	++	+	x
Capital cost for WW and SW management	++	++	++	+	x
O & M costs for WW and SW management	++	++	++	+	x
Waste water generation	++	++	++	+	x
Waste water composition	++	++	++	+	+
Solid waste generation	++	++	++	+	+
Acceptance by stakeholders	++	++	++	+	+

Key: ++ Good +Fair x Bad

The results of the analysis indicate that Cold storage of meat, fish and dairy would be the most suitable sectors in Entebbe Free Zone.

8. Way Forward

8.1 Water and Sanitation Infrastructure at the Free Zone

The proposed water and sanitation infrastructure at the Free Zone includes:

i.   Water Supply: Storage reservoir tanks fed by the existing NWSC piped water system
ii. Wastewater: Pre-treatment units and a lifting station to transfer wastewater from the Free Zone to selected WSPs
iii. Solid Waste: Offsite co-digestion of organic solid waste and kitchen waste.
iv. Stormwater: Use of rainwater harvesting tanks and construction of bioswales

8.2 Proposed greening options for water and sanitation infrastructure

The proposed greening options have been considered in the detailed water and sanitation assessment for the free zone. Specifically, the following greening option have been considered:

i.   Water Supply: Provision of 5 No. 62 m^3 rainwater harvesting tanks for non-potable uses at the freezone
ii. Wastewater: Construction of a dome for recovery of biogas from the existing NWSC waste stabilization ponds and use of constructed wetlands for tertiary treatment of treatment wastewater effluent prior to discharge to Lake Victoria
iii. Solid waste: co-digestion of organic waste generated at the freezone and generation of biogas for cooking purposes.
iv. Stormwater: Construction of bioswales for stormwater collection and transportation and rainwater harvesting for non-potable uses.

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