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CLOSURE PLAN OF AN OLD LANDFILL IN KAMPONG CHHNANG, CAMBODIA

A study on closing a dumpsite in a developing country

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ABSTRACT

The thesis focuses on the comprehensive closure plan for an old landfill, commissioned by Polarix Consulting Oy. The primary objective of the study was to develop a systematic plan encompassing the relocation of accumulated waste, sealing procedures, and the implementation of essential infrastructure to an old landfill in Cambodia. This involved designing a cover structure (capping) for the landfill, devising a water management strategy (without purification), establishing a protocol for landfill gas management, and ensuring physical barriers to restrict public access to the area.

Qualitative research methods were employed throughout the study to assess the environmental impact and feasibility of various closure techniques. The process involved extensive literature review, combining preliminary data and reports from the client, drawing details sections and a layout of the capping by using AutoCAD design program and on-site evaluations to understand the specific challenges and requirements of the project in a developing country.

Overall, the thesis contributes to the body of knowledge in landfill closure practices and offers practical recommendations for stakeholders involved in similar projects. By prioritizing environmental protection and sustainable development, the study benefits not only the client but also the broader community by ensuring the safe and responsible management of waste disposal sites.

Keywords: waste management, landfill, dumpsite, closure planning, developing country, capping

CONTENTS

LIST OF ABBREVIATIONS

ADB	Asian Development Bank
AutoCAD	Autodesk’s 2D and 3D computer-aided design software application
ECOS	Environmental Coalition on Standards
EPA	Environmental Protection Agency
EU	European Union
LFG	Landfill gas

1 INTRODUCTION

The goal of the thesis is to plan, construct and write an instructional closure plan of an old landfill in Kampong Chhnang, Cambodia. The landfill in question is more of a dumpsite due to the lack of existing landfill structures on the site but considering the nature of the thesis and for consistency, the term “landfill” is used when practical. The plan instruction section is the results of the thesis, and it consists of a cover structure, the capping, water management plan (no cleansing), management plan of the landfill gases and the physical closing of the area from the public. In addition, the local people and environmental factors are considered and discussed as a part of the closure plan.

The thesis is commissioned by and made for Polarix Consulting Oy. Many of the materials for the client are provided by ADB (Asian Development Bank), which is the primary organization financing the closure processes in Cambodia, and by Ministry of Public Works and Transport, which is the organization working on the closures in the location. The plan of the closing and the required actions are made so, that no harm is caused for the surrounding environment and by using the standards and regulations approved by ADB.

The thesis aims to contribute to sustainable development, environmental preservation, and the enhancement of working conditions and opportunities in waste management in Kampong Chhnang and similar areas. The reasons for this scope are the ever-growing environmental concerns, interest in community welfare, professional development and knowledge advancement in e.g. regulatory compliance.

The primary inquiry driving this thesis revolves around the effective closure plan of the Kampong Chhnang landfill in accordance with local regulations and environmental standards. The thesis aims to answer the following questions:

- At what condition and stage of decomposition does the landfill currently stand?
- What factors and stages must be considered when implementing landfill cover?

- What materials and methods are viable for the final closure of the landfill and how the capping should be constructed?

2 THEORETICAL FRAMEWORK

This chapter introduces the Kingdom of Cambodia, the legislation concerning waste management and landfilling in the project, the current situation of the landfill, and introduces the main factors to consider in a landfill closure and possible techniques for the closing process itself.

2.1 Kingdom of Cambodia

Cambodia is located in the heart of Southeast Asia. With a population of over 16 million people, Cambodia is known for its ancient temples, markets, and diverse landscapes ranging from rainforests to beaches. Phnom Penh, the capital city, serves as the political, economic, and cultural hub of the country. (Kingdom of Cambodia´s Ministry of Foreign Affairs and International Cooperation 2024).

2.1.1 Geography and climate

Bordered by Thailand to the west, Laos to the north, Vietnam to the east and the Gulf of Thailand to the southwest (see Figure 1), Cambodia boasts a diverse geography characterized by low-lying plains, fertile river valleys, and mountainous regions. The Mekong River and Tonle Sap River flow through the country, playing a crucial role in agriculture, transportation, and livelihoods. (Kingdom of Cambodia´s Ministry of Foreign Affairs and International Cooperation 2024).

Cambodia experiences a tropical climate with distinct wet and dry seasons. The rainy season typically occurs from May to October, bringing heavy monsoon rains and occasional flooding, while the dry season extends from November to April, marked by clear skies and cooler temperatures. (Climate Change Knowledge Portal 2024).

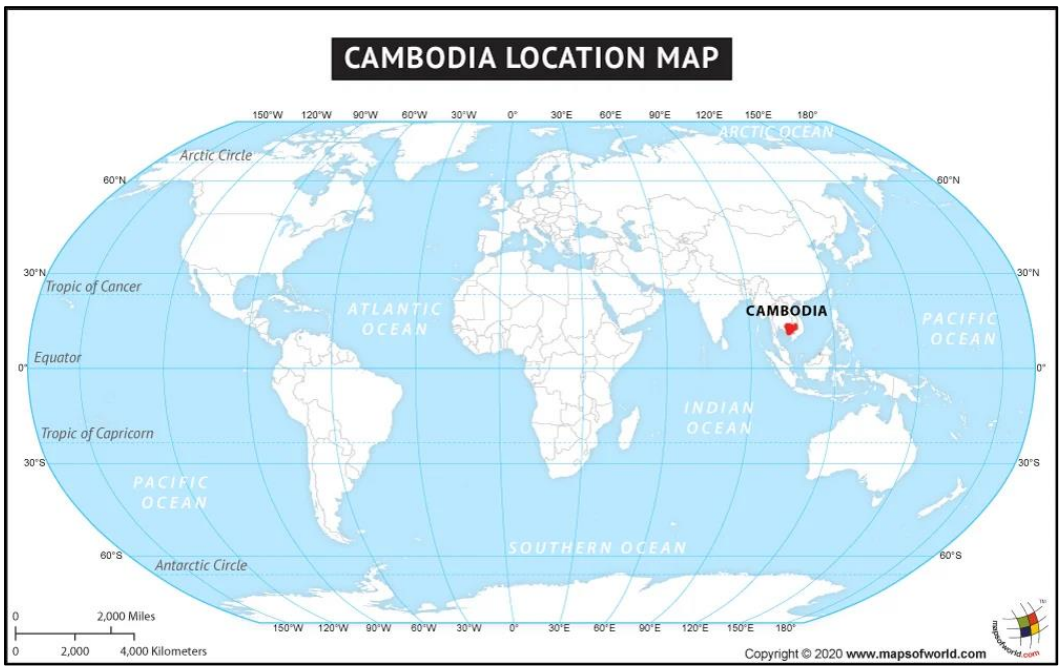

Figure 1. Location of Cambodia on the world map. (MapsofWorld.com 2020).

Kampong Chhnang is a province located in the central part of Cambodia. It is located alongside Tonel Sap River, on the south side of Tonle Sap Lake (see Figure 2). Kampong Chhnang faces various challenges, including environmental degradation, infrastructure development, and poverty. (Kingdom of Cambodia´s Ministry of Foreign Affairs and International Cooperation 2024).

Figure 2. Map of Cambodia with general information. Kampong Chhnang is underlined with red. (Kingdom of Cambodia´s Ministry of Foreign Affairs and International Cooperation 2024).

2.1.2 Economy and development

In recent decades, Cambodia has undergone significant economic development, driven largely by agriculture, tourism, and manufacturing industries. The country's economy has experienced steady growth, supported by foreign investment, infrastructure development, and improvements in education and healthcare. (The World Bank 2023).

However, Cambodia continues to face socio-economic challenges, including poverty, inequality, and limited access to basic services in rural areas. Rapid urbanization and industrialization have also placed strains on natural resources and environmental sustainability. (The World Bank 2023).

2.1.3 Environmental situation and waste management

According to Mongtoeun et al. (2023), Cambodia, like many developing countries, struggles with environmental issues, including deforestation, soil erosion, water pollution, and inadequate waste management. Rapid population growth, urban expansion, and industrial activities have contributed to environmental degradation and ecological imbalance.

Waste management poses a significant challenge in Cambodia, particularly in urban areas like Kampong Chhnang, where population density and consumption patterns strain existing infrastructure. Limited public awareness and enforcement of regulations exacerbate the problem, leading to improper disposal of waste, pollution of waterways, and degradation of natural habitats. (Mongtoeun et al. 2023).

In Cambodia, solid waste management is primarily outsourced to the private sector, which oversees integrated collection systems including truck pickups alongside the main roads, pushcart collection in narrower areas, and collection from waste bins in common use and some market containers. However, awareness of solid waste management issues among the general population remains low, resulting in inadequate attention to proper waste disposal. Notably, not all towns in Cambodia possess proper waste collection systems, with effective official waste collection, transportation, and disposal primarily observed in the major population cities like Phnom Penh city, Siem Reap and Battambang municipalities. In some towns, waste collection is limited to markets. (Kingdom of Cambodia´s Ministry of Public Works and Transport 2024).

In Kampong Chhnang Municipality, there are two existing dumpsites. The first, Phnom Touch dumpsite that is located near the Phnom Touch -mountain, covers approximately three hectares and is situated about 11 kilometres from the municipal centre. It was officially closed from Kampong Chhnang municipality in 2012, but a local market still disposes their waste there weekly, although in rather small quantities. Currently, municipal waste is disposed of at a new dumpsite in Sntouch village, Sre Thmey commune, about four kilometres from the

municipality, rented by the waste contractor. In the thesis, the aim is to plan the proper closing of Phnom Touch dumpsite (see Figure 3), which is not officially in use anymore. (Kingdom of Cambodia´s Ministry of Public Works and Transport 2024).

Figure 3. The old landfill of Kampong Chhnang. Photographed by the author (2024).

Both dump sites face significant environmental challenges due to poor conditions and lack of proper technical design. Issues such as leachate, flies, fire hazards, and unpleasant odours are prevalent, highlighting the urgent need for environmental protection measures. (Kingdom of Cambodia´s Ministry of Public Works and Transport 2024).

2.1.4 Cambodian regulations

The Sub-decree on Solid Waste Management was enacted in April of 1999, providing a legal framework for managing solid waste. It includes both municipal solid waste and hazardous waste. The primary objective of the Sub-decree is to

govern the management of solid waste in a technically sound and safe manner, aiming to safeguard human health and preserve biodiversity. It encompasses various activities such as disposing, storing, collecting, transporting, recycling, and dumping of both regular waste and hazardous wastes. (The Council for the Development of Cambodia 2002).

The Sub-decree (The Council for the Development of Cambodia 2002) employs technical terminology to specify: “1. Solid waste refers to hard objects, hard substances, products or refuse which are useless, disposed of, are intended to be disposed of, or required to be disposed of; 2. Garbage is the part of solid waste which does not contain toxin or hazardous substance, and is discarded from dwellings, public buildings, factory, market, hotel, business building, restaurant, transport facilities, recreation site, ... etc.”

The essential provisions in the Sub-decree (The Council for the Development of Cambodia 2002) relevant to the Kampong Chhnang Solid Waste Management are presented below, as defined in the Sub-decree:

Article 4	The Ministry of Environment shall have established guidelines on disposal, collection, transport, storage, recycling, minimizing, and dumping of household waste in province and cities in order to ensure the management of household waste with safe way. The authorities of the provinces and cities shall establish the waste management plan in their province and city for short, medium and long-term.
Article 6	The Ministry of Environment shall monitor the implementation in disposal, collection, transport, storage, recycling, minimizing and dumping of the household waste in the provinces and cities.
Article 7	The disposal of waste in public sites or anywhere that is not allowed by the authorities shall be strictly prohibited.
Article 8	The domestic investment in construction of landfill, incinerator, storage sites or recycling plant for household waste shall be subject to prior approval from the Ministry of Environment.
Article 9	The exportation of the household waste from the Kingdom of Cambodia to abroad could not be conducted unless there are approval from the Ministry of Environment, and export license from the Ministry of Trade, and permit from the import country.

Figure 4. The essential provisions in the Sub-decree relevant to the Kampong Chhnang Solid Waste Management. (The Council for the Development of Cambodia 2002).

2.1.5 EU legislation

In cases where waste disposal through landfilling is necessary, it must be directed to landfills that adhere to the specifications outlined in the 1999/31/EC Directive on waste landfilling. The primary objective of this Directive is to mitigate or minimize various environmental impacts, especially on surface waters, groundwater areas, soil quality, air quality, and heath of humans and animals, by imposing rigorous technical standards for waste management as well as landfill operations. (European Union 1999).

Under the Landfill Directive, various categories of waste including municipal waste, inert wastes, hazardous and non-hazardous waste, are delineated. These

regulations apply universally to all landfill sites, which are defined as areas designated for waste disposal either onto or into land. (European Union 1999).

2.2 The current situation of local people and waste pickers

In Kampong Chhnang, the old landfill serves as more than just a site for waste disposal; it is also a source of livelihood for a significant number of local waste pickers. These individuals, who are often considered marginalized as well as economically disadvantaged, play a crucial role in the waste management ecosystem of the region. This chapter explores the presence and contributions of local waste pickers in Kampong Chhnang's old landfill, shedding light on their socio-economic circumstances and the challenges they face. (Kingdom of Cambodia´s Ministry of Public Works and Transport 2024).

Local waste pickers (see Figure 5), also known as scavengers, are individuals who scour through discarded waste at the landfill in search of recyclable materials. These materials consist of mainly plastic, metal, and paper. Despite the hazardous and unsanitary conditions, these waste pickers play an important role in diverting and collecting the various recyclable materials from the waste piles, contributing to resource recovery and environmental sustainability. (Chhun 2012).

Figure 5. A family living at the dumpsite. Waste picking is a livelihood for some of the local people. Photographed by the author (2024).

Many waste pickers in Cambodia come from low-income households and marginalized communities, facing limited access to education, employment, and social services. For these individuals, scavenging provides a means of income generation to support themselves and their families. However, their work is often precarious, with uncertain earnings and exposure to health and safety risks. (Chhun 2012).

Waste pickers in Kampong Chhnang are in a very similar position as the waste pickers in Phnom Pehn (Asian Development Bank 2021) and according to G. Chhun (2012) encounter various challenges in their work, including health risks, social stigma, economic vulnerability and lack of support.

Exposure to hazardous waste materials poses significant health risks, such as respiratory illnesses, skin infections, and injuries from sharp objects. Scavenging is often stigmatized, leading to discrimination and social exclusion for individuals engaged in this occupation. Fluctuations in market prices for recyclable materials can impact waste pickers income stability, exacerbating their economic vulnerability. Waste pickers often lack access to formal support systems, such as

healthcare, education, and social welfare programs, further marginalizing their socio-economic status. (Cointreau 2006).

2.3 Steps required for the dumpsite closure

According to the instructions presented in Environmental Guidelines on Solid Waste Management (Ministry of Environment of Cambodia 2006), the final closure of a landfill should occur within six months after the landfill is no longer in use. The following steps are required during a closure process as explained in the Environmental Guidelines on Solid Waste Management (Ministry of Environment of Cambodia 2006) as well as in a preliminary report by Kingdom of Cambodia´s Ministry of Public Works and Transport (2023):

Step 1: the last disposed waste layer on the landfill must be compacted.

Step 2: the waste should be covered with soil and compacted to a thickness of at least 1.5 meters. This covering is essential to facilitate the growth of grass or plants and to prevent the percolation of rainwater through the waste layer.

Step 3: leachate and landfill gas must be controlled at least twice a year until it can be ensured that there are no negative environmental impacts from leachate or landfill gas.

Step 4: the function of fencing around the landfill must be maintained to prevent unauthorized access and to ensure the safety of the surrounding environment.

Step 5: the landfill manager is responsible for planting grass or plants on the cover of the landfill to further prevent rainfall infiltration and enhance the overall environmental integrity of the site.

2.4 Landfill gas production and management

According to EPA (2024) landfill gas (LFG) is formed in landfills as a natural byproduct of the decomposition of organic waste and it consists mainly of

methane (CH4) and carbon dioxide (CO2), which is why LFG poses environmental and health risks if left unmanaged. In a Global Methane Initiative publication (2012), it is explained that in developing countries, where waste management infrastructure may be limited, effective management of LFG is essential to mitigate these risks and harness the potential benefits of this renewable energy source.

Common landfill gas (LFG) management practices in developing countries include landfill gas collection, gas treatment, energy recovery, landfill gas flaring, and landfill gas monitoring. Landfill gas collection involves installing gas collection systems to capture and extract LFG from landfills, preventing its release into the atmosphere. Gas treatment is necessary to remove impurities and contaminants like hydrogen sulfide (H2S) and volatile organic compounds (VOCs) from collected LFG to comply with air quality standards. Energy recovery involves utilizing LFG as a source of renewable energy for example electricity generation, heating, or other industrial processes, reducing reliance on fossil fuels. Landfill gas flaring involves controlled burning of LFG to prevent uncontrolled emissions of methane, a potential greenhouse gas, and decrease overall greenhouse gas emissions from landfills. Finally, landfill gas monitoring ensures regular assessment of LFG emissions and landfill gas migration to identify environmental impacts, public health risks, and compliance with regulatory standards for air quality and greenhouse gas emissions. (Global Methane Initiative 2012).

Developing countries face various challenges in managing LFG effectively, including limited technical and financial resources, inadequate waste management infrastructure, and regulatory constraints. However, there are also opportunities to overcome these challenges and improve LFG management practices through international cooperation, capacity building, technology transfer, and financial support. (Global Methane Initiative 2012).

2.5 Leachate and water management

As defined by ECOS (2024) leachate in landfills is a liquid formed when water percolates through waste material and collects many different contaminants in

the process. Typically, the leachate consists of organic and inorganic compounds, heavy metals, and other pollutants mixed together. Leachate is generated continuously as rainfall infiltrates through the waste pile. The decaying of organic matter within the waste also contributes to leachate formation. (ECOS 2024).

According to a review article by Parvin & Tareq (2021) leachate can contaminate soil, groundwater, and surface water bodies if not properly managed, which is a common issue in developing countries and it poses environmental and health risks because of the presence of toxic substances and pathogens. In the review article (Parvin & Tareq 2021) it is explained that in dumpsites, leachate is often collected through drainage systems or simply accumulates at the bottom of the waste pile and that proper containment measures, such as lining the bottom with impermeable materials, may be lacking in such sites. In the review article (Parvin & Tareq 2021) it is stated that treating leachate is essential to minimize its environmental impact.

2.6 Covering layer and capping

Capping, also known as landfill closure, is the process of covering a waste disposal site, such as a dumpsite or landfill, with a final layer of soil or other materials to seal off the waste and prevent further environmental contamination. It is a crucial step in the management and rehabilitation of dumpsites, ensuring the long-term protection of human health and the environment. (Cossu & Garbo 2018).

The primary objective of capping is to contain and isolate the waste within the dumpsite to prevent and restrict the release of contaminants to the surrounding environment. By covering the waste with impermeable materials, such as clay or geomembranes, capping reduces the risk of groundwater and surface water pollution. Capping helps minimize the generation of leachate by reducing the infiltration of rainfall into the waste pile. By creating a barrier that prevents the percolation of water through the waste layer, capping reduces the volume of leachate produced and the possible contamination of groundwater. In addition to

liquid waste (leachate), landfills also produce landfill gas, which consists primarily of methane and carbon dioxide. Capping helps prevent the migration of the formed landfill gas by creating a barrier that limits the escape of gases from the waste pile. This reduces the risk of air pollution and potential safety hazards. (Cossu & Garbo 2018).

Capping transforms the dumpsite into a stabilized landform that can be reclaimed for other uses, such as green spaces, recreational areas, or even sustainable development projects. By covering the unsightly waste pile, the capping also improves the visual look of the area and reduces its negative impact on the surrounding landscape. (EPA 2012).

The final cover structure is the topmost layer of landfill capping and typically consists of a combination of materials, including soil, geomembranes, geotextiles, and vegetation. It serves as a protective barrier against water infiltration, erosion, and gas migration. Beneath the final cover, drainage and gas venting systems may be installed to manage the movement of water and gas within the landfill. These systems help prevent the buildup of pressure under the cap, which could lead to structural damage or the release of gases. (Cossu & Garbo 2018).

Capped landfills often include provisions for long-term monitoring and maintenance to ensure the integrity of the cap and the continued protection of the environment. This may involve periodic inspections, groundwater monitoring, gas sampling, and vegetation management. (Kingdom of Cambodia´s Ministry of Public Works and Transport 2024)

Capping plays a critical role in safeguarding the environment by preventing the release of contaminants from the dumpsite into soil, water, and air. It helps to decrease the environmental risks that are associated with waste disposal and promotes the restoration of ecological balance. By containing hazardous materials and reducing the potential for exposure to pollutants, capping helps protect public health and safety. It minimizes the risk of groundwater

contamination, air pollution, and other adverse effects on nearby communities. (Cossu & Garbo 2018).

2.6.1 Capping materials

The selection of appropriate materials for capping plays a vital role in improving the effectiveness and longevity of landfill capping systems. Therefore, the various materials used for capping landfills, focusing on their properties, suitability, and considerations for application, should be carefully discussed. (Simon & Müller 2004).

Low permeability soil, such as clay-rich soil or silty clay, is commonly used as a cover material in landfill capping systems. These soils have low hydraulic conductivity, preventing the infiltration of rainwater and minimizing leachate generation. Low permeability soil is suitable for providing a protective barrier against moisture infiltration and promoting surface water runoff. It is often used as the base layer in landfill capping systems to enhance the impermeability of the cap. The selection of low permeability soil should consider factors such as soil composition, compaction characteristics, and availability. It is important to make sure that the soil is at a proper condition for compaction and permeability to achieve effective capping. (Simon & Müller 2004).

Compacted clay is a dense, impermeable material formed by compacting natural clay or clay-rich soil. It provides an effective barrier against water infiltration and serves as the primary impermeable layer in landfill capping systems. Compacted clay is highly suitable for landfill capping due to its low permeability and high compaction ability. It forms a durable and long-lasting barrier that prevents the migration of moisture and contaminants from the landfill waste mass. Proper compaction techniques and quality control measures are essential to achieve the desired density and impermeability of the clay layer. Additionally, the clay material should be sourced from reliable sources and tested for suitability and compatibility with the site conditions. (Simon & Müller 2004).

Growing media, such as loam or compost, is used as a top layer in landfill capping systems to support vegetation growth and enhance the aesthetic and ecological value of the capped area. It provides a suitable substrate for plant roots and helps stabilize the soil surface. Growing media is suitable for promoting vegetation establishment and enhancing biodiversity in capped landfill areas. It improves soil fertility, moisture retention, and nutrient availability, creating favorable conditions for plant growth and ecosystem development. The selection of growing media should consider factors such as nutrient content, pH level, and weed seed content. It is important to choose a well-balanced growing medium that supports diverse plant species and minimizes the risk of weed invasion. (Simon & Müller 2004).

2.6.2 Capping regulations

According to EU (1999) the capping of a dumpsite should including following minimum layers (see Figure 6 and 7). The layer demands are classified for solid waste and hazardous waste as presented in Figure 6.

According EU directives

LAYER	LANDFILL	
	SOLID WASTE	HAZARDOUS WASTE
PROTECTIVE LAYER ≥1,0 m	NEEDED	NEEDED
DRAINAGE LAYER ≥0,5 m	NEEDED	NEEDED
BARRIER LAYER≥0,5 m	NEEDED	NEEDED
ARTIFICIAL SEALING LAYER	NOT NEEDED	NEEDED
GAS COLLECTION LAYER	NEEDED	CASE BY CASE

Figure 6. Layers required for capping. (Kingdom of Cambodia´s Ministry of Public Works and Transport 2024).

The required layers of a surface structure and the minimum depths are presented in Figure 7. The structure consists of a barrier layer, drainage layer and protective

layer constructed over the waste. A gas collection chamber is included in the structure.

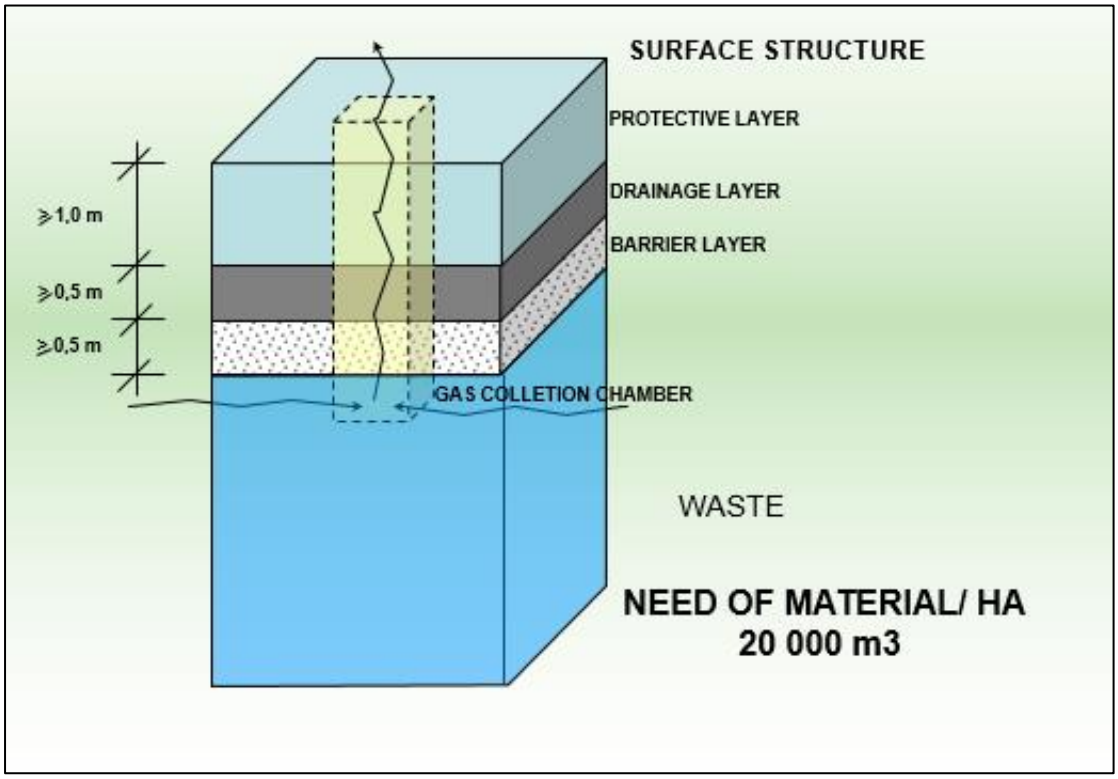

Figure 7. Layers required for capping and gas collection. (Kingdom of Cambodia´s Ministry of Public Works and Transport 2024).

2.7 Physical closing

The physical closure of dumpsite areas is a critical factor of the closure process, which aims to restrict access to the site and prevent further illegal dumping or scavenging activities. This typically involves the installation of physical barriers such as fences, gates, or walls around the perimeter of the site. These barriers serve to deter unauthorized entry, enhance security, and protect public safety. Additionally, signage indicating the closure and potential hazards of the site should be prominently displayed to inform visitors and discourage trespassing. Implementing effective physical closure measures is essential to minimize ongoing environmental degradation, mitigate risks to human health, and facilitate the transition of the site to post-closure land uses. (Jaramillo 2003).

2.8 Environmental aspects

The closure of dumpsites involves addressing significant environmental impacts caused by decades of waste disposal. These impacts include soil and groundwater contamination, air pollution from landfill gas emissions, and habitat degradation. Leachate generated from decomposing waste can infiltrate soil and water sources, leading to the spread of pollutants and endangering local ecosystems. Furthermore, open dumpsites often attract scavenging animals, contributing to unhygienic conditions and potential disease transmission. Addressing these environmental impacts is paramount to safeguarding the surrounding environment and public health. (Mongtoeun et al. 2023).

2.9 Aiding and re-educating scavengers

Dumpsites often have profound effects on nearby communities, impacting their health, livelihoods, and overall quality of life. Residents and especially children (see Figure 8) living near dumpsites may suffer from respiratory problems due to air pollution or waterborne illnesses caused by contaminated water sources. Additionally, the presence of dumpsites can stigmatize communities, affecting property values and economic opportunities. Engaging with local communities throughout the closure process is essential to address their concerns, provide alternative waste management solutions, and ensure their participation in long-term monitoring and maintenance efforts. Re-education of the local people to a different livelihood and about the hazards of the dumpsite would be an ideal solution as it would benefit all parties. (Cointreau 2006).

Figure 8. A child scavenging the landfill in Kampong Chhnang, Cambodia. Photographed by the author (2024).

3 METHODS

The methodology of this research-based thesis initiates with a thorough desk-based study, delving into various closure methods and materials, alongside considering pertinent local challenges and factors affecting the landfill. Local regulations and environmental guidelines serve as the framework for this investigation, most of which are provided by the client (Polarix Consulting Oy). The detail drawings for the capping and gas collection are made with AutoCAD.

Additionally, on-site visit to the dumpsite in Kampong Chhnang provided firsthand insights into the current situation, possible closure techniques, material availability, and available construction practices. Fieldwork in Kampong Chhnang

involves a site visit to assess landfill and environmental conditions, the living conditions of the local people and a visual estimate of leachate production.

3.1 On-site visit; the current situation of the landfill

The on-site visit took place on February 16th, 2024. It consisted of a visit on the dumpsite of Kampong Chhnang, photographing the area and its surroundings (by using a camera and a drone camera) and an overlook of the surrounding area by car.

The on-site visit provided firsthand observations that informed the development of strategies and recommendations for landfill management and closure in Kampong Chhnang. These observations were instrumental in understanding the site's unique challenges and identifying opportunities for sustainable waste management practices. It also provided a profound understanding of the real-life situation surrounding the dumpsite and the people and animals (see Figure 9) impacted by the site.

Figure 9 Cows on the old landfill of Kampong Chhnang. Photographed by the author (2024).

3.2 Analyzing the data from client (Polarix Consulting)

Most of the materials for the thesis is provided by the client and are available through a secure databank. The data provided includes preliminary documentation, legislations, regulations and guidelines.

In the development of the thesis on landfill closure for the Kampong Chhnang site the documents provided by the Asian Development Bank (ADB) for Polarix Consulting Oy, serve as crucial sources of information and guidance.

3.3 Literature study

The literature-based sources utilized in this study provide valuable insights and theoretical frameworks that contribute to the understanding and analysis of solid waste management and landfill closure practices. The literature study is based on online sources. These sources encompass peer-reviewed research articles, academic publications, government reports, and industry guidelines related to waste management, landfill closures, environmental protection, and sustainable development.

The publication dates of the source materials vary within a 25-year period, the oldest reference material dating to 1999. Most of the material used are from 2020 to 2024, which was stressed as one of the main priorities in the research as the some of the data required, especially from the specific location, can be considered time sensitive.

Other criteria for the literature study were to explore information from similar cases around the world and with comparable environmental and economical conditions. The aim was to information that is suitable for the specific conditions present in Kampong Chhnang.

3.4 AutoCAD drawings

The design drawings for the capping are made by using an Autodesk´s computer-aided design software as a tool. The drawings aim to provide a visual design of the closure plan and capping.

4 RESULTS AND ANALYSIS

In this chapter, the results of the research are presented in detail and concluded. The results are justified, and the suitability is analyzed.

4.1 Closure plan

The closure plan provides the necessary technical information for the closure and the suggested practices for the closing process. It also discusses the suitability of the proposed technique for the site in question. The steps required for the closure are represented in Table 1. The steps and other required activity and precautions are presented, justified and discussed later in this chapter.

Table 1. Steps required for the closure.

Step of closure process	Estimated necessity
Gas management	Necessary
Leachate management	Not necessary
Capping	Necessary
Fencing	Not necessary

4.1.1 On-site observations

For the closure process the dumpsite and its surroundings were observed and photographed. The photographs are used as a visual demonstration of the current state.

The waste on the area was observed as widely burned and very dry. It is likely that the formation of leachate water is minimal, since the conditions are so dry,

hot and dusty, and the waste consists of mainly dry materials such as plastic. The waste was mainly not well-decomposed, because the waste type was mainly non-biodegradable.

The local waste-pickers live on the edges of the dumpsite in self-made shelters, and they were not wearing any kind of protection when picking up the waste. The odor of the dumpsite was strongly present in the living area. Amongst the waste-picking adults, there were also children wandering around the area. Cows and birds were also inhabiting the dumpsite and its surroundings.

There were no permanent buildings in the immediate presence of dumpsite. The only permanent infrastructure was the gravel road passing by the dumpsite. There was no electricity availability and no sewerage structures.

4.1.2 Best available techniques

In the design for the restoration of old dumpsites, consideration has been given to implementing the best available techniques. These techniques aim to address various factors crucial for effective restoration and environmental protection.

Firstly, extensive monitoring of the impacts caused by the dumpsite on the environment should be conducted to understand the scope of contamination and inform restoration efforts. This monitoring serves as a baseline for the assessment of the effectivity of the restoration measures and identifying areas of concern. For Kampong Chhnang, the monitoring has been conducted preliminary by the client.

As concluded in a review article by Parvin & Tareq (2021), efforts should be made to reduce the leachate volume produced in the landfill, if necessary. This could include implementing measures to minimize waste decomposition and optimize waste compaction, ultimately reducing the amount of liquid waste generated. (Parvin & Tareq 2021).

Improving drainage around the site is another key aspect of restoration design. By enhancing drainage systems and implementing proper runoff management strategies, the risk of leachate migration and groundwater contamination can be mitigated, if necessary. Where feasible, initiatives to collect and burn landfill gas should be integrated into the restoration plan. This helps mitigate air pollution and reduces the potential for explosive gas buildup within the landfill. (Parvin & Tareq 2021).

To further reduce the potential leachate volume produced in the landfill, several specific strategies should be employed as concluded in the articles by Parvin & Tareq (2021) and Simon & Müller (2004). These include, according to Simon & Müller (2004), minimizing the surface area of the site to limit exposure to rainfall and runoff, as well as increasing the side slope gradients of the waste pile to promote effective runoff of precipitation.

Finally, capping the final waste pile with low permeability soil serves as a crucial measure to contain and isolate the waste, preventing the release of contaminants into the surrounding environment. This final layer acts as a protective barrier, sealing off the waste and minimizing the risk of pollution. (Simon & Müller 2004).

On behalf of the timing for the closure, the ideal timing would be between October and April when Cambodia experiences dry season according to Climate Change Knowledge Portal (2024). This is because of the more practical conditions of a dry season in comparison to a rainy season, as dry conditions are more suitable for the construction of a capping and gas management systems as described in the article by Cossu & Garbo (2018).

4.1.3 Landfill gas management in Kampong Chhnang

Gas collection trenches and ventilation systems will be constructed up to the top of the waste hill, with ventilation manholes installed at the highest points of the dumpsite as seen in Figure 10. Gravel ditches will be utilized to channel landfill gas (LFG) from the dumpsite area to the ventilation manholes. Additionally,

drainage ditches measuring 1m x 1m will be excavated beneath the clay layer to facilitate drainage of the waste filling, as explained by Cossu & Garbo (2018).

Passive venting will be employed for gas treatment, utilizing the capping layer, particularly the humus-rich portion, to facilitate natural gas dispersion. The final soil cover will contain microorganisms capable of converting methane into water and carbon dioxide. To avoid excessive compaction caused by machinery such as dozers and compactors, as mentioned in the article by Simon & Müller (2004), the final soil cover will be installed lightly. Following installation, the surface will be seeded with grass and other vegetation, which minimizes soil erosion according to Simon & Müller (2004).

In addition to the covering layer, facilities will be established to implement passive gas venting technology as a measure against uncontrolled migration of landfill gas into the surroundings. (Cossu & Garbo 2018).

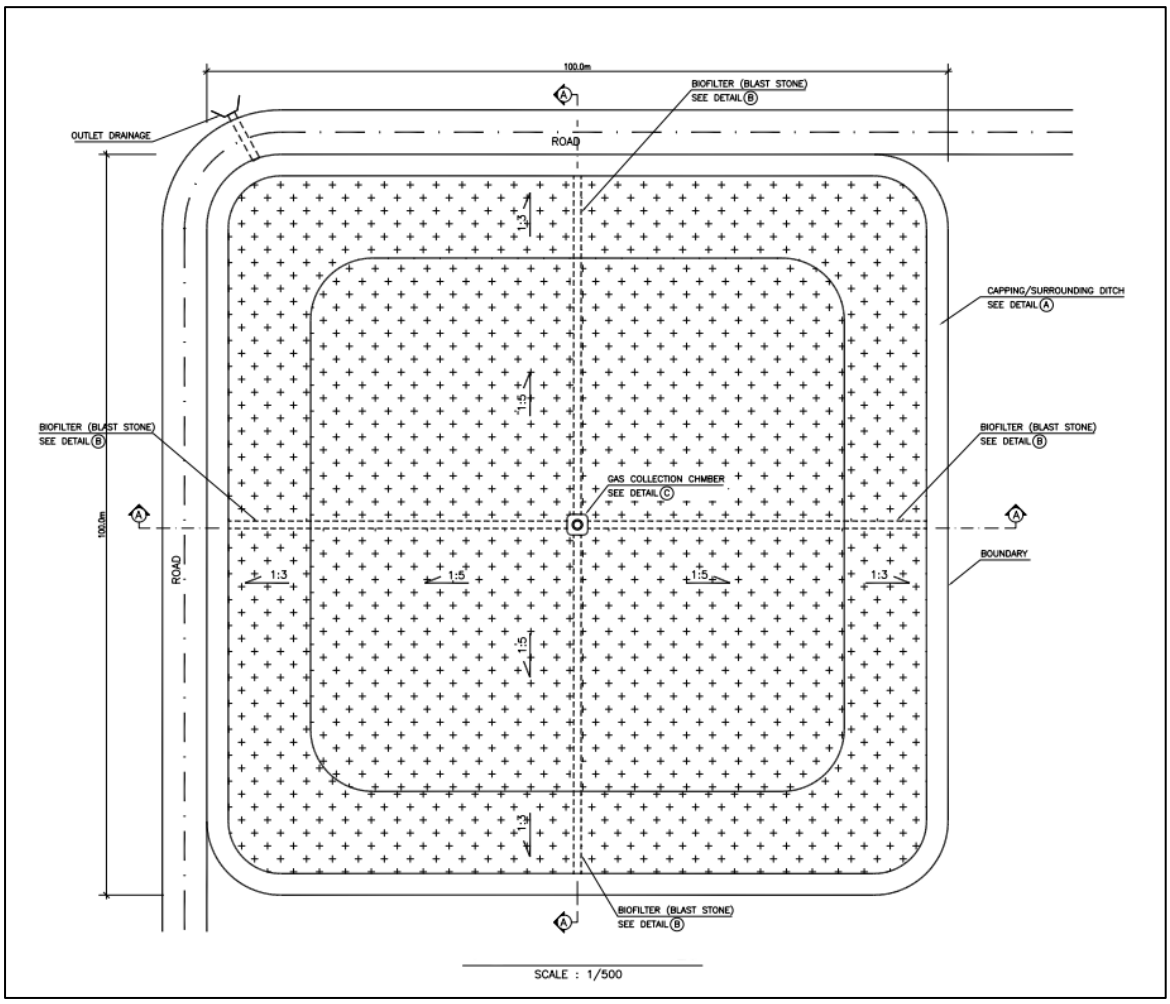

Figure 10 Type layout with gas collection ditches. Made by the author. (Appendix 1, 2024).

4.1.4 Leachate management in Kampong Chhnang

Leachate collection and treatment are not required on the landfill site considering the dry conditions detected in the feasibility study (Asian Development Bank 2021) and confirmed by the on-site visit. In addition, the on-site visit confirmed that there is no electricity available near the site, which would make the collection of leachate waters difficult and expensive. However, as described in Amra Serdarevic´s publication (2018) there are measures to minimize leachate production and mitigate its potential impacts and can still be implemented:

1. Surface Area Reduction

Reducing the surface area of the landfill site helps minimize the infiltration of rainfall and the formation of leachate. By compacting waste materials and

optimizing landfill layout, the exposed surface area is reduced, thereby decreasing the potential for leachate generation.

2. Side Slope Gradients

Increasing the side slope gradients of the waste pile promotes runoff of rainfall, reducing the infiltration of water into the waste mass. Steeper slopes facilitate surface water drainage and minimize the accumulation of moisture within the landfill, thus limiting leachate production.

3. Capping with Low Permeability Soil

To further minimize leachate production and prevent its migration into the surrounding environment, the final waste pile is capped with low permeability soil. This impermeable layer acts as a barrier, preventing rainwater from infiltrating the waste mass and minimizing the generation of leachate.

4.2 Capping in Kampong Chhnang

The capping plan for the landfill site is designed to minimize the generation of leachate and mitigate potential environmental risks associated with landfill operations. By constructing a robust capping system consisting of impermeable materials, the aim is to decrease rainwater infiltration into the waste mass, thereby minimizing the leachate generation and preventing contamination of surrounding soil and groundwater. (Cossu & Garbo 2018).

This chapter outlines the proposed capping plan, detailing the materials, construction methods, and considerations for implementation. The capping should be constructed in relation to the gas management systems of the dumpsite.

4.2.1 Capping System Design

The capping plan proposes a multi-layered capping system, that is aiming to reduce the amount of leachate generated from the closed dumpsite. The basis of the values and requirements are based on the feasibility study (Ministry of

Environment of Cambodia 2006) and EU directives (1999). Due to the lack of financial aid, the layer thicknesses are reduced to 300 mm. The key components of the capping system include low permeability soil cover, collection and placement of windblown waste, impermeable clay layer and growing media installation (see Figure 11 and Appendix 2).

1. Low Permeability Soil Cover: The waste at the closed dumpsites shall be covered with a layer of 300 mm of low permeability soil. This soil layer will be profiled to achieve a minimum slope of 5% to minimize rainwater infiltration and facilitate surface water runoff.

2. Impermeable Clay Layer: A 300 mm thick layer of compacted clay shall be placed on top of the final packed waste. This impermeable clay layer acts as a barrier, preventing rainwater from infiltrating the waste mass and minimizing leachate generation.

3. Blast stone ditch: > 65 cm. Ditches allow for the safe venting and dispersal of gases that may build up within the landfill.

4. Collection and Placement of Windblown Waste: The waste distributed around the site by wind and weather conditions will be collected and packed into the partially full cell, along with the other waste. This consolidation of waste helps optimize space utilization and ensures uniform coverage within the landfill cells.

5. Growing Media Installation: On top of the clay layer (2), a growing media with similar depth (300 mm) will be installed. This layer can consist of for example compost or loam material and it provides a suitable substrate for vegetation growth, enhancing the aesthetic and ecological value of the capped landfill area.

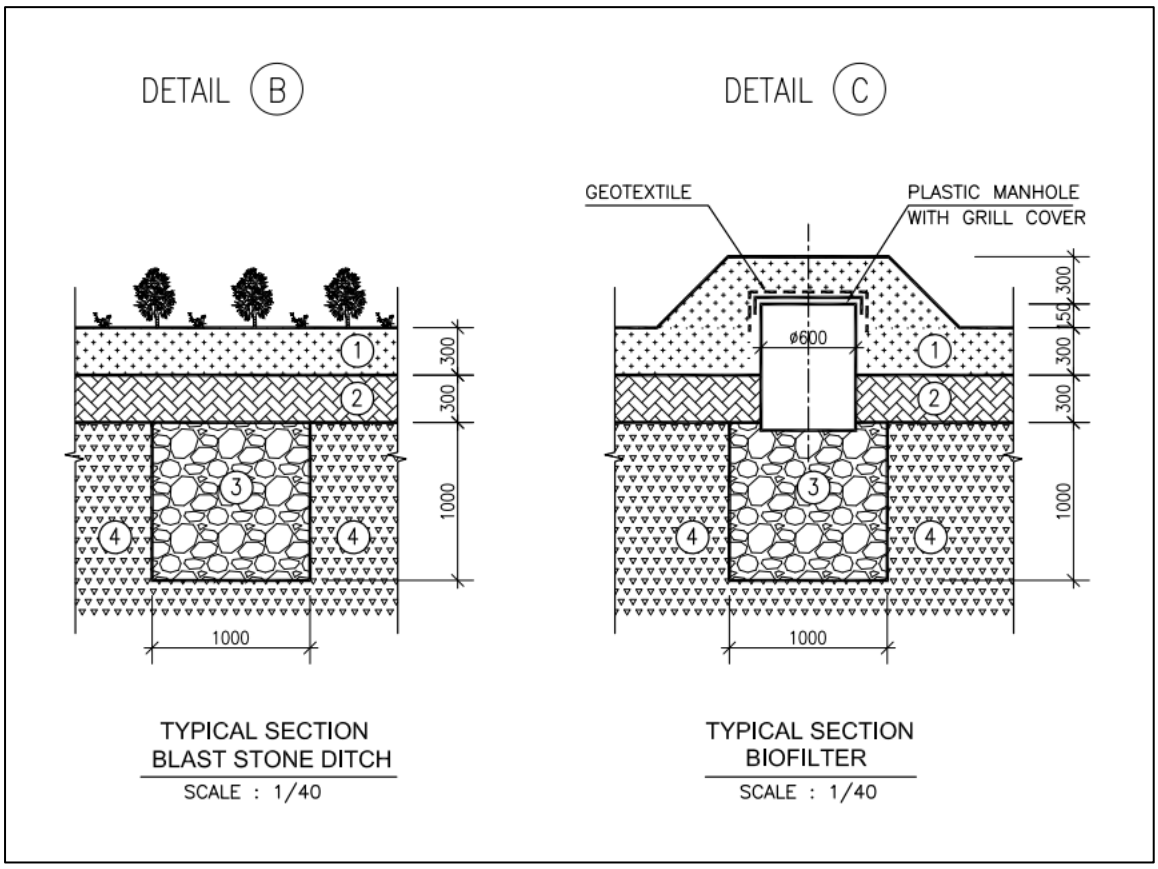

Figure 11. Detail drawing of the capping of Kampong Chhnang. Made by the author (2024). (See Appendix 2 for full drawing).

4.3 Environmental impact prevention techniques

This sub-chapter provides suggested measures to protect the surrounding environment and people in addition to the closure. It discusses the necessity of fencing the area and possible ways to assist the local people.

4.3.1 Fencing

It is not recommending to fence-of the closed dumpsite completely, due to risk of thefts and vandalism as the site are not guarded after the closing according to a preliminary report by Kingdom of Cambodia´s Ministry of Public Works and Transport (2023). Therefore, it is proposed to limit the “fencing” to only information signs/boards and a boom-gate at the entrance to the site. In principle, then the site is safe for the public once it has been finally covered. If a need for

full fencing arises, it can be done post-closure, as explained in the closing guidelines of a landfill by Jorge Jaramillo (2003).

4.3.2 Re-education and protection of the local scavengers

As the strive towards sustainable waste management practices proceeds, it is essential to recognize and support the rights and well-being of local waste pickers, ensuring their inclusion and empowerment in the transition towards a cleaner and more equitable future. (Chhun 2012).

One way of aiding the locals is exploring alternative livelihood opportunities for scavengers to reduce their dependency on waste picking. Providing vocational training and support for income-generating activities in sectors such as small-scale entrepreneurship, agriculture, handicrafts and other skills could be a good option. Promoting economic diversification and resilience by facilitating access to microfinance, market linkages, and business development services is also a possible option. (Chhun 2012).

If it is not possible, it would be important, as explained by Cointreau (2006), to implement occupational health and safety measures to protect the waste pickers from the possible hazards of their work. As suggested by Chhun (2012), the local people can be aided by providing them personal protective equipment (PPE), like protective gloves, facemasks, and boots, and offer training on safe handling practices to minimize the risks for injuries and exposure to detrimental and heath threatening substances.

By implementing these measures, the livelihoods and well-being of the local waste pickers can be improved, fostering a more inclusive and sustainable waste management system that benefits the environment as well as the local community. (Chhun 2012).

5 CONCLUSION

In this chapter, the final recommendations for the closure are represented and justified. Methods, sources and limitations are discussed with criticism and concluded.

5.1 Final recommendations

The landfill in Kampong Chhnang is currently out of service and in the process of planning and constructing closure. It consists of piled waste and requires a plan for sealing, including a cover structure, water management plan, and management of landfill gases. The closure plan aims to prevent harm to the surrounding environment, adhering to regulations and minimizing adverse effects.

To minimize environmental impact, factors such as waste composition, decomposition phase, leachate and gas management, and proper cover materials must be considered. Viable materials for closure include low permeability soil, compacted clay, and growing media. The closing plan includes reducing leachate production, proper waste consolidation, capping with impermeable clay and growing media layers and physical closing measures to limit trespassing.

To address the livelihoods of local waste pickers, formalization of their role, access to social services, and alternative livelihood opportunities such as vocational training and entrepreneurship should be considered, ensuring their well-being during and after the landfill closure process.

The closure plan recommendations presented in this thesis, including the gas collection system implementation and capping and monitoring of landfill subsidence represent crucial steps towards sustainable waste management in Kampong Chhnang. The solutions are based on the data available, on-site visit and other research on the topic, and they are constructed by using the necessary regulations and legislation as a framework.

5.2 Criticism of methods and sources

The materials provided from Polarix Consulting Oy (conducted by ADB and local operators) can be considered as trustworthy, due to the aims and funders of the organizations. The legislative information from EU can be considered reliable as well, since it is a supervised and well-updated source. On-site visit provides reliable yet limited data but is a rather trustworthy source for general information.

While efforts were made to utilize reputable and peer-reviewed sources e.g. other studies on landfill closures and general information of Cambodia, the reliability of some information may be questionable. This could be due to outdated data, biased perspectives, or lack of validation by independent experts. However, since the study was conducted mainly from data provided by the client, the result can be considered as reliable.

5.3 Limitations

This thesis focuses on the specific conditions present in Kampong Chhnang, Cambodia, considering local factors and regulations. The study centres on the Kampong Chhnang landfill, with material sourcing considerations tailored to the local context. Local regulatory frameworks guide legal considerations, while assumptions about the landfill's closure span the foreseeable future.

Economic constraints within Cambodia did influence the material amount of the closure, while language barriers and data availability may constrain the study's scope. Additionally, variations in local regulations and environmental standards may impact the applicability of certain methodologies and findings.

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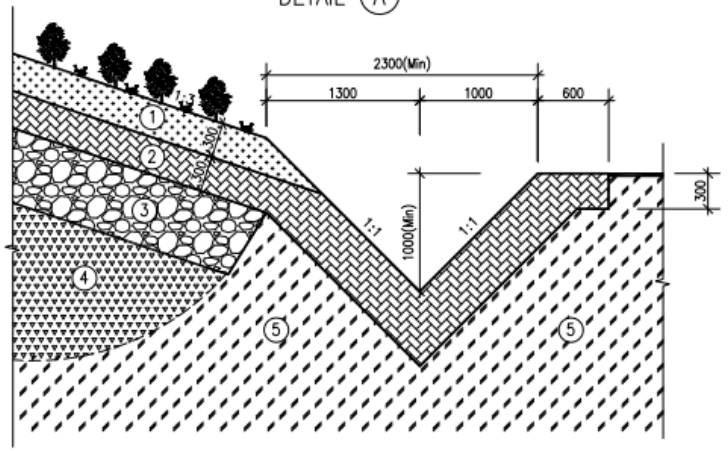
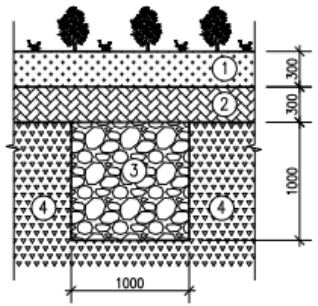
LIST OF FIGURES

DETAIL (A)



TYPICAL SECTION
CAPPING/SURROUNDING DITCH
SCALE : 1/40

DETAIL (B)



TYPICAL SECTION
BLAST STONE DITCH
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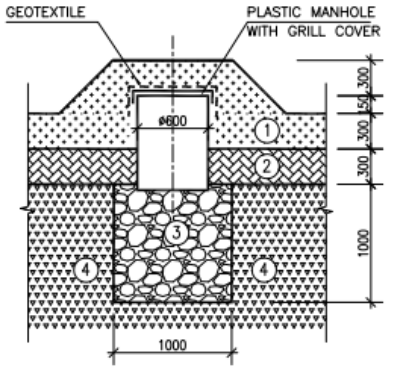
DETAIL (C)



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BIOFILTER
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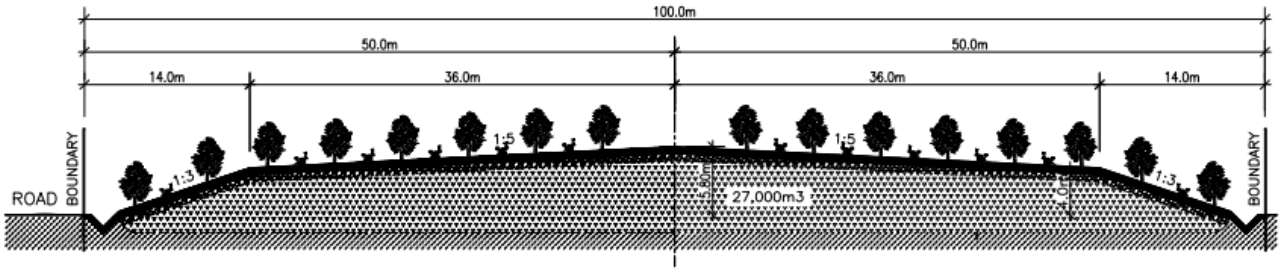


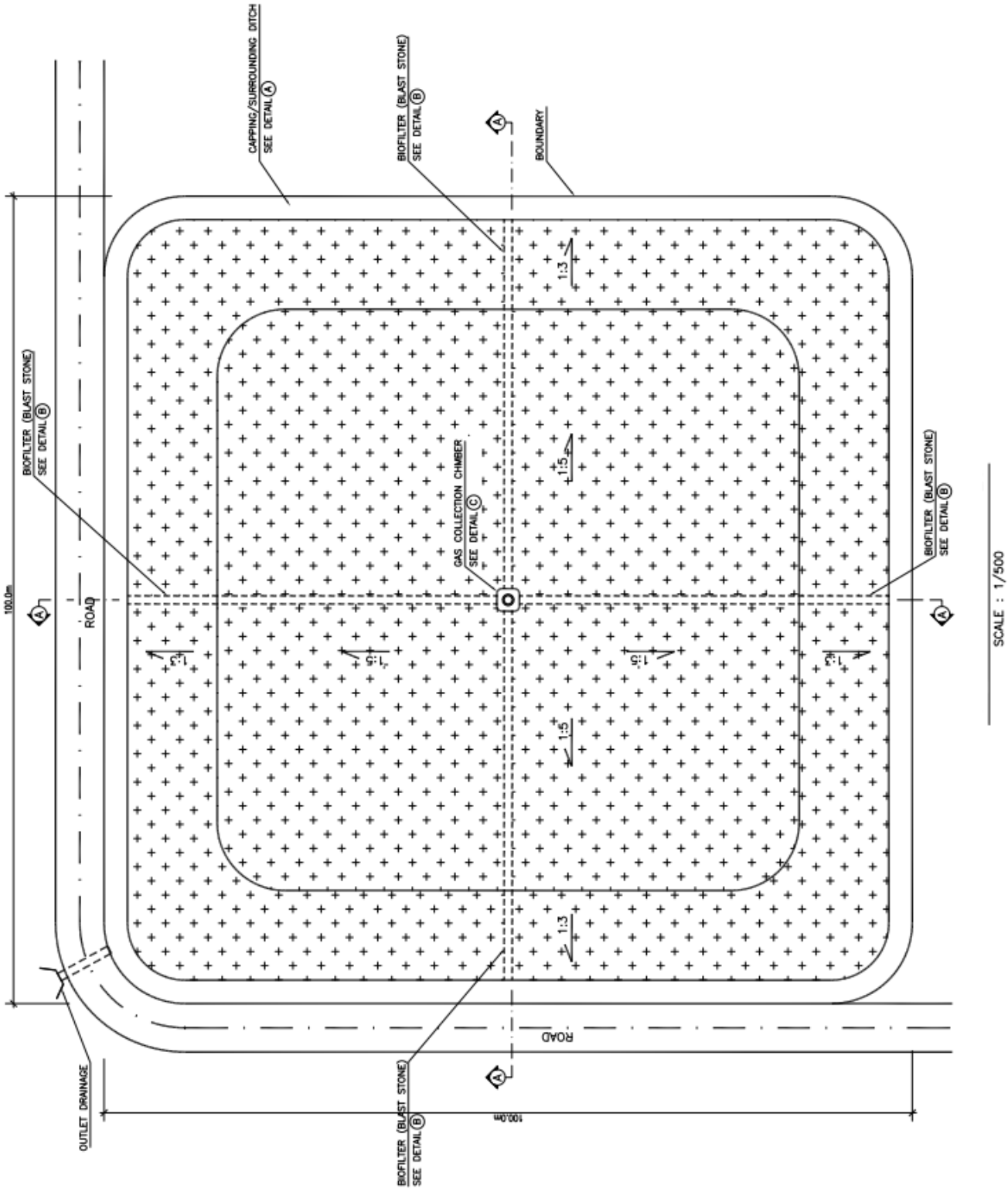
SECTION A-A
DUMPSITE CLOSURE SECTION
SCALE : 1/400

ABBREVIATION

1. BLACK SOIL
2. SILTY SAND/ CLAY
3. BLAST STONE SIZE > 65 cm
4. SOLID WASTE COMPACTION
5. NATURAL SOIL

Appendix 1.

Appendix 2.


CAPPING/SURROUNDING DITCH
SEE DETAIL (A)
BIOFILTER (BLAST STONE)
SEE DETAIL (B)
BOUNDARY
BIOFILTER (BLAST STONE)
SEE DETAIL (B)
GAS COLLECTION CHMBER
SEE DETAIL (C)
BIOFILTER (BLAST STONE)
SEE DETAIL (B)
1:3
1:5
1:3
1:5
1:3
1:3
ROAD
ROAD
100.0m
100.0m
OUTLET DRAINAGE
BIOFILTER (BLAST STONE)
SEE DETAIL (B)
SCALE : 1/500