SIZING LEACHATE DAMS AND TREATMENT INFRASTRUCTURE IN SOUTH AFRICAN LANDFILLS

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Declaration

I, Khutso Nkwane, declare that this research report is my own unaided work. It is being submitted to the University of the Witwatersrand, Johannesburg for the Degree of Master of Science in Engineering. It has not been submitted before for any degree or examination at any other university.

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(Signature of Candidate)

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ABSTRACT

Adequate leachate management through leachate collection, storage, and treatment is vital for preventing groundwater and surface water pollution during landfilling. The storage of leachate using lined pollution control dams, referred to as leachate dams, before treatment is common in landfills. However, leachate dams are at a high risk of leakage and spillage if they are not designed and sized appropriately. Furthermore, the size of a leachate dam directly informs the sizing of the leachate treatment processes that follow it by establishing a required average treatment rate. The purpose of this research is to provide a framework for the adequate design and sizing of leachate dams and leachate treatment infrastructure in South Africa, by investigating the regulations for the design of leachate dams and leachate treatment; investigating applicable processes for treating leachate; and analysing the suitability of hydrological models and methods to estimate leachate discharge and leachate evaporation for leachate dam size water balance modelling.

A thorough literature review was conducted to study: (1) the regulatory requirements for leachate dam design and leachate treatment; and (2) the different methods and processes used for leachate treatment. Analyses were conducted to verify whether the Hydrologic Evaluation of Landfill Performance model (HELP model) is suitable for estimating leachate generation and discharge; predicted leachate discharge values computed by the HELP model using climatic records of an existing landfill were compared to leachate discharge values observed and recorded at the landfill. Furthermore, a method for estimating leachate evaporation was derived in this research; the method's suitability was analysed by comparing its predicted leachate evaporation values, computed using climatic and leachate composition records at a landfill, to the actual leachate evaporation values observed and recorded at the landfill.

To prevent excessive leachate seepage into groundwater, South African regulations mandate that leachate dams be designed with a liner system that is adequate for the waste disposed in the landfill. Moreover, the regulations mandate that leachate dams must be designed with a storage capacity large enough that they are not likely to spill

more than once every 50 years. Finally, there is a requirement for leachate to be adequately treated for permanent containment or discharge into the environment; the regulations provide minimum requirements for treated effluent's quality, as well as its allowable temperature and discharge rate if it is to be discharged into the environment.

Studies on leachate treatment systems discuss the use of physical and chemical processes, such as flotation and precipitation; biological processes, such as activated sludge processes; and advanced treatment processes, such as reverse osmosis. The studies recommend the use of reverse osmosis as a final leachate treatment step, with a biological treatment and/or chemical treatment step preceding it.

The percent error between the observed average daily leachate discharge rate and the average daily leachate discharge rate predicted by the HELP model was found to be 9.780 %. This proves this research's hypothesis of 10 % was correct. However, this was achieved through the use of an apparent saturated hydraulic conductivity that was significantly higher than what is reported in existing literature for landfilled waste. This variance is considered to be attributable to the methods used in the existing literature for determining saturated hydraulic conductivity; the methods do not take into account large impenetrable pieces of waste, such as drums and containers, creating large flow paths.

The percent error between the observed monthly leachate evaporation and the monthly evaporation predicted by the derived leachate evaporation method was found to be 7.91 %. This slightly surpassed the research's hypothesis of 10 %. The derived method also predicted monthly leachate evaporation more accurately in the wet season than in the dry season.

Both the HELP model and derived leachate evaporation method were found to be suitable for use in leachate dam sizing to ensure that leachate dams fulfil South Africa's regulatory requirements on leakage and spillage. Further research is required using data recorded over longer periods in order to further verify the HELP model's suitability. Given the significant variability in the chemical and biological composition of leachate, further research is also required using leachates with different compositions in order to further verify the suitability of the derived leachate evaporation method.

Acknowledgement

Firstly, I would like to express my sincerest gratitude to my supervisor, Doctor Precious Biyela, for her guidance, earnestness, and patience. Her knowledge, wisdom, and words of motivation were crucial throughout the process of this research. I cannot thank her enough.

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1. INTRODUCTION

1.1 Introduction

Landfills are defined as engineered facilities where waste is systematically disposed of so as to control gas, liquid, and solid emissions from contaminating the surrounding environment (United Nations Office for Disaster Risk Reduction, 2020). In addition to waste disposal areas, landfills may also have roads; storm*water* and pollution control infrastructure; laboratories; waste treatment areas; and leachate treatment systems, depending on the size of the landfill, its location's climate, and the type of waste disposed of (Department of Water Affairs and Forestry, 1998). Globally, 2.01 billion metric tonnes of municipal solid waste is generated annually, with 37 % of it being disposed of in some form of a landfill (Kaza, et al., 2018). Furthermore, landfilling is one of the most common forms of solid industrial waste disposal; over 9 billion metric tonnes of solid industrial waste is produced globally (Vignesh, et al., 2021). In South Africa, 98 million metric tonnes of waste is disposed of across the nation's 826 landfill sites (Department of Environmental Affairs , 2012; Engineering News , 2018). This accounts for 60 % of the municipal solid waste and 95 % of the hazardous industrial waste produced in South Africa (Nyika , et al., 2019).

The disposal of waste material by the process of landfilling presents a variety of difficulties for engineers to solve. One such difficulty is potential contamination, at best, and pollution, at worst, of groundwater and surface water by leachate from the landfill. Leachate is defined as liquid (typically rainwater and the initial water content of the disposed of waste) that has percolated through a landfill and has extracted suspended and dissolved contaminants from the landfill due to the physical, chemical, and microbial processes in the waste (Christensen, et al., 2000). Of the several environmental issues that landfills pose, groundwater pollution is considered the most important (Bjerg, et al., 2014). Leachate may contain concentrations of dissolved organic matter and inorganic components that are 1000 to 5000 times higher than in groundwater (Christensen, et al., 2000). Designed landfill's waste disposal areas typically include a liner system that serves as a barrier between leachate and groundwater and a drainage system, above the liner, to collect and transfer the leachate (Tolaymat & Krause, 2020). However, the inadequate design, construction, and maintenance of these systems may result in the leakage of this leachate, thus contaminating the groundwater (Bjerg, et al., 2014). Sholichin (2012) investigated the groundwater and surface water contamination around a landfill located in Indonesia and found that leachate had a significant impact on the quality of both groundwater and surface water. Ololade et al., (2019) studied the influence of leachate on the groundwater quality around a landfill located in South Africa; the findings indicated that the groundwater was unfit for drinking, domestic use, and irrigation due to being polluted by leachate. The contamination and pollution of groundwater and surface water by leachate can occur through spillages and through leakage of the landfill's liner system. Spillage occurs when leachate builds-up, spills over the waste disposal area's liner system, and either infiltrates into the surrounding soil or runs off into surrounding water bodies. South African regulations require that the liner systems of municipal and hazardous industrial landfills' be composed of a high density polyethylene (HDPE) geomembrane underlain by an impermeable clay layer (Department of Forestry, Fisheries and the Environment, 2024); leakage through these liner systems occur when leachate flows into holes in the geomembrane, caused by damage and manufacture defects, and permeates through the clay layer and then into the ground (Katsumi, et al., 2001; Rowe, 2012).

South African regulations require that landfills have leachate management systems for the collection and treatment of leachate (Department of Water Affairs and Forestry, 1998). A leachate management system is composed of a gravity drainage system, above a waste disposal area's liner system, that collects and discharges leachate into a leachate dam or sump for storage before treatment (Department of Water and Sanitation, 2021; George, 2021). Many landfills opt for the use of leachate dams due to cost implications (George, 2021). Leachate dams typically have leachate discharge and direct rainfall as inflows and evaporation, leakage, and abstraction for treatment as outflows. Thus, leachate dams act as equalization basins for the subsequent leachate treatment processes. Therefore, the size, efficiency, and effectiveness of the treatment processes rely on the adequate sizing of the upstream leachate dams (Tchobanoglous, et al., 2014). South African regulations require that leachate dams be lined to the same standard as their upstream waste disposal areas (Department of Water and Sanitation, 2021). Leachate dams pose a higher risk of leakage than waste disposal areas due to having higher leachate depths; leakage through a liner system is proportional to the leachate depth above the liner system (Rowe, 2012). Leachate dams are also more susceptible to spillages due to being directly open to the climate, unlike waste disposal areas where rainfall is attenuated by waste.

Leachate management, achieved through collection, storage, and treatment, is one of the most significant contributors to landfill operational and maintenance (O&M) costs, accounting for up to 30 % to 50 % of the O&M expenses for landfills over a life cycle (Gisbert, et al., 2003; Kremen, 2020). Landfill disposal costs in South Africa are approximately R 650 per metric tonne, with 98 million metric tonnes of waste disposed of across 826 landfill sites (ReSource, 2023; Engineering News , 2018). Thus, the average cost of a South African landfill is approximately R 77 million, with the cost of leachate management being approximately between R 23 million and R 39 million. Therefore, there is a substantial cost implication to adequately designing leachate management systems; over-sized leachate collection, storage, and treatment infrastructure adds a high unnecessary cost to the construction and O&M of a landfill.

1.2 Problem Statement

Leachate poses a serious risk to the environment and to human health through the pollution of groundwater and surface water (Dervisevic, et al., 2016). This risk is compounded by the fact that South Africa is a water-scarce country that has several communities obtaining drinking, domestic, and irrigation water directly from the ground and rivers (Odiyo & Makungo, 2012). Groundwater and surface water pollution can result from the inadequate design of a landfill (Bjerg, et al., 2014); this extends to the inadequate design of a landfill’s leachate collection, storage, and treatment systems. Conversely, over-designing a landfill's leachate management systems adds an unnecessary cost to the construction and operation of a landfill.

Several studies have been conducted on the generation of leachate (Schroeder & Peyton, 1988; Fellner & Brunner, 2010), the environmental impacts of leachate (Engelbrecht, 1993; Bjerg, et al., 2014), the treatment of leachate (Renou, et al., 2008; Wiszniowski, et al., 2006), and the design of landfills' waste disposal areas to mitigate leachate leakage (Katsumi, et al., 2001; Rowe, 2012; Giroud & Bonapart, 1989). South African regulations are clear on the liner system design and size requirements of leachate dams, however, very limited information exists on the methods to be used for the sizing of leachate dams in order to achieve the requirements; this is especially relevant given the prevalence of leachate dams and the high risk that they pose to the environment and to human health due to the larger volumes of leachate stored, which lead to a higher probability of leakage and spillages when compared to landfills' waste disposal areas. Furthermore, adequately sized leachate dams serve as effective equalization basins to downstream leachate treatment processes. Thus, it is crucial that factors that inform the appropriate sizing of leachate dams, and hence leachate treatment infrastructure, be investigated.

1.3 Research Questions

This research attempts to address the following questions:

"Is the Hydrologic Evaluation of Landfill Performance (HELP) model suitable for predicting leachate discharge in order to adequately size leachate dams?"

"Is the leachate evaporation equation presented in this research appropriate for adequately sizing leachate dams?"

1.4 Hypothesis

Leachate discharge can be predicted to a percent error of 10 % using the Hydrologic Evaluation of Landfill Performance (HELP) model and leachate evaporation can be predicted to a percent error of 10 % using correlations and equations reported in Valderrama et al. (2015) and Schroeder et al. (1994).

1.5 Aim and Objectives

This research aims to provide a framework for adequately sizing leachate dams and treatment infrastructure in South Africa, in order to minimise environmental impacts and optimise cost. The objectives of this study are to: (1) conduct a review of the South African regulations on leachate dams and leachate treatment; (2) conduct a review of existing leachate treatment processes; (3) analyse the Hydrologic Evaluation of Landfill Performance (HELP) model's suitability for predicting leachate discharge for the purpose of dam sizing; and (4) derive and analyse a method for predicting the leachate evaporation for the purpose of dam sizing, using correlations and equations reported in Valderrama et al. (2015) and Schroeder et al. (1994).

1.6 Assumptions

Two assumptions were made for this study: (1) Water balance modelling can be used for appropriately sizing leachate dams and (2) the only inflows and outflows considered in a leachate dam are leachate discharge, rainfall, evaporation, leakage, and abstraction for treatment.

1.7 Rationale for the study

The annual quantity of solid waste generated in Africa is expected to nearly triple by 2050, with there being a large focus on building sustainable final disposal sites (Kaza, et al., 2018). Furthermore, existing landfills in South Africa have nearly reached their final capacity, with the cities of Johannesburg, Cape Town, and Tshwane reported to have less than ten years of landfill life left (Engineering News, 2021; Engineering

News , 2018). Thus, an increase in the design and construction of new landfills in South Africa is imminent.

Given the risks that landfills pose to the environment and human health, adequate design methods for landfills are vital in preventing pollution due to landfilling. This research attempts to add to the knowledge of adequate landfill design by establishing a framework for the sizing of leachate dams, which are more likely to leak and spill than waste disposal areas. Furthermore, this research attempts to provide a model for predicting leachate evaporation; outside of leachate dam sizing, this model may be used in the water balance modelling of leachate treatment processes that are open to the environment as well, such as lagoons, sequencing batch reactors, and clarifiers.

1.8 Research Report Structure

The structure of the research is as follows:

Chapter 1:	Introduces the research subject, discusses its relevance, and highlights the aim and objectives of the research.
Chapter 2:	Conducts a literature review on the formation of leachate, its treatment, South African regulations surrounding it, and the hydrological models for the estimation of its generation/discharge and evaporation that the research attempts to verify.
Chapter 3:	Details the study area, instrumentation, and methods to be used to attempt to verify the hydrological models that estimate leachate discharge and leachate evaporation.
Chapter 4:	Presents the results and discussion of the research.
Chapter 5:	Concludes the research, highlighting its implications and making recommendations for future research.

2. LITERATURE REVIEW

2.1 Introduction

Landfills present significant environmental impacts, such as greenhouse emissions and air pollution, however, groundwater contamination is considered the most important (Bjerg, et al., 2014). Along with groundwater, landfills also present a substantial environmental impact to surface water and soil. The contamination of groundwater and surface water, as well as the contamination of soil, through landfilling is caused by leachate percolating through a landfill's waste and leaking into the ground, as well as spilling over the landfill’s boundaries. Although the chemical and biological composition of leachate varies significantly depending on the waste composition and age of a landfill, as well as the landfilling methods used, leachate typically contains toxic metals, a significant community of pathogenic organisms, and hazardous organic and inorganic matter; these contaminates are severely harmful to living organisms (Siddiqua, et al., 2022; Christensen, et al., 2000; Bjerg, et al., 2014). The pollution of soil, groundwater, and surface water due to landfilling seriously endangers people's health, with children being the most affected due to having weaker immune systems (Dervisevic, et al., 2016; Siddiqua, et al., 2022). These contaminants are also severely harmful to aquatic organisms, causing eutrophication and altering the reproductive rates of marine animals and plants (Siddiqua, et al., 2022).

The adequate design and construction of landfills is vital to the prevention of groundwater, surface water and soil pollution due to leachate (Bjerg, et al., 2014). South African regulations mandate the use of liner systems, to limit the movement of leachate into groundwater, and leachate management systems, to collect, store and treat leachate (le Roux, 2010). The type of liner system used is mandated by South African regulations and depends on the type of waste to be disposed of; however, it typically consists of a combination of HDPE geomembranes and low-permeability soils, such as clays. Leachate collection systems consist of a drainage layer, typically a granular material with perforated pipes embedded, directly above the liner system to drain and discharge leachate into a sump or leachate dam (Department of Water and

Sanitation, 2021). This drainage layer is also required to reduce the hydraulic head on the liner system, thus further limiting leachate movement into groundwater (Department of Water and Sanitation, 2021). From the sump or leachate dam, leachate is treated before release into the environment (Department of Water Affairs and Forestry, 1998).

This chapter reviews: (1) literature on the formation, composition, and treatment of leachate; (2) South African regulations on treated leachate effluent; (3) South African regulations on the design of leachate dams' liner systems; (4) literature on the leakage of leachate through liner systems; (5) the hydrological model that this research expects will be suitable for the prediction of leachate discharge for the purpose of a dam sizing water balance; and (6) literature that the research used to derive a model for the prediction of leachate evaporation.

2.2 Formation and Composition of Leachate

Landfill leachate is generated by rainwater infiltrating and percolating through landfilled waste layers. The physical, chemical, and microbial processes that occur in the waste layers then transfer pollutants from the waste to the percolating water, thus creating leachate (Christensen, et al., 2000). Leachate composition significantly varies according to the waste composition and age of a landfill (Bjerg, et al., 2014). In particular, the age of a landfill is important in determining the composition of leachate due to the fact that there are changes in the physical, chemical, and microbiological processes that occur in the landfill's waste over time. Focusing on typical landfills receiving a mixture of municipal and industrial waste, younger landfills contain large amounts of biodegradable organic matter; thus, rapid anaerobic fermentation occurs resulting in a large release of volatile fatty acids (VFAs) – this phase of a landfill's life is called the acidogenic phase (Wiszniowski, et al., 2006). Leachate generated in the acidogenic phase is characterized by average BOD_5/COD ratios of around 0.58, indicating easy biodegradability, lower average pH values of around 6.1, and higher concentrations of inorganic matter and heavy metals (Wiszniowski, et al., 2006; Christensen, et al., 2000; Bader, et al., 2022). In contrast, older landfills develop methanogenic microorganisms that convert VFAs into methane and carbon dioxide – this phase in a landfill's life is called the methanogenic phase (Wiszniowski, et al., 2006). Leachate generated in this phase is characterized by lower average BOD_5/COD ratios of around 0.06, higher average pH values of around 8, and an organic fraction dominated by non-biodegradable compounds, such as humic acids (Wiszniowski, et al., 2006; Christensen, et al., 2000). Leachate generated in the methanogenic phase nevertheless has lower concentrations of pollutants (Christensen, et al., 2000).

Although the composition of leachate varies from landfill to landfill, according to waste, it can generally be characterised as containing large amounts of four groups of pollutants: (1) dissolved organic matter, expressed in COD, such as methane and VFAs; (2) Inorganic macro components, such as ammonium and sodium; (3) heavy metals, such as lead and zinc; and (4) xenobiotic organic compounds that originate from household and industrial chemicals (Bjerg, et al., 2014; Christensen, et al., 2000). Other compounds, such as lithium and mercury, can also be found in leachate; however, when measured, they are found to exist in low concentrations (Christensen, et al., 2000). **Table 2-1** presents a range of the concentrations of some of the contaminants found in leachate generated in the acidogenic phase and methanogenic phase.

Table 2-1: Contaminant Concentrations Found in Leachate (Christensen, et al., 2000; Wdowczyk & Szymanska-Pulikowska, 2020; Kulikowska, 2012)

Contaminant	Acidogenic phase	Methanogenic Phase
pH	4-5 – 8.9	7.5 – 9.1
Chemical Oxygen Demand (mg/l)	843 – 60 000	500 – 4500
Total Dissolved Solids (mg/l)	3470 – 7830	2140 – 3050

Ammonia nitrogen (mg/l)	66 – 786	0.002 – 786
Calcium (mg/l)	43.9 – 1200	69 – 339
Chloride (mg/l)	11.5 – 2811	0.82 – 765
Iron (mg/l)	2.6 – 2100	0.019 – 280
Zinc (mg/l)	0.1 – 12	0.03 – 4

Table 2-1 was adapted from Christensen et al., (2000) and updated using Wdowczyk and Szymanska-Pulikowska (2020), as well as Kulikowska (2012). Although there is a significant variation in the concentration of contaminants across different landfills, it can be seen that leachates generated in the methanogenic phase generally have smaller concentrations of contaminants than leachates generated in the acidogenic phase.

2.3 Leachate Treatment Systems

Leachate treatment systems reviewed from literature can be broadly classified into four categories: (1) leachate transfer and recycling; (2) biological treatment through aerobic and anaerobic processes; (3) chemical and physical treatment, such as flotation, precipitation, and coagulation; (4) and advanced treatment processes, such as reverse osmosis (Wiszniowski, et al., 2006; Renou, et al., 2008). These categories are often combined in modular or multistage units for the removal of multiple contaminants, which may vary in concentration over time (Wiszniowski, et al., 2006). This section of the literature review investigates the processes used in each category. It will also investigate leachate treatment by leachate absorption and capping, as proposed in the "Minimum Requirements for Waste Disposal by Landfilling" (Department of Water Affairs and Forestry, 1998).

2.3.1 Leachate Transfer and Recycling

Leachate transfer refers to the treatment of leachate together with municipal sewage in a wastewater treatment plant (Renou, et al., 2008). It is a preferred leachate treatment method due to its easy maintenance and low cost of operation, however, it has been criticized because it introduces heavy metals and organic inhibitory compounds with low biodegradability into wastewater treatment plants, reducing the plants' efficiency (Renou, et al., 2008; Wiszniowski, et al., 2006). Multiple studies were published to find the optimal ratio between leachate and sewage that would lead to effective treatment: it was found that when the ratio between sewage and leachate was nine to one, nearly 95% BOD and 50% nitrogen removals were obtained and that a decrease in the ratio would result in a decrease in removal rate (Renou, et al., 2008).

Leachate recycling refers to the recirculation of leachate back into the landfill's waste disposal area (Renou, et al., 2008). This treatment method is widely used due to being one of the least expensive options available. Several studies have shown the benefits of this technique; authors have reported reductions in COD of between 63% to 73% due to leachate recycling (Renou, et al., 2008). Significant decreases in methane production have also been reported when the volume of recirculated leachate was 30% of the initial volume of waste. However, high recirculation rates may cause high concentrations of organic acids, lowering the pH value of leachate and causing acidic conditions in the waste; this has an adverse effect on the anaerobic degradation of the solid wastes due to acidic conditions being toxic to methanogenic microorganisms (Renou, et al., 2008).

2.3.2 Leachate Absorption and Capping

The "Minimum Requirements for Waste Disposal by Landfilling" (1998) states that at the end of a leachate dam's operating life, it must be emptied or filled with an absorbent solid material and sealed by a capping layer. The leachate is stored in the absorbent material, thus preventing leakage through the leachate dam's liner system, while the capping layer serves to separate the leachate from the environment, thus preventing precipitation from infiltrating into the absorbent material and creating more leachate.

Figure 2-1 presents the capping system required for leachate dams if this method of leachate containment is followed (Department of Water Affairs and Forestry, 1998). The "Minimum Requirements for Waste Disposal by Landfilling" notes, however, that the design of capping systems is highly dependent on on-site conditions and circumstances.

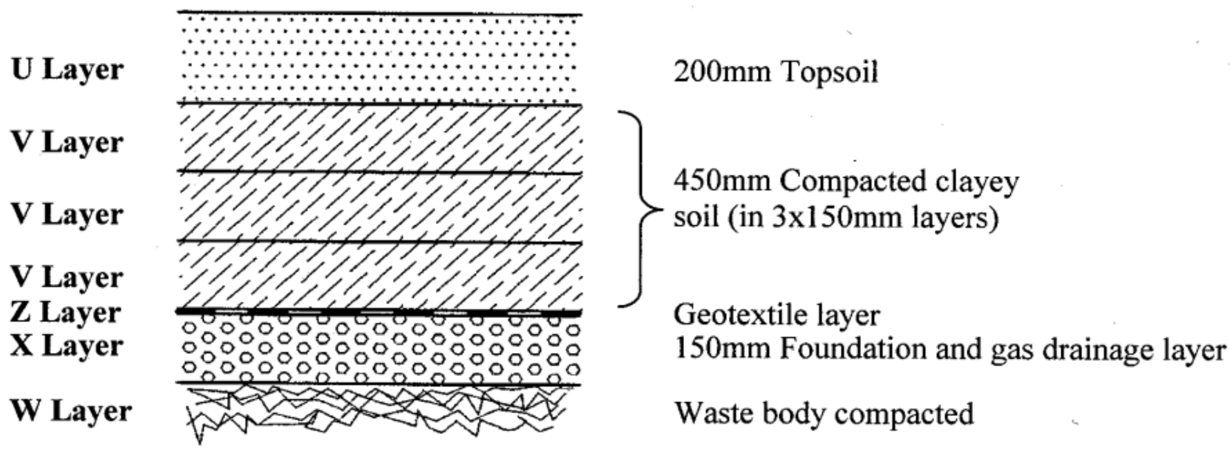


Figure 2-1: Leachate Dam Capping System (Department of Water Affairs and Forestry, 1998)

2.3.3 Microbial Biological treatment

The purpose of biological treatment is the removal of dissolved and particulate organic matter and nutrients using a variety of microorganisms (Tchobanoglous, et al., 2014; Wiszniowski, et al., 2006). Biological treatment can also be accomplished using other living organisms, such as with plant vegetation in constructed wetlands (Bakhshoodeh, et al., 2020). Due to its reliability and cost-effectiveness, microbial biological treatment, in the form of suspended-growth and attached-growth, is commonly used for leachate containing high BOD concentrations. Microbial biological processes have been shown to be very effective in the removal of organic and nitrogenous matter from leachates that have been generated in young landfills, where the BOD/COD ratio is high (Renou, et al., 2008). However, as the landfill becomes older, the presence of refractory compounds limits the treatment's effectiveness (Renou, et al., 2008).

Due to the effectiveness and cost of treating leachate, the most often used microbial biological treatment process is the activated sludge process (Wang, et al., 2018). Activated sludge reactors consist of a reactor, in which microorganisms responsible for treatment are aerated and kept in suspension, and a downstream liquid-solid separation unit where washed-out microorganisms decant and are returned to the reactor (Tchobanoglous, et al., 2014; Wiszniowski, et al., 2006).

Anaerobic activated sludge processes used for treating leachate include anaerobic membrane bioreactors (MBRs) shown in Figure 2-2**(a)**, and upflow anaerobic sludge blanket reactors (UASBs), shown in Figure 2-2**(b)**.

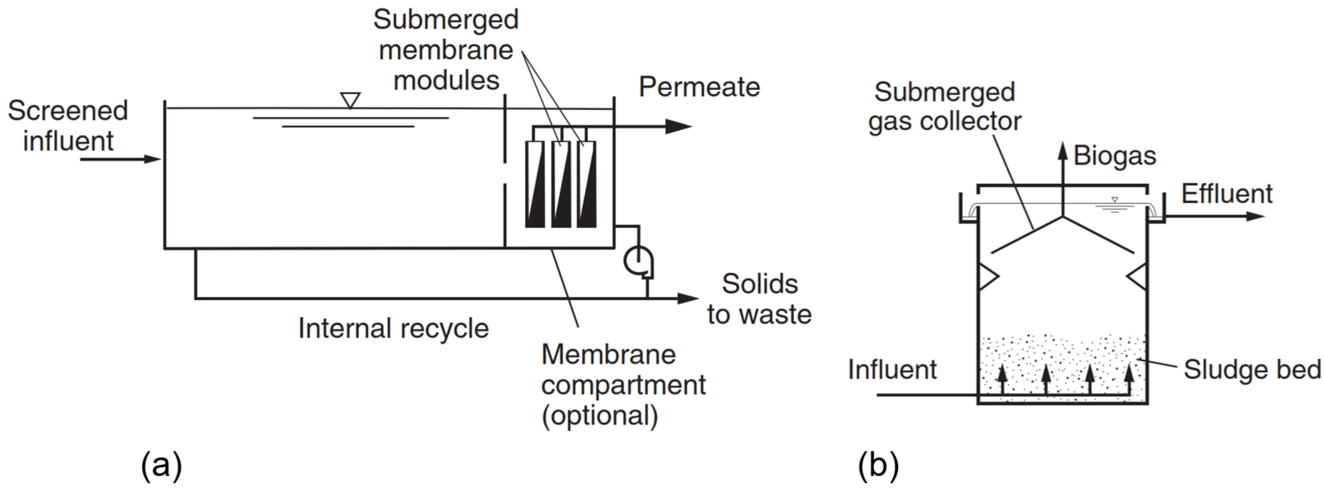


Figure 2-2: Schematics of Anaerobic Activated Sludge Processes: (a) Aerobic Membrane Bioreactor and (b) Upflow Anaerobic Sludge Blanket Reactor (Tchobanoglous, et al., 2014)

MBRs are activated sludge systems where membranes are located at the end of the reactor for liquid-solid separation in lieu of a downstream separation unit where solids have to decant (Tchobanoglous, et al., 2014). UASBs are activated sludge systems that consist of a bottom sludge bed and a dense granular biomass; mixing of the biomass in UASBs is achieved through upflow velocity and biogas generation (Tchobanoglous, et al., 2014). Studies conducted found that MBRs and UASBs are capable of achieving COD removal rates of 62% and 80%, respectively (Wang, et al., 2018). The UASB process is often used to treat leachate with a high organic content (Wang, et al., 2018).

Aerobic activated sludge processes are typically used to remove ammonium from leachate; however, they have been shown to be effective in reducing COD (Wang, et al., 2018). The most predominant activated sludge systems used in leachate treatment, due to their simple structures and large capacities, are the sequencing batch reactors (SBRs). SBRs consist of single complete-mix reactors in which all of the activated sludge process steps occur, eliminating the need for downstream solid separation units (Tchobanoglous, et al., 2014). Studies conducted have shown that aerobic SBRs are capable of achieving ammoniacal nitrogen removal rates of 99 %. Studies have also shown that aerobic SBRs are capable of achieving COD removal rates between 80 % and 85 % (Wang, et al., 2018).

2.3.4 Chemical and Physical Treatment

Physical and chemical treatment involves the reduction of suspended solids, colloidal particles, toxic substances, and refractory compounds through the application of physical forces and the induction of chemical reactions (Renou, et al., 2008; Wang, et al., 2018; Tchobanoglous, et al., 2014). Due to the high organic matter and ammoniacal nitrogen present in leachate, physical and chemical treatment is typically used before microbial biological treatment processes to reduce toxicity and improve biodegradability (Wang, et al., 2018; Wiszniowski, et al., 2006). Physical and chemical treatment methods include flotation, coagulation/flocculation, precipitation, and chemical oxidation.

Flotation refers to the separation of particles from a liquid through the introduction of fine gas bubbles into the liquid (Tchobanoglous, et al., 2014). Floatation is effective in the reduction of turbidity, COD, and non-biodegradable compounds such as humic acids (Renou, et al., 2008; Palaniandy, et al., 2010). Under optimised conditions, flotation has been found to achieve turbidity and COD removal rates of 32 % and 36 %, respectively in leachates, as well as a humic acid removal rate of 60 % (Palaniandy, et al., 2010; Renou, et al., 2008). Flotation systems that included coagulant dosages were found to achieve turbidity and COD removal rates of 79 % and 70 %, respectively (Palaniandy, et al., 2010).

Coagulation refers to the process of adding a substance into a solution to chemically destabilise its particles' repelling charges in order to aggregate the particles through microflocculation (Tchobanoglous, et al., 2014). Microflocculation refers to the aggregation of particles smaller than 2 μm through collisions brought about by the random thermal motion of fluid particles (known as Brownian motion). Flocculation refers to the aggregation of particles larger than 2 μm through physical collisions so that they become large enough to settle out of a solution or be filtered out. (Tchobanoglous, et al., 2014). Coagulation and flocculation are widely used in leachate treatment as a pre-treatment, before biological treatment or reverse osmosis, or as a final treatment step in order to remove non-biodegradable organic matter (Renou, et al., 2008). Studies have found coagulation and flocculation to achieve COD removal rates of between 10 % and 38 % for leachates generated in younger landfills and between 50 % and 75% for leachates generated in older landfills (Renou, et al., 2008). Coagulants commonly used include alum, ferrous sulphate, ferric chloride (Wiszniowski, et al., 2006).

Chemical precipitation refers to the addition of chemicals into a solution in order to cause dissolved and suspended solids to settle out of the solution as a solid precipitate (Tchobanoglous, et al., 2014; United States Environmental Protection Agency, 2000). While used in wastewater treatment for the removal of metals, suspended solids, oils, and greases, it has been widely used in leachate treatment as a pre-treatment process for the removal of high strength ammonia and ammonium nitrogen, prior to biological treatment (Renou, et al., 2008; United States Environmental Protection Agency, 2000). Studies have found chemical precipitation to have ammonia removal rates of between 66 % and 86 % (Renou, et al., 2008). Chemicals used in chemical precipitation include lime, ferrous sulphate, ferric chloride, and alum (United States Environmental Protection Agency, 2000; Tchobanoglous, et al., 2014).

Chemical oxidation refers to the use of oxidizing agents to bring about a change in a substance's chemical composition (Tchobanoglous, et al., 2014). Chemical oxidation is used for the removal of non-biodegradable organic matter and toxic substances (Wiszniowski, et al., 2006; Tchobanoglous, et al., 2014). Studies have found commonly used oxidants, such as chlorine and ozone, to have COD removal rates of between 20 % and 50 % when used for leachate treatment. In particular, advanced oxidation processes (AOPs) have been widely studied as a method for removing non-biodegradable organic matter from leachate. AOPs, such as ozone/UV and ozone/hydrogen peroxide, have been found to have COD removal rates of between 28 % to 95 % (Renou, et al., 2008).

2.3.5 Membrane Processes

Membrane processes involve the removal of particulate and dissolved matter using diffusion and/or sieving through a membrane with minuscule pore sizes; the purpose of the membrane is to act as a selective barrier that allows for selected matter to pass through while preventing and retaining the rest (Tchobanoglous, et al., 2014). The membrane process that is most effective in the removal of particulate and dissolved matter is reverse osmosis (RO). A schematic of the RO process is shown in Figure 2-3.

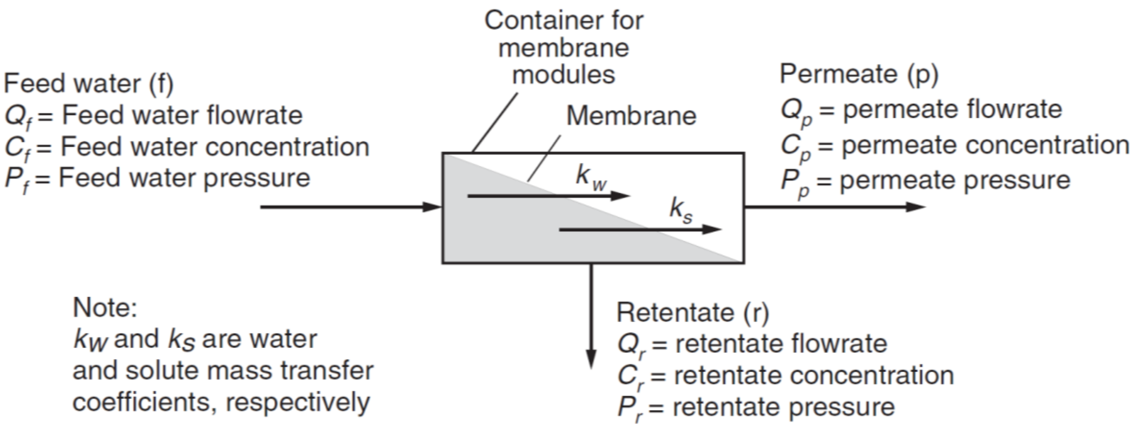


Figure 2-3: Schematic of the RO Process (Tchobanoglous, et al., 2014)

RO has been proven to be the most efficient and indispensable solution in achieving leachate treatment effluent regulations and has become one of the most commonly used methods for leachate treatment (Renou, et al., 2008; Talalaj, et al., 2021). Studies have shown RO to achieve removal rates of between 98 % to 99 % for most contaminants in leachate, such as heavy metals and COD (Wiszniowski, et al., 2006; Renou, et al., 2008; Pure Water Products, LLC, 2023). The most frequent problem related to the use of RO systems is fouling (Talalaj, et al., 2021; Wiszniowski, et al., 2006). Fouling occurs when contaminants in the incoming water (feed water) accumulate on the RO membrane surface or inside its pores and severely decrease flow through the membrane (Tchobanoglous, et al., 2014; Talalaj, et al., 2021). Fouling results in decreased productivity and short membrane lifespans (Renou, et al., 2008). The removal of potential foulants can be achieved through the introduction of biological treatment before the RO process, or through the introduction of chemical and physical treatment, such as coagulation and flocculation (Talalaj, et al., 2021; Wiszniowski, et al., 2006).

2.4 Regulations for Leachate Effluent Quality

Once the leachate is treated, the effluent is generally discharged into the environment, although a portion may be used for landfill operations, such as waste treatment and dust suppression to minimize air pollution (Department of Water Affairs and Forestry, 1998). The general limits of the chemical and physical parameters for water discharged into a surface water resource are regulated by the "Revisions of General Authorisations in terms of Section 39 of the National Water Act, 1998" (2013). The general authorisation replaces the need for users to apply for licenses for the discharge of domestic and industrial wastewater into a surface water resource based on the following conditions: (1) the maximum discharge into a water resource is equal to or less than 2000 m^3 on any given day; (2) the discharge does not alter the receiving water body's normal ambient temperature by greater than 3 ˚C for general water resources and by more than 2 ˚C for specific water resources that are listed in the gazette; (3) wastewater complies with the general wastewater limit values set out in **Table 2-2**.

Special limits to specific water bodies that are listed in the gazette are also given in **Table 2-2**.

Table 2-2: Wastewater Limit Values Applicable for Discharge into a Surface Water Resource (Department of Water Affairs, 2013)

Substance/Parameter	General Limit	Special Limit
Faecal Coliforms (per 100 ml)	1 000	0
Chemical Oxygen Demand (COD) (mg/l)	75	30
pH	5.5 – 9.5	5.5 - 7.5
Ammonia (ionised and un-ionised) as Nitrogen (mg/l)	6	2
Nitrate/Nitrite as Nitrogen (mg/l)	15	1.5
Chlorine as Free Chlorine (Cl) (mg/l)	0.25	0
Suspended Solids (SS) (mg/l)	25	10
Electrical Conductivity (EC) (mS/m)	70 mS/m above intake to a maximum of 150 mS/m	50 mS/m above background receiving water, to a maximum of 100 mS/m
Orthophosphate as phosphorous (mg/l)	10	1 (median) and 2.5 (maximum)

Fluoride (F) (mg/l)	1	1
Soap, oil, or grease (mg/l)	2.5	0
Dissolved Arsenic (As) (mg/l)	0.02	0.01
Dissolved Cadmium (Cd) (mg/l)	0.005	0.001
Dissolved Chromium-VI (Cr-VI) (mg/l)	0.05	0.001
Dissolved Copper (Cu) (mg/l)	0.01	0.002
Dissolved Cyanide (CN) (mg/l)	0.02	0.01
Dissolved Iron (Fe) (mg/l)	0.3	0.3
Dissolved Lead (Pb) (mg/l)	0.01	0.006
Dissolved Manganese (Mn) (mg/l)	0.1	0.1
Mercury and its compounds (Hg) (mg/l)	0.005	0.001
Dissolved Selenium (Se) (mg/l)	0.02	0.02
Dissolved Zinc (Zn) (mg/l)	0.1	0.04
Boron (B) (mg/l)	1	0.5

When comparing **Table 2-2** to the typical range of concentrations of contaminants found in leachate, shown in **Table 2-1**, it can be seen that removal rates of up to nearly 100 % may be required for COD and ammonia nitrogen in order to achieve effluent quality standards. Removal rates of up to nearly 100 % may also be required for heavy metals.

2.5 South African Regulations on the Design of Leachate Dams

The design requirements for leachate dams, in order to limit leachate's movement into groundwater and minimise the risk of spillage, are regulated by the "Minimum Requirements for Waste Disposal by Landfill" (1998) and the "Regulations on Use of Water for Mining and Related Activities Aimed at the Protection of Water Resources" (2010). This section discusses the regulations' requirements on: (1) the liner system design of leachate dams; (2) the permissible leakage rates through leachate dams' liner systems; and (3) the acceptable risk of spillage.

2.5.1 Liner System Design of Leachate Dams

the "Minimum Requirements for Waste Disposal by Landfill" (1998) classifies landfills into two categories: (1) landfills where hazardous waste is disposed of and (2) landfills where general waste is disposed of. The regulation states that leachate dams at hazardous waste disposal landfills must have a hazardous waste lagoon liner system, shown in Figure 2-4, while leachate dams at general waste disposal landfills must have the same liner system as the landfills' waste disposal areas, excluding the leachate collection system, and including a 2 mm thick HDPE geomembrane as the uppermost layer.

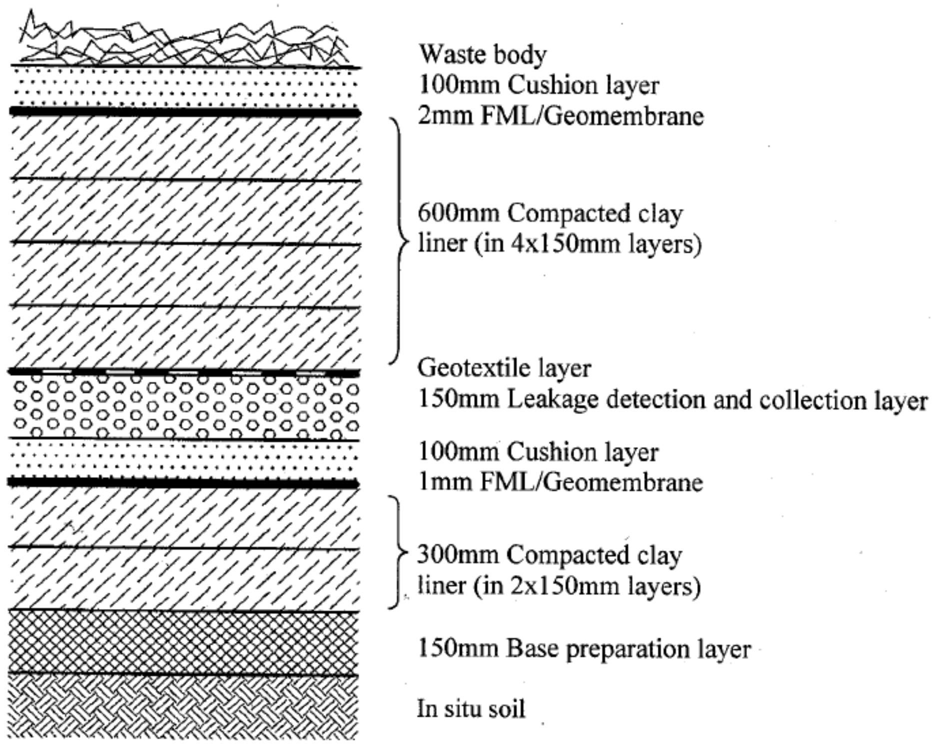


Figure 2-4: Hazardous Waste Lagoon Barrier System (Department of Water Affairs and Forestry, 1998)

Landfill liner systems are discussed in this section as leachate dam liner systems at general waste disposal landfills are adapted from them. In South Africa, the regulatory requirements for the liner system of landfills are set in the "National Norms and Standards for Disposal of Waste to Landfill" (2013) and its amendment (2024). The regulations assign a liner system to a landfill based on the type of waste that can be disposed of in the landfill. The regulation classifies wastes into five categories: Type 0 wastes, which include pesticides and untreated medical waste; Type 1 wastes, which include asbestos and chemicals from analytical or academic laboratories; Type 2 wastes, which include domestic wastes; Type 3 wastes, which include plastics and packaging waste; and Type 4 wastes, which include building rubble, excavated earth, etc. While Type 0 wastes cannot be disposed of in a landfill without going through a treatment and re-classification process, Type 1, 2, 3, and 4 wastes can be disposed of in landfills that have Class A, B, C, and D liner systems, respectively. The different classes of liner systems are shown in Figure 2-5. The Class A liner system is used for wastes that are considered hazardous (Department of Water and Environmental

Affairs, 2013); it consists of a primary 2 mm thick HDPE geomembrane and a 600 mm clay layer to limit leachate leakage. Below the clay layer, a leakage detection system is installed to monitor possible leakage through the primary geomembrane; below the leakage detection system, a secondary 1.5 mm thick HDPE geomembrane and 300 mm clay layer is installed to prevent the possible leachate leakage from seeping into the ground. The Class B, C, and D liner systems are used for the disposal of wastes that are considered general (Department of Water and Environmental Affairs, 2013). Class B and C liner systems consist of a single 1.5 mm thick HDPE geomembrane and clay layer, without a leakage detection system underneath. The Class D liner system has no geomembrane or clay layer. The Class B, C and D liner systems are adapted for their landfills' leachate dam liner systems as follows; for the Class B and C liner systems, the single 1.5 mm thick HDPE geomembrane is replaced with a 2 mm thick HDPE geomembrane, while for the Class D liner system, a 2 mm geomembrane is added.

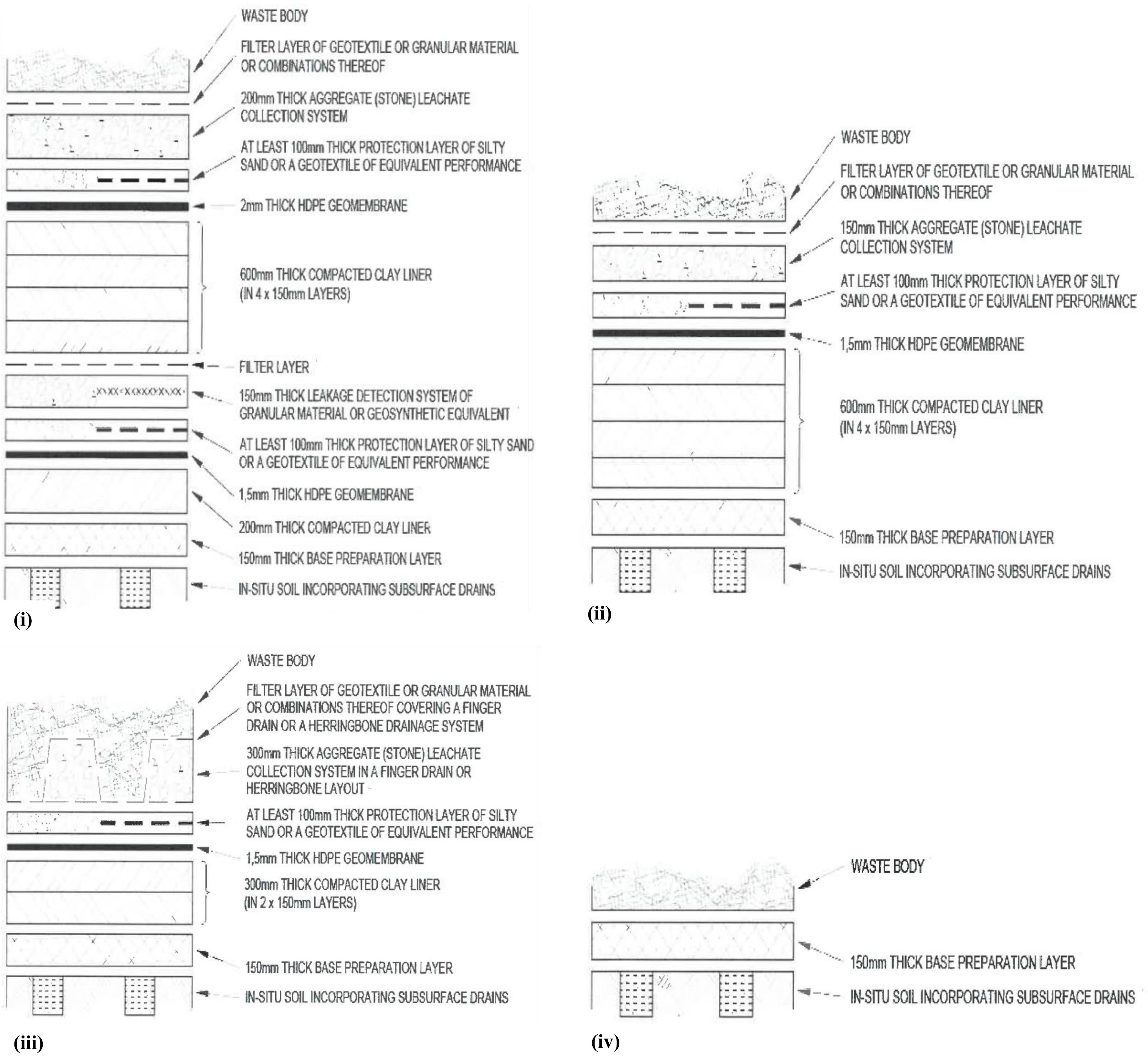


Figure 2-5: Landfill Liner Systems in South Africa: (i) Class A Liner System; (ii) Class B Liner System; (iii) Class C Liner System; (iv) Class D Liner System (Department of Forestry, Fisheries and the Environment, 2024)

Waste types are defined according to the "National Norms and Standards for the Assessment of Waste for Landfill Disposal" (2013). The objective of this regulation is to quantify chemical substances of concern in a waste by obtaining the Total Concentration (TC) of the substances in the waste, as well as the Leachable Concentration (LC) of the substances through the waste. The TCs and LCs are then used to categorise the waste as a Type 0 to a Type 4 waste. The regulation specifies that the TC of the chemical substances must be determined using methods that provide precise, consistent, and repeatable results (Department of Water and Environmental Affairs, 2013). A summary of some of the Total Concentration thresholds (TCTs) is presented in **Table 2-3**.

Table 2-3: Total Concentration Thresholds (Department of Water and Environmental Affairs, 2013)

Elements & Chemical Substances in Waste	TCT 0	TCT 1	TCT 2
Metal Ions (mg/l)			
Arsenic (As)	5.8	500	2 000
Boron (B)	150	15 000	60 000
Cadmium (Cd)	62.5	6 250	1040
Chromium Total (Total Cr)	50	800 000	Not Applicable
Chromium-VI (Cr-VI)	46 000	500	2 000
Copper (Cu)	16	19 500	78 000
Mercury (Hg)	0.93	160	640
Manganese (Mn)	1 000	25 000	100 000

Lead (Pb)	20	1 900	7 600
Selenium (Se)	10	50	200
Zinc (Zn)	240	160 000	640 000
Inorganic Anions (mg/l)			
Fluoride (F)	100	10 000	40 000
Cyanide Total (CN)	14	10 500	42 000
Organics (mg/l)			
Vinyl chloride	-	0.015	0.03
Pesticides (Aldrin and Dieldrin)	0.05	1.2	4.8

The LC analysis of a waste must be conducted using the "Australian Standard Leaching Procedure" (1999) The standard provides an outline for the preliminary assessment of a liquid or waste's potential to contaminate groundwater (Standards Association of Australia, 1999). A summary of the leachable concentration thresholds (LCTs) used to categorise wastes is presented in **Table 2-4**.

Table 2-4: Leachable Concentration Thresholds (Department of Water and Environmental Affairs, 2013)

Elements & Chemical Substances in Waste	LCT 0	LCT 1	LCT 2	LCT 3
Metal Ions (mg/l)				
Arsenic (As)	0.01	0.5	1	4

Boron (B)	0.5	25	50	200
Cadmium (Cd)	0.003	0.15	0.3	1.2
Total Chromium (Total Cr)	0.1	5	10	40
Chromium—VI (Cr-VI)	0.05	2.5	5	20
Copper (Cu)	2.0	100	200	800
Mercury (Hg)	0.006	0.3	0.6	2.4
Manganese (Mn)	0.5	25	50	200
Lead (Pb)	0.01	0.5	1	4
Selenium (Se)	0.01	0.5	1	4
Zinc (Zn)	5.0	250	500	2000
Inorganic Anions (mg/l)				
Total Dissolved Solids (TDS)	1 000	12 500	25 000	100 000
Chloride	300	15 000	30 000	120 000
Sulphate	250	12 500	25 000	100 000
NO3 as N, Nitrate-N	11	550	1 100	4 400
F, Fluoride	1.5	75	150	600
CN- (total), Cyanide Total	0.07	3.5	7	28

Organics (mg/l)				
Vinyl chloride	0	0.015	0.03	0.12
Pesticides	0	0	0	0

Once the TC and LC of the substances of concern are quantified, the waste can be categorised as a Type 0 to Type 4 waste. **Table 2-5** presents the categorisation system for wastes based on waste types. The TC and LC of all of the substances of concern must relate to their TCT and LCT in the manner described.

Table 2-5: Waste Assessment Classifications (Department of Water and Environmental Affairs, 2013)

Waste Type	Classification
Type 0	LC > LCT3 or TC > TCT2
Type 1	LCT2 < LC ≤ LCT3 or TCT1 < TC ≤ TCT2
Type 2	LCT1 < LC ≤ LCT2 and TC ≤ TCT1
Type 3	LCT0 < LC ≤ LCT1 and TC ≤ TCT1
Type 4	LC ≤ LCT0 and TC ≤ TCT0

Along with Type 0 wastes, as defined in the "National Norms and Standards for the Assessment of Waste for Landfill Disposal" (2013), other types of wastes that are prohibited from disposal by landfill include wastes that are explosive, corrosive, or oxidizing under landfill conditions; wastes with a pH greater than 12 or less than 6; wastes that are flammable or contain compressed gases; untreated mercury; and infectious animal carcasses and animal waste.

2.5.2 Leakage Through a Liner System

The "Minimum Requirements for Waste Disposal by Landfill" (1998) sets the regulatory requirements for the maximum allowable leachate outflow rate through a liner system's clay layers over a year. It states that the outflow rate through a liner system's clay layers (i.e., the rate at which leachate will pass through the clay layers, taking into account the hydraulic head of leachate that is likely to accumulate over the liner system) must not exceed 0.3 m/year (1×10^{7} cm/s) for hazard waste disposal landfills and 0.1 m/year (1×10^{-6} cm/s) for general waste disposal landfills (Department of Water Affairs and Forestry, 1998).

For leakage to occur through a leachate dam liner system's clay layers, it must first travel through the 2 mm HDPE geomembrane placed above the clay layers. There are two primary mechanisms for the transport of leachate through a geomembrane: (1) diffusion through the geomembrane and (2) leakage through holes and defects in the geomembrane. Diffusion occurs when leachate travels through an intact geomembrane at the molecular level, due to a hydraulic head or vapour pressure gradients, (Schroeder, et al., 1994; Katsumi, et al., 2001). Leakage through holes and defects occurs when leachate travels through holes accidentally caused during a geomembrane's installation or manufacture (Katsumi, et al., 2001; Schroeder, et al., 1994; Rowe, 2012). The level of leakage through diffusion is smaller than the level of leakage through a hole or defect (Schroeder, et al., 1994); thus, leakage through a hole or defect will produce the highest leachate outflow rate through a liner system's clay layers. Giroud and Bonaparte (1989) investigated the occurrence of holes in installed geomembranes and found that they are unavoidable; 1-2 holes per hectare were found even when construction quality assurance was excellent. Once leachate leaks through a geomembrane hole, it flows through a liner system's clay layer due to the leachate's hydraulic head, based on Darcy's law (Rowe, 2012).

Rowe (2012) shows that leakage outflow rates through composite liner systems (i.e., liner systems that include a geomembrane and clay layer) are higher when a hole sits on or coincides with a wrinkle in the geomembrane, compared to the outflow rates through a hole that is in direct contact with the clay layer. Wrinkles in HDPE geomembranes occur due to thermal expansion after installation and can cover 3 % to 15 % of the entire installation area (Rowe, 2012). Rowe (1998), as cited in Rowe (2012), presents **Equation 2-1** to predict the leakage outflow rate through clay layers located under a geomembrane hole that has coincided with a geomembrane wrinkle, shown in Figure 2-6.

$$Q = 2L[kb + (kD\theta)^{0.5}]h_d/D$$

Equation 2-1 (Rowe, 2012)

Where,

- Q = Leakage rate through one hole (m^3/s)
- L = Length of a connected wrinkle (m)
- k = Hydraulic conductivity of the compacted clay liner (m/s)
- b = Half of the wrinkle width (m)
- $D = H_L + H_A$ (m)
- $h_d = h_w + H_L + H_A - h_a$ (m)
- θ = Geomembrane-clay liner transmissivity (m^2/s)

$Log_{10}\theta = 0.07 + 1.036(log_{10}k_L) + 0.0180(log_{10}k_L)^2$ – for good contact.

Equation 2-2 (Rowe, 2012)

$Log_{10}\theta = 1.15 + 1.092(log_{10}k_L) + 0.0207(log_{10}k_L)^2$ – for poor contact.

Equation 2-3 (Rowe, 2012)

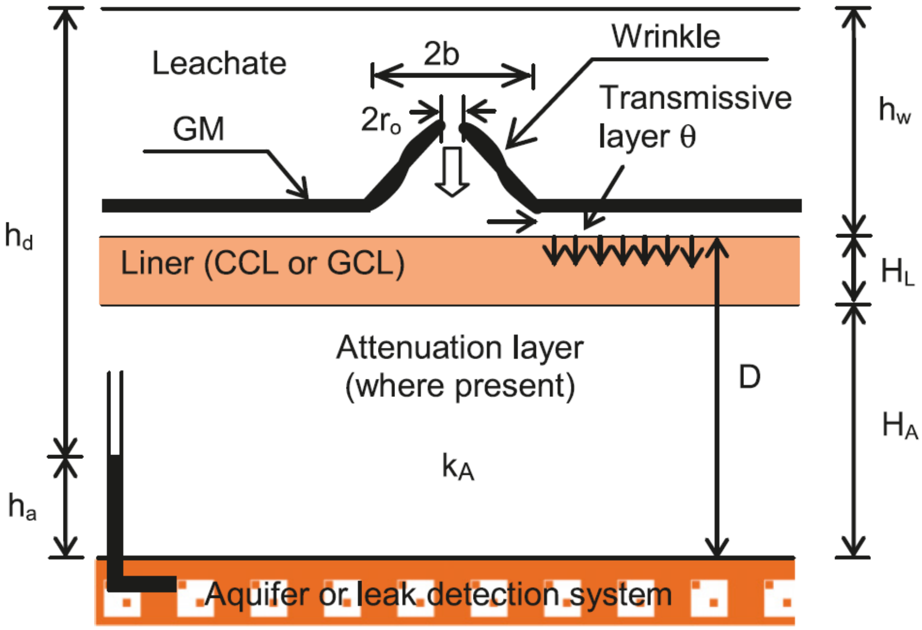


Figure 2-6: Leachate Outflow Rate through a Liner System with a Hole in the Geomembrane (Rowe, 2012)

Rowe (2012) states that the probability of a hole coinciding with a wrinkle is approximately 50 %. Thus, if there is more than one hole in a geomembrane after installation, it is likely that a hole will coincide with a wrinkle. Therefore, given that 1-2 holes per hectare are likely when construction quality assurance is excellent, it can be assumed that one hole will coincide with a wrinkle (Giroud & Bonapart, 1989; Rowe, 2012). The length of a connected wrinkle can vary from 20 m to 1400 m, depending on the solar radiation and temperature on the geomembrane (Rowe, et al., 2012). Although wrinkles occasionally reach 0.2 m in height and 0.5 m in width, the average height of a wrinkle is approximately 0.06 m, while the average width ranges between 0.2 m and 0.25 m (Rowe, 2012). Rowe (2012) states that leachate dams require a suitable ballast layer, such as a thick inorganic granular layer, over their liner systems for **Equation 2-1** to be applicable.

2.5.3 Acceptable Risk of Spillage

The sizing of a leachate dam is regulated by the *Regulations on Use of Water for Mining and Related Activities Aimed at the Protection of Water Resources* (2010). The regulation requires that dirty water systems be designed, constructed, operated, and maintained in such a manner that they are not likely to spill more than once in 50 years – the regulation defines a "dirty" area as an area that causes, or is likely to cause the pollution of a water resource (Department of Water Affairs and Forestry, 2010); thus, leachate dams are considered dirty water systems. This requirement is accomplished by conducting a site water balance for the leachate dam using climactic data that spans more than 50 years to ensure that it will not spill more than once in the 50 years, however full it is at that point in time (Department of Water Affairs and Forestry, 2006).

2.6 Predicting Leachate Discharge

This section of the literature review gives a background on the Hydrologic Evaluation of Landfill Performance model (HELP Model), details the inputs required for the model, and explains the model's process for computing daily leachate discharge. This section also discusses the studies conducted on the saturated hydraulic conductivity of landfill wastes.

2.6.1 The HELP Model

The HELP model is a hydrological model that predicts the movement of water into, through, and out of landfills. The model was developed by the "U.S. Army Corps of Engineers' Waterways Experiment Station" for the "U.S. Environmental Protection Agency (EPA)". Many United States governmental agencies require the use of the HELP model for landfill design evaluation and regulatory licencing. Additionally, the model is used in more than a dozen countries, with more than 50 universities using the model for training and research (Tolaymat & Krause, 2020). The model is suggested for use in South Africa by the "Minimum Requirements for Waste Disposal by Landfill" (1998).

In order to use the model to compute the leachate discharge out of a landfill's waste disposal area for use in a daily water balance, it requires: (1) a historical daily rainfall record of the landfill; (2) a historic daily record of the solar radiation at the landfill;

(3) other climactic parameters, including humidity, temperature, and wind speed; (4) hydrological parameters of the waste disposed of at the landfill, including the waste's curve number, total porosity, field capacity, wilting point, and saturated hydraulic conductivity; and (5) the disposed of waste's evaporative zone depth (Tolaymat & Krause, 2020).

The model uses the historical daily rainfall record, along with the curve number of the waste disposed of, to compute the daily infiltration into the waste. Historical daily rainfall records from rainfall stations across South Africa can be acquired from the Daily Rainfall Extraction Utility (DREU) software, developed by the "Institute for Commercial Forestry Research (ICFR)", in conjunction with the School of Bio-resources, Engineering, and Environmental Hydrology (BEEH) at the University of KwaZulu-Natal (Lynch, 2004). The software can be used to obtain daily rainfall data from all rainfall stations across South Africa, from 1900 to 2000.

The model uses the SCS method to calculate infiltration (Tolaymat & Krause, 2020); a curve number (CN) is an index that is used in the SCS method to express a catchment's run-off response to a rainfall event. Specifically, the HELP model requires an initial curve number (CN_{II}) input; CN_{II} considers the hydrological properties and land cover properties of a catchment, with no regard to moisture conditions of the catchment, before a rainfall event (The South African National Roads Agency SOC Limited, 2013). Using CN_{II}, the curve number for "dry" moisture conditions is calculated using **Equation 2-4**.

$$CN_I = 3.751\ \times 10^{-1} CN_{II} + 2.751\ \times 10^{-3} {CN_{II}}^2 - 1.639 \times 10^{-5} {CN_{II}}^3 +\ 5.143 \times 10^{-7} {CN_{II}}^4$$

Equation 2-4 (Schroeder, et al., 1994)

The maximum moisture retention parameter (S_{mx}) is then calculated using **Equation 2-5**. The moisture retention parameter (S) is used to take moisture conditions into account when determining run-off and infiltration – the maximum moisture retention parameter (S_{mx}) is the moisture retention parameter (S) when moisture conditions are dry.

$$S_{mx} = \frac{1000}{CN_I} - 10$$

Equation 2-5 (Schroeder, et al., 1994)

Since moisture is not evenly spread through the waste layers and the moisture near the waste body's surface has a higher influence on infiltration than moisture located deeper in the waste, the moisture retention parameter (S) is weighted according to depth using the evaporative zone depth (EZD) input. The depth-weighted S is computed using **Equation 2-6** and **Equation 2-7**. The EZD is divided into 7 layers, with the thicknesses and weighting factors presented in **Table 2-6**.

$$S = \sum_{j=1}^{7} W_j \times S_j$$

Equation 2-6 (Schroeder, et al., 1994)

$$Sj = \begin{cases} S_{mx}\left[1 - \dfrac{SM_j - \left[\dfrac{(FC_j + WP_j)}{2}\right]}{UL_j - \left[\dfrac{(FC_j + WP_j)}{2}\right]}\right], & For\ SM_j > \dfrac{(FC_j + WP_j)}{2} \\ S_{mx}, & For\ SM_j \leq \dfrac{(FC_j + WP_j)}{2} \end{cases}$$

Equation 2-7 (Schroeder, et al., 1994)

Where,

- W_j = Weighting factor for segment j
- S_j = Moisture retention parameter for segment j
- SM_j = Soil water storage in segment j, meters

- UL_j = Storage at saturation in segment j, meters
- FC_j = Storage at field capacity in segment j, meters
- WP_j = storage at wilting point in segment j, meters

Table 2-6: Moisture Retention Parameter Weighting Factors (Schroeder, et al., 1994)

Layer (relative to the surface)	Thickness	Weighting Factor
1 (top segment)	$\frac{1}{36}EZD$	0.111
2	$\frac{5}{36}EZD$	0.397
3	$\frac{1}{6}EZD$	0.254
4	$\frac{1}{6}EZD$	0.127
5	$\frac{1}{6}EZD$	0.063
6	$\frac{1}{6}EZD$	0.032
7	$\frac{1}{6}EZD$	0.016

Once the moisture retention parameter (S) is obtained, run-off (R) is calculated using **Equation 2-8**. Rainfall (P) is measured in meters.

$$R = \frac{(P - 0.2S)^2}{P + 0.8S}$$

Equation 2-8 (Schroeder, et al., 1994)

Assuming that there is no snow cover and no vegetation (bare ground), the infiltration into the waste ($DR(j)$) is computed using Equation 2-9.

$$DR(j) = P - R$$

Equation 2-9 (Schroeder, et al., 1994)

Once the infiltration is computed, the HELP model computes the daily leachate discharge out of a landfill using Equation 2-10 to Equation 2-14.

$$Q_i = DR_i(j+1) \cdot A \ = [\Psi_j(\Pi_i)^{\frac{\lambda_j}{3\lambda_j+2}} + \Upsilon_j + DR_{i-1}(j) - DR_i(j) - ET_{i-1}(j) - ET_i(j)] \cdot A$$

Equation 2-10 (Schroeder, et al., 1994)

$$\Psi_j = -2[UL(j) - RS(j)]$$

Equation 2-11 (Schroeder, et al., 1994)

$$\Pi_i = \frac{DR_i(j+1)}{K_s(j) \cdot i}$$

Equation 2-12 (Schroeder, et al., 1994)

$$\lambda_j = \frac{Log[SM(j) - RS(j)] - Log[UL(j) - RS(j)]}{Log[\psi_b] - Log[\psi]}$$

Equation 2-13 (Schroeder, et al., 1994)

$$\Upsilon_j = 2[SM_{i-1}(j) - RS(j)]$$

Equation 2-14 (Schroeder, et al., 1994)

Where,

- Q_i = Daily leachate discharging out of the landfill (m^3/day)
- A = Landfill footprint/plan Area (m^2)
- $DR_i(j+1)$ = Drainage out of landfill waste body to underlying leachate collection layer (m/day)
- $UL(j)$ = Saturated water content/total porosity of waste body (m)
- $RS(j)$ = Residual water content (m)
- $K_s(j)$ = Saturated hydraulic conductivity of waste body (m/day)
- i = Hydraulic gradient of the waste body – assumed to be 1 when the waste body is not saturated (unitless)
- $SM_{i-1}(j)$ = leachate stored in the waste body on the previous day (m)
- $DR_{i-1}(j)$ = Water into landfill waste body on the previous day – i.e., the portion of the previous day's rainfall that infiltrated into the waste body (m/day)
- $DR_i(j+1)$ = Water into landfill waste body – i.e., the portion of rainfall that infiltrates into the waste body (m/day)
- $ET_{i-1}(j)$ = Evaporation out of the waste body on the previous day (m/day)
- $ET_i(j)$ = Evaporation out of waste body (m/day)
- ψ_b = Capillary pressure (bars). 0.33 bar when $SM(j)$ = Wilting Point and 15 bar when $SM(j)$ = Field Capacity
- ψ = Bubbling pressure (bars)

The model uses the inputted daily global solar radiation, temperature, relative humidity, and wind speed to compute the evaporation ($ET_i(j)$). ψ and λ_j are computed simultaneously using **Equation 2-13** by equating $SM(j)$ to 0.33 bar and then 15 bar. The waste body's leachate storage ($SM(j)$) is calculated using **Equation 2-15**.

$$SM_i(j) = 0.5\,\{[DR_i(j) + DR_{i-1}(j)] - [DR_i(j+1) + DR_{i-1}(j+1)] - [ET_i(j) + ET_{i-1}(j)]\} + SM_{i-1}(j)$$

Equation 2-15 (Schroeder, et al., 1994)

2.6.2 Saturated Hydraulic Conductivity of Landfilled Waste

Schroeder and Peyton (1988) state that hydraulic conductivity is the most important parameter for determining leachate discharge. Experiments to estimate the saturated hydraulic conductivity of municipal waste have been conducted across several landfill facilities around the world. Machado et al. (2010) conducted borehole infiltration testing in two Brazilian landfills and sampled the waste to test for its saturated hydraulic conductivity using triaxial testing; the saturated hydraulic conductivity was found to range between 1×10^{-5} cm/s and 1×10^{-3} cm/s. Reddy et al. (2009) used auger drilling to collect municipal waste samples from an American landfill to test for the waste's saturated hydraulic conductivity using a large-scale rigid wall permeameter, a small-scale rigid wall permeameter, and a small-scale triaxial permeameter, which had diameters of 30 cm, 6.3 cm, and 5 cm, respectively. The saturated hydraulic conductivities were found to range between 0.2 to 7.8×10^{-5} cm/s, 2.8×10^{-3} to 11.8×10^{-3} cm/s, and 10^{-4} to 10^{-6} cm/s for the large-scale rigid wall permeameter, small-scale rigid wall permeameter, and small-scale triaxial permeameter, respectively. Reddy et al. (2009) attributed the large variation in the large-scale rigid wall permeameter's saturated hydraulic conductivity results to increasing the vertical pressure during testing, which lead to a lower void ratio. It is noted that the saturated hydraulic conductivity increases with the size of the testing apparatus; the larger apparatus tests a more representative sample. Zeis and Majors (1993) sampled municipal waste from a Canadian landfill to test for its porosity, field capacity, residual water content, and unsaturated hydraulic conductivity; the saturated hydraulic conductivity was then computed from these values. The testing apparatus used to compute the saturated hydraulic conductivity had a diameter of 59 cm. They reported an apparent saturated hydraulic conductivity that ranged between 200 cm/s and 2×10^{2} cm/s.

2.6.3 Alternative Method for Predicting Leachate Discharge

A verified analytical method of predicting leachate discharge is the two-dimensional two-domain approach proposed in Fellner and Brunner (2010). In the method, a landfill is modelled as being composed of highly permeable vertical flow paths surrounded by a less permeable waste mass (Fellner & Brunner, 2010). Fellner and Brunner (2010) simulated the leachate discharge of an existing landfill using the HYDRUS-2D software and the Rosetta software which calculate water flow using Richard's equation and van Genucthen's equation. Fellner and Brunner (2010) state that the method computes predicted leachate discharge rates that are similar to the leachate discharge rates observed; the predicted cumulative leachate discharge over their analysis period was 2394 m^3 compared to an observed cumulative leachate discharge of 2251 m^3. This results in a percent error of 5.97 %. The advantage of using the HELP model over the method proposed in Fellner and Brunner (2010) is that the HELP model is freeware based in Microsoft Excel thus making it more accessible.

2.7 Predicting Evaporation from the Leachate Dam

Valderrama et al. (2015) presented **Equation 2-16** for determining a saline solution's latent heat of vaporization based on the salinity of the solution and the ambient temperature at the location of the solution. Latent heat of vaporization is defined as the heat required to change a unit mass of a substance from a liquid to a gas.

$$L_s = [a_1 + a_2(T - 273.15) + a_3(T - 273.15)^2 + a_4(T - 273.15)^3 + a_5(T - 273.15)^4] \times \left(1 - \frac{S}{1000}\right)$$

Equation 2-16 (Valderrama, et al., 2015)

Where,

- L_S = Latent heat of vaporisation (kJ/kg)
- T = Temperature (K)
- S = Salinity (g/kg)

- a_1 = constant = 2.501 × 10^6
- a_2 = constant = -2.369 × 10^3
- a_3 = constant = 2.678 × 10^{-1}
- a_4 = constant = -8.103 × 10^{-3}
- a_5 = constant = -2.079 × 10^{-5}

Equation 2-16 is suitable for salinities that range between 0 and 120 g/kg, at temperatures between 0 and 200 ˚C. The equation has a reported accuracy of ±1% for seawater (Generous, et al., 2020).

Ritchie (1972), as cited in Schroeder et al. (1994), states that the latent heat of vaporization is related to potential evaporation (E_o) according to **Equation 2-17**.

$$E_o = \frac{LE}{25.4L_s}$$

Equation 2-17 (Schroeder, et al., 1994)

Where,

E_o = Potential evaporation (inches)

LE = Energy available for evaporation (langelys)

L_s = Latent heat of vaporisation (langelys per mm)

The subsequent chapters of this research will discuss the use **Equation 2-16** and **Equation 2-17** in developing a method for predicting leachate evaporation for the purpose of leachate dam sizing.

3. METHODOLOGY

This chapter presents: (1) the study area, field data, instruments, and procedures that were used to measure and record leachate discharge and leachate evaporation; (2) the procedures and input parameters that were used in the HELP Model to compute predicted leachate discharge; and (3) the derivation that was used to compute predicted leachate evaporation.

3.1 Description of study area

The data used for verifying the HELP model and the derived leachate evaporation method was recorded from an existing landfill that is located in the South African inland. The landfill cannot be named in this research due to its owners' request that it remain confidential. The landfill is located in a region with a generally dry climate. Summers are warm to hot, with the average daily high temperature being approximately 26 ˚C, while winters are mild to cold, with the average daily temperature being approximately 18 ˚C. The mean annual precipitation (MAP) at the landfill facility is approximately 709 mm, with 85% of the annual precipitation falling between the months of October and March (Lynch, 2004). The mean annual evaporation (MAE) of open-water surfaces in the region is between 2000 and 2200 mm (Schulze, et al., 2008).

Geotechnical investigations carried out at the landfill facility show that the site is typically composed of a medium dense silty sand hillwash from the surface to a depth of 1.2 m; a clayey silt nodular ferricrete from a depth of 1.2 m to 2.6 m; and a firm to stiff clayey silt reworked/residual siltstone from a depth of 5.2 m to 25 m. Ground water seepage is encountered at a depth of 4.0 m below ground level.

The landfill in question consists of multiple waste disposal areas (cells) and leachate dams. A single cell and leachate dam was used for this research report; the cell and leachate dam used are hereby referred to as Cell A and Leachate Dam A, respectively.

Cell A and Leachate Dam A were constructed in the early 2010s, as extensions to the landfill. Cell A reached its final landform (FLF) in 2019, remaining significantly unchanged over the course of the collection of the leachate discharge data, while Dam A is currently still in use.

Cell A's liner system consists of a 2 mm thick HDPE geomembrane installed on top of a 600 mm thick clay layer that has been compacted in 150 mm thicknesses. Below the 600 mm clay layer, a 150 mm thick stone layer, embedded with 110 mm perforated HDPE pipes, has been installed to serve as a leakage detection layer. Below the 150 mm thick stone layer, a 300 mm clay layer compacted in 150 mm thick layers has been constructed to prevent potential leakage from seeping into the ground. A subsoil drainage system, embedded with 110 mm perforated HDPE pipes, has been constructed below the 300 mm thick clay layer to prevent groundwater from pushing up against the liner system. Above the liner system, a leachate collection system has been constructed. The collection system consists of a 300 mm thick stone layer with 315 mm diameter perforated HDPE pipes embedded in the stone, spaced at horizontal lengths of between 44 m and 66 m. The stone and HDPE pipes slope at approximately 4 % to 4.5 % towards a low point. Two HDPE solid pipes (315 mm diameter) are connected to the perforated pipes at the low point. The solid outlet pipes penetrate through the 2 mm HDPE geomembrane and gravitationally discharge into a lined concrete sump; the penetration through the geomembrane was designed and constructed to be watertight. From the lined concrete sump, leachate is continuously pumped to Leachate Dam A. A layer of protection sand is placed below the 300 mm stone layer to protect the geomembrane from damage. Separation geotextiles are installed between the different soil and stone layers to act as filters. A cross-section of the liner system and leachate collection system is shown in **Figure 3-1**.

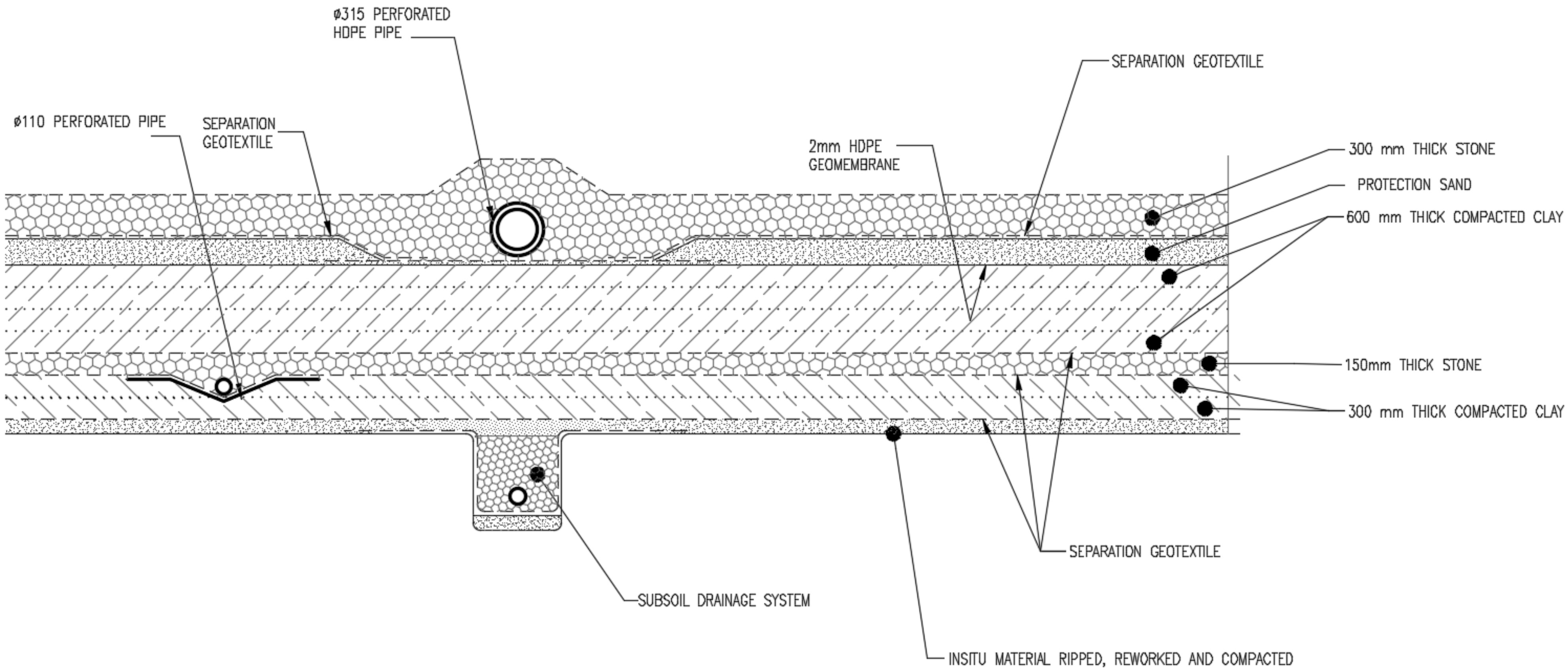


Figure 3-1: Cell A's Liner System

3.2 Instruments and Procedures for Data Gathering

This section describes the instruments and procedures that were used to record field data that was essential as inputs into the HELP model and the derived leachate evaporation method. The data gathered was also used for verification of the model and method; the recorded leachate discharge and leachate evaporation were compared to the predicted values from the model and method.

3.2.1 Observed Leachate Discharge and Leachate Evaporation

Leachate discharge was recorded manually at the landfill every afternoon (excluding public holidays) from 2019 to 2023. The discharge was measured using electronic flow metres connected to Cell A’s two 315 mm solid outlet pipes, as they gravitationally drained into Cell A’s concrete lined sump. 3.8 years of continuous cumulative daily leachate discharge was recorded over the period that Cell A remained unchanged.

Leachate evaporation was measured and recorded every afternoon (excluding public holidays) at the landfill using A-pans, under conditions recommended by the World Meteorological Organization (2008). If the A-pan’s level was found to have dropped by more than 20 mm from its reference level (50 mm), it would be refilled back to the reference level using leachate from Leachate Dam A. Rainfall was also measured at the landfill so that it would be taken into account when computing the evaporation. 2.7 years of continuous daily leachate evaporation was recorded.

3.2.2 Rainfall, Evaporation, and Other Climatic Data

Rainfall and water evaporation were also measured and recorded at the landfill. These records are essential inputs to the HELP model and derived leachate evaporation method. Rainfall was measured daily using conical rain gauges, while water evaporation was measured using A-pans, under conditions recommended by World Meteorological Organization (2008). The MAP of the measured rainfall was 814.7 mm; the percent error between the measured MAP and the MAP reported by Lynch

(2004) is 14.9%. The measured MAE falls with the range reported in Schulze et al. (2008) when converted to lake evaporation using Bosman (1990) and Midgely et al. (1994).

Other climatic data required, such as wind speed and temperature, was provided by the website, *Time and Date AS*. The website accuracy was accessed and confirmed by comparing its average daily temperatures provided to the daily temperature records of a weather station that is located approximately 28 km from the landfill site and lies within the same quaternary catchment as the landfill, according to Midgley et al. (1994). The weather station's daily temperature records were taken at irregular intervals from 1973 to 2020, with every month having around 1 300 days of recorded data (the minimum being February, with 1 278 days recorded). The average per cent difference between the two data sets was found to be 5.06 %.

3.2.3 Composition of Leachate

Nine leachate samples from Dam A were collected and tested for total dissolved solids (TDS) and electrical conductivity (EC), over nine years; this data is to be used in computing predicted leachate evaporation. The samples were tested by a third-party laboratory. The TDS and EC results are shown in **Table 3-1**. The TDS to EC ratio (f-value) was calculated and is also shown **Table 3-1**. The f-values ranged from 0.683 to 1.146. This range falls within the range that is reported by Hubert and Wolkersdorfer (2015), which is between 0.25 and 1.34 for 45 South African mine-water samples; thus, the TDS and EC results are deemed to be realistic.

Table 3-1: TDS and EC Sampled from Leachate Dam A

Sample No.	Date Sampled	TDS (ppm)	EC (µS/cm)	f-value
1	16/07/2014	99 579	102 200	0.974
2	13/07/2015	87 425	115 800	0.755

3	17/07/2016	79 890	117 130	0.682
4	10/07/2017	92 241	135 130	0.682
5	05/07/2018	121 260	120 750	1.004
6	10/07/2019	159 600	139 250	1.146
7	06/07/2020	89 700	135 330	0.663
8	06/07/2021	139 360	123 020	1.133
9	05/07/2022	87 925	118 780	0.740

The nine samples collected from Leachate Dam A were also tested for pH and COD; the results are presented in **Table 3-2**. These results are presented in this research in order to compare the typical range of concentrations of contaminants found in leachate, presented in **Table 2-2**, to Leachate Dam A's leachate; this comparison is important when discussing the derived leachate evaporation method's suitability when applied to different landfills.

Table 3-2: pH and COD of Leachate Dam A

Sample No.	Date Sampled	pH	COD as O_2 (mg/l)
1	16/07/2014	8.1	16 252
2	13/07/2015	4.9	15 677
3	17/07/2016	7.5	15 571
4	10/07/2017	7.5	18 115
5	05/07/2018	8.4	17 030

6	10/07/2019	8.1	25 819
7	06/07/2020	8.2	25 247
8	06/07/2021	8.2	18 000
9	05/07/2022	8.3	14 331

3.3 Predicting Leachate Discharge Using HELP Model

The cumulative predicted leachate discharge computed on the HELP 4.0 software was compared to the cumulative recorded leachate discharge. The predicted leachate discharge was computed using rainfall and evaporation that was recorded over the same period as the observed leachate discharge. The observed leachate discharge records had 119 non-consecutive days missing due to errors in recording and public holidays – this amounts to a reliability of 91.6 %. The days on which records had been missing were excluded from both the cumulative observed and predicted discharge. The cumulative predicted leachate discharge was computed for all of HELP 4.0's standard waste types to find the waste type that computed predicted leachate discharge values that most closely matched the recorded leachate discharge; each of the model's waste types has a unique saturated hydraulic conductivity, porosity, field capacity, residual water content (expressed, as wilting point). Hydraulic conductivity is the most important parameter for determining leachate discharge that is to be used for the purposes of a water balance (Schroeder & Peyton, 1988); thus, an analysis was carried out on the closest matching waste type to determine the apparent saturated hydraulic conductivity (K_s) that led to an even closer match. The match between the observed and predicted leachate discharge was evaluated by graphical comparison, as well as through the use of the coefficient of determination (r^2).

The input parameters used in the HELP model computations are presented in **Appendix A**. However, two parameters, solar radiation and latitude, are crucial to this research and are highlighted in this section.

3.3.1 Solar Radiation and Latitude

In HELP 4.0, the daily solar radiation input required is the daily global horizontal radiation (R_{si}) at the landfill (Tolaymat & Krause, 2020). The R_{si} is defined as the radiation of the sun on a surface area that is horizontal to the surface of the earth. HELP uses this input to simulate evaporation through the landfill (The World Bank Group, 2023). Daily A-pan evaporation was measured at the landfill, in lieu of solar radiation. The R_{si} was then manually computed in Microsoft Excel using the following formulae from Ritchie (1972), as cited in Schroeder et al. (1994):

$$E_{oi} = \frac{LE_i}{L_v}$$

Equation 3-1 (Schroeder, et al., 1994)

$$L_v = 59.7 - T_{ci}$$

Equation 3-2 (Schroeder, et al., 1994)

$$LE_i = PENR_i + PENA_i$$

Equation 3-3 (Schroeder, et al., 1994)

$$PENR_i = \frac{\Delta_i}{\Delta_i + \gamma} R_{ni}$$

Equation 3-4 (Schroeder, et al., 1994)

$$PENA_i = \frac{15.36\gamma}{\Delta_i + \gamma}(1 + 0.1488^u)(e_{oi} - e_{ai})$$

Equation 3-5 (Schroeder, et al., 1994)

$$\Delta_i = 1.9993[(0.00738T_{ci} + 0.8072)^7 - 0.0005793]$$

Equation 3-6 (Schroeder, et al., 1994)

$$e_{oi} = 33.8639[(0.00738T_{ci} + 0.8072)^8 - (0.000019)|1.8T_{ci} + 48| + 0.001316]$$

Equation 3-7 (Schroeder, et al., 1994)

$$e_{ai} = 33.8639 \times RH[(0.00738T_{ci} + 0.8072)^8 - (0.000019)|1.8T_{ci} + 48| + 0.001316]$$

Equation 3-8 (Schroeder, et al., 1994)

$$R_{ni} = (1 - \alpha)R_{si} - R_{bi}$$

Equation 3-9 (Schroeder, et al., 1994)

$$R_{bi} = R_{boi}\left[a_i\left(\frac{R_{si}}{R_{soi}}\right) - b_i\right]$$

Equation 3-10 (Schroeder, et al., 1994)

$$R_{boi} = 1.171 \times 10^{-7}(T_{ci} + 273)^4\left(0.39 - 0.05\sqrt{e_{ai}}\right)$$

Equation 3-11 (Schroeder, et al., 1994)

$$R_{soi} = 711.38DD_i[(H_i \times \sin|LAT| \times sinSD_i)(sinH_i \times cos|LAT| \times cosSD_i)]$$

Equation 3-12 (Schroeder, et al., 1994)

$$DD_i = 1 + \{0.0335sin[0.0172(J_i + 88.2)]\}$$

Equation 3-13 (Schroeder, et al., 1994)

$$SD_i = 0.4102sin[0.0172(J_i - 80.25)]$$

Equation 3-14 (Schroeder, et al., 1994)

$$H_i = arc\ cos[(-tan|LAT|)(tan\ SD_i)]$$

Equation 3-15 (Schroeder, et al., 1994)

Where,

- E_{oi} = Potential evaporation on day i (mm)
- LE_i = Energy available on day i for potential evaporation
- L_v = Latent heat of vaporization for evaporation water (langleys/mm)
- T_{ci} = mean air temperature on day i (˚C)
- $PENR_i$ = Radiative component of potential evaporation on day i (langleys)
- $PENA_i$ = Aerodynamic component of the potential evaporation on day i (langleys)
- Δ_i = The saturation vapour pressure slope curve at mean air temperature on day i (mm/˚C)
- γ = Wet and dry bulb psychrometer equation constant – assumed to be 0.68 mbar/˚C by HELP 4.0
- u = wind speed at a height of 2 metres – assumed to be annual wind speed by HELP 4.0 (km/h)
- e_{oi} = Saturation vapour pressure, on day i, at mean air temperature (mbar)
- e_{ai} = Mean vapour pressure, on day i, of the atmosphere (mbar)
- RH = quarterly average relative humidity on days without rain and equal to one on days with rain.
- R_{ni} = net solar radiation received by the surface on day i (langleys)
- α = albedo (reflectivity coefficient of the surface) – HELP 4.0 uses a value of 0.23 if there is no snow present.
- R_{si} = global horizontal radiation on day i (langleys)
- R_{bi} = long-wave radiation flux from soil on day i (langleys)
- R_{boi} = maximum outgoing long-wave radiation on day i (langleys) – assuming a clear day
- R_{soi} = maximum potential global solar radiation on day i (langleys)

- a_i and b_i = constants that are dependent on humidity on day i (unitless). For RH < 50 %, $a_i = 1.2$ and $b_i = 0.2$. For 50% <= RH < 75 %, $a_i = 1.1$ and $b_i = 0.1$. For RH >= 75 %, $a_i = 1.0$ and $a_i = 0$
- J_i = The Julian date for day i when in the northern hemisphere and the Julian date minus 182.5 when in the southern hemisphere
- LAT = Latitude of location (radians)

HELP 4.0 uses an albedo (α) value of 0.23 – this value falls within the range of the albedo for grasslands (Bralower & Bice, 2024). Therefore, the recorded A-pan evaporation readings were converted to "false grassland" readings by applying the monthly factors presented in Midgley et al. (1994). A table of the conversion is presented in **Appendix B**.

The latitude of location input proved to be a challenge for this research. South Africa stretches from -22˚ to -35˚ latitude and is therefore out of the bounds of HELP 4.0, which can only accept a latitude input that is between-14.32˚ to 71.25˚. To use HELP 4.0, the latitude where the landfill is located was changed to a positive value for input. The latitude value only affects HELP 4.0's calculation of the evaporation through the landfill's surface; outside of frozen soil conditions, the only times that latitude is used in the "HELP Model Engineering Documentation" (1994), which details the computation procedures of the HELP model, is in **Equation 3-12** and **Equation 3-15**. The HELP model considers a soil to have entered frozen soil conditions when the average temperature over the previous 30 days is less than 0˚C (Schroeder, et al., 1994). For Cell A, the temperature never drops to less than 0˚C; thus, it is considered never to have frozen soil conditions. Therefore, the latitude input's sign change was insignificant due to the daily solar radiation (R_{si}) being manually calculated; the manual calculation counter-acted the sign change by not subtracting 182.5 from the Julian date (ji) in **Equation 3-13** and **Equation 3-14** (see ji's definition above).

To access and confirm the accuracy of the solar radiation manual calculations, and hence the latitude input modification, the computed average daily R_{si} was compared to the average daily R_{si} from Global Solar Atlas, a web-based solar radiation, air temperature, and PV power simulation model developed by SolarGIS on behalf of the "World Bank Group" and the "International Finance Corporation". Global Solar Atlas calculates solar resource parameters, such as R_{si}, using data inputs obtained from geostationary satellites and meteorological models (The World Bank Group, 2023). When comparing the computed average daily R_{si} to the average daily R_{si} from the Global Solar Atlas, the percentage difference was found to be 2.78 %.

3.4 Predicting Leachate Evaporation

The cumulative predicted leachate evaporation was computed using the derived method presented in this section. The predicted leachate evaporation was then compared to the cumulative observed leachate evaporation that was recorded over the same period that the predicted leachate was computed. Over the recorded 968 days, the observed evaporation had 66 non-consecutive days missing due to errors in recording, public holidays, and extreme weather events – this amounts to a reliability of 90.5 %. The days on which records had been missing were excluded from both the cumulative observed and predicted evaporation. The comparison between the observed and predicted leachate evaporation was evaluated by graphical comparison, as well as through the use of the coefficient of determination (r^2).

3.4.1 Derived Method for Predicting Leachate Evaporation

This method uses water evaporation typically recorded at a landfill, or from a nearby weather station, and the salinity of the leachate at that landfill in order to predict leachate evaporation. For this research, water evaporation was measured at the landfill. Ritchie (1972), as cited in Schroeder et al. (1994) proposed **Equation 2-17** to calculate evaporation. When the water evaporation is known, the energy available for evaporation (LE) required for **Equation 2-17** can be calculated using **Equation 3-1** by multiplying the observed water evaporation by the latent heat of vaporization of water. The latent heat of vaporization of water is presented in **Equation 3-16**.

$$L_v = 59.7 - 0.0564T_{ci}$$

Where,

- T_{ci} = Mean air temperature on day i (˚C)

Equation 3-16 (Schroeder, et al., 1994)

Valderrama et al. (2015) proposed **Equation 2-16** to determine the latent heat of vaporisation of a saline solution, based on its salinity and the ambient temperature. **Equation 2-17** and **Equation 2-16** were used to develop this research's equation for predicting leachate evaporation, presented as **Equation 3-17**.

$$E_{oi} = \frac{41966 \times LE_i}{[a_1 + a_2T_i + a_3{T_i}^2 + a_4{T_i}^3 + a_5{T_i}^4] \times \left(1 - \frac{S}{1000}\right)}$$

Equation 3-17

Where,

- E_{oi} = Potential evaporation (mm) on day i (mm)
- LE_i = Energy available for evaporation for day i (mm)
- T_i = Temperature on day i (˚C)
- S = Salinity (g/kg)
- a_1 = constant = 2.501×10^6
- a_2 = constant = -2.369×10^3
- a_3 = constant = 2.678×10^{-1}
- a_4 = constant = -8.103×10^{-3}
- a_5 = constant = -2.079×10^{-5}

Four of the nine leachate samples, discussed in **Section 3.2.3**, have f-values that are close to one – these samples have f-values that range between 0.974 and 1.132. For these samples, it is assumed that the difference between TDS and salinity (S) is negligible. Thus, these samples were used to predict the leachate evaporation over the analysis period using **Equation 3-17**. The equation given by Valderrama et al. (2015) is only applicable to solutions with salinities between 0 g/kg and 120 g/kg. The average and median TDS for the four leachate samples used are 129.95 g/kg and 130.31 g/kg, respectively; thus, the results of the predicted leachate evaporation may be negatively affected. The average TDS was used to compute the predicted leachate evaporation.

4. RESULTS AND DISCUSSIONS

4.1 Introduction

Amongst the objectives of this research was the analysis of the suitability of the Hydrologic Evaluation of Landfill Performance (HELP) model and the derived leachate evaporation method in predicting leachate discharge and leachate evaporation for the purpose of water balance modelling in order to meet South African regulations on leachate dam design and sizing. This was achieved by comparing the leachate discharge and leachate evaporation computed by the model and method with the leachate discharge and leachate evaporation recorded at an existing landfill over more than 3 years and 2 years, respectively. In this chapter, the results of these comparisons are presented and discussed. Details of the methodology are presented in **Chapter 3**. The computed data of the model and method are presented in **Appendix C**.

4.2 Predicting Leachate Discharge

Figure 4-1 presents the observed monthly precipitation and leachate discharge depth over the period of analysis. The observed monthly precipitation was computed by summing the daily precipitation within a month, excluding days when leachate discharge was not recorded, as discussed in **Section 3.3**. The observed monthly leachate discharge depth was computed by summing the daily leachate discharge depths within a month. The observed leachate discharge depth (mm/day) was calculated from the observed leachate discharge (m^3/d) using **Equation 4-1**.

$$O_i = \frac{1000\ \times Q_i}{LA}$$

Equation 4-1

Where,

- O_i = Observed leachate discharge depth on day i (mm/day)
- Q_i = Observed leachate discharge on day i (m^3/day)
- LA = Landfill Footprint Area (m^2)

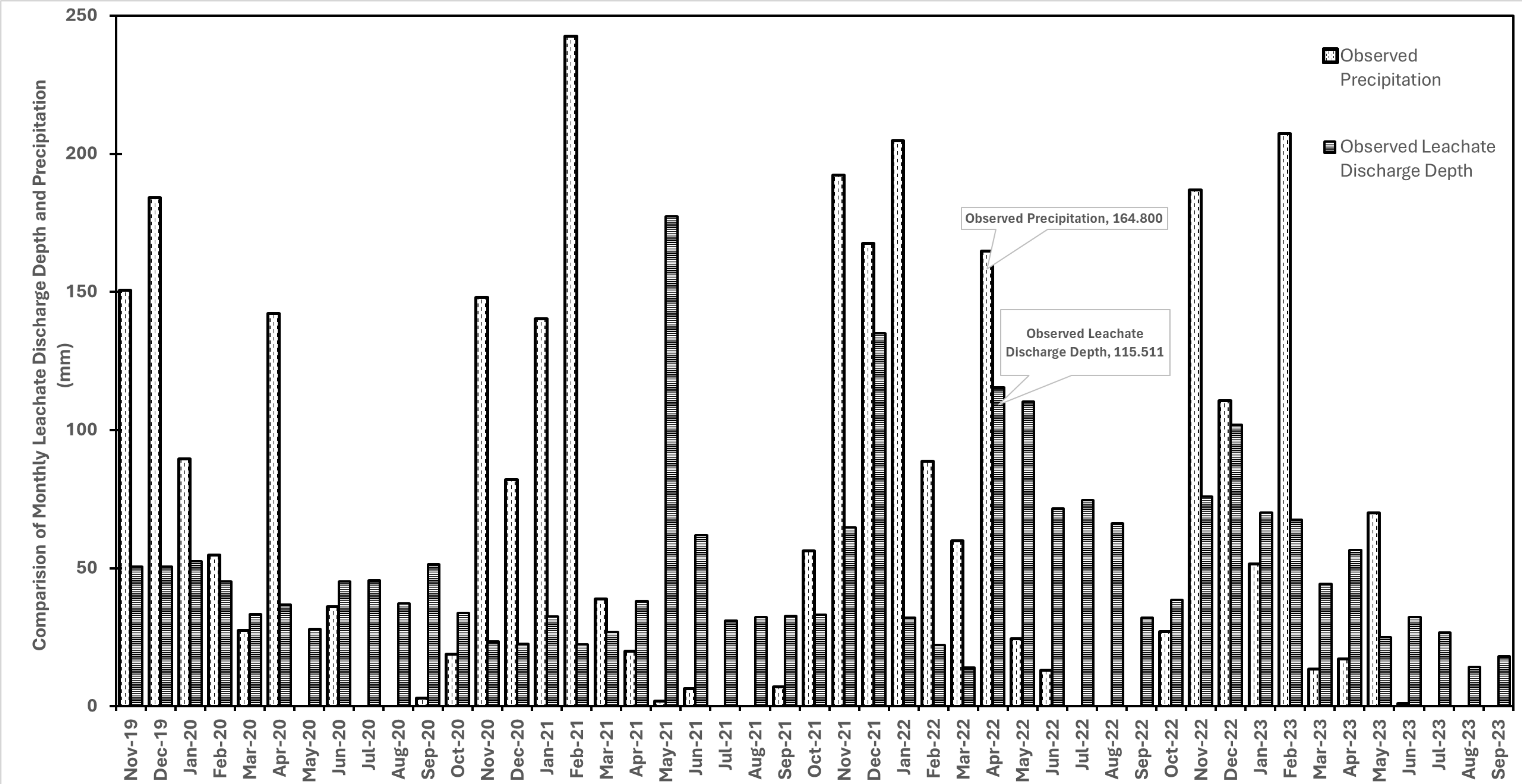


Figure 4-1: Monthly Precipitation and Leachate Discharge Depth Recorded at the Landfill Facility

A visual analysis of **Figure 4-1** shows that the monthly precipitation varies significantly between wet seasons and dry seasons, while the monthly leachate discharge depth is generally constant. Over the analysis period, the average monthly precipitation during the wet and dry seasons was calculated to be 110.6 mm and 21.1 mm, respectively. The average monthly leachate discharge depths during the wet and dry seasons were calculated to be 47.5 mm and 52.6 mm. Thus, the average monthly leachate discharge depth is 42.9 % of the average precipitation during the wet season and 2.5 times greater than the average precipitation during the dry season.

Figure 4-2 presents a comparison of the observed leachate discharge depth to what was predicted by the HELP 4.0 software, using the standard waste types found in the software; the figure shows the first seven months of the analysis period. In the analyses presented in the figure, the initial moisture content of the wastes was input as each waste type's field capacity as this is the most likely state of Cell A after six years of operation and exposure to weather.

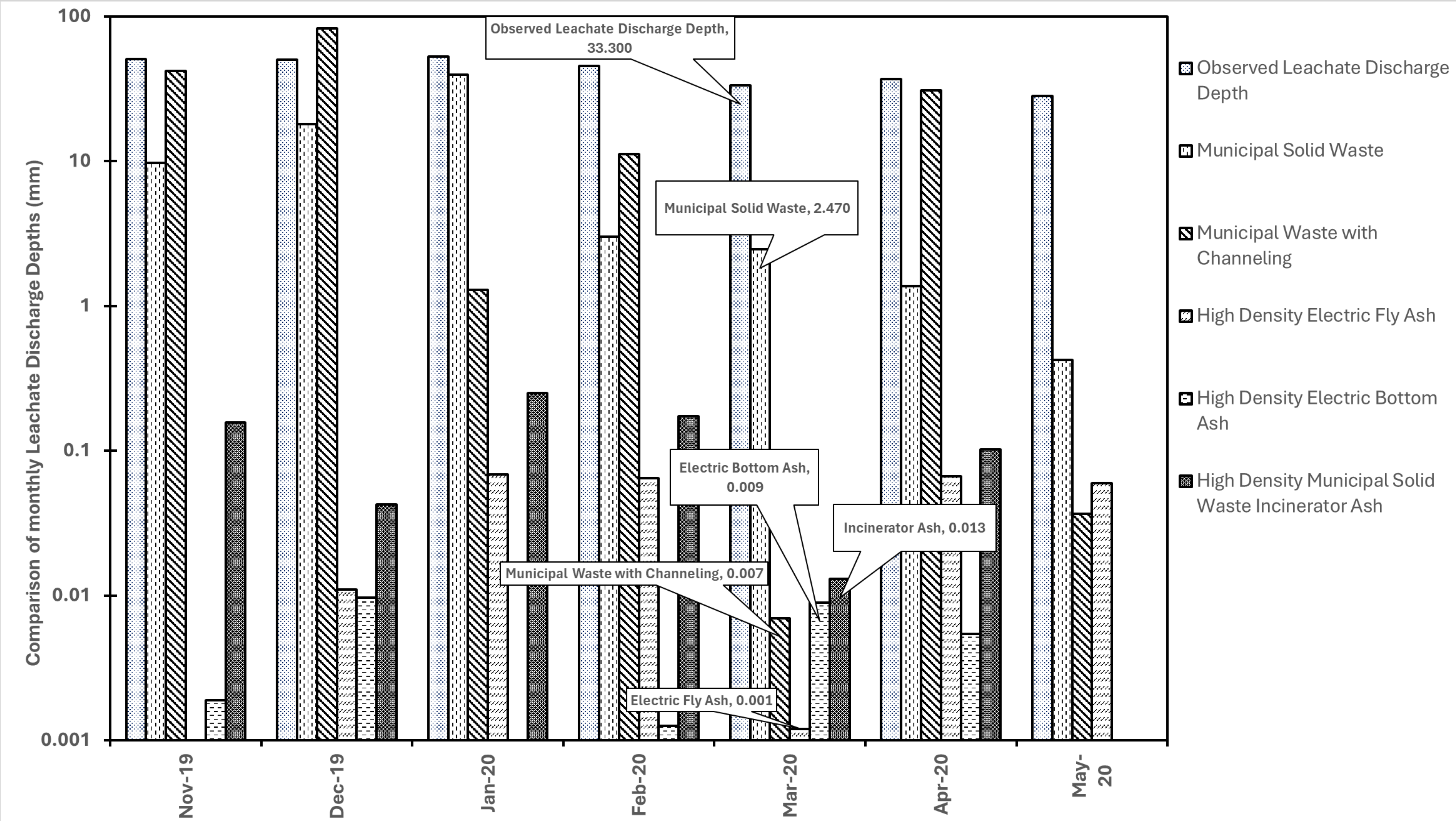


Figure 4-2: Monthly Observed and Predicted Leachate Discharge Depth Over First Seven Months

The monthly average of the observed leachate discharge depth for the first seven months of the analysis period was computed to be 42.433 mm/month. Over the first seven months, the monthly averages of the predicted leachate discharge depths using “municipal waste”, “municipal waste with channelling”, “electric fly ash”, “electric bottom ash”, and “incinerator ash” were 10.627 mm/month, 23.976 mm/month, 0.039 mm/month, 0.039 mm/month, and 0.105 mm/month, respectively. “Municipal waste and “municipal waste with channelling” had the closest averages to the observed leachate discharge depth. Thus, **Figure 4-3** presents a comparison of the cumulative observed leachate discharge depth and the predicted leachate discharge depths from the “municipal waste” and “municipal waste with channelling” standards waste types. The cumulative comparisons are reported because the Rippl mass curve analysis is commonly used to size dams and reservoirs; thus, cumulative comparisons are used to assess the suitability of the HELP model.

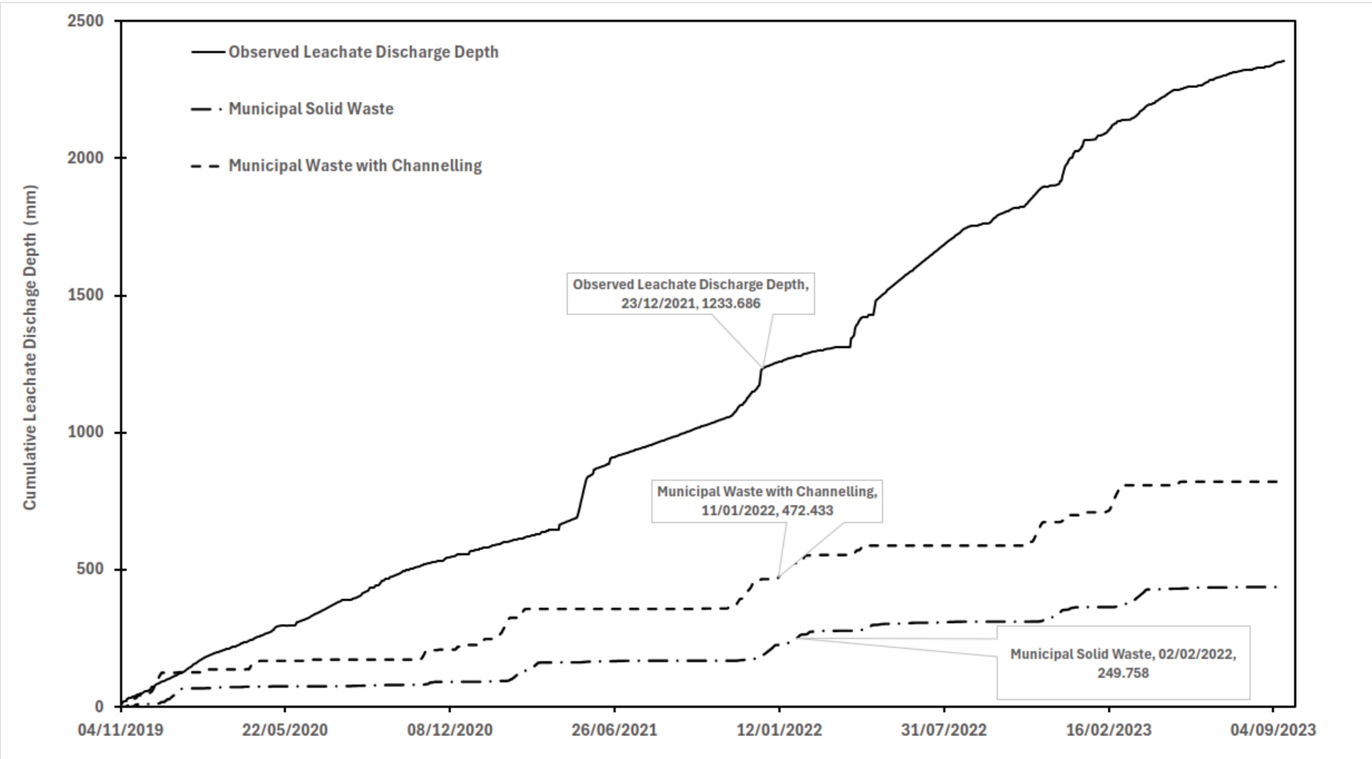


Figure 4-3: Observed Cumulative Leachate Discharge Depth Compared to the Predicted Cumulative Leachate Discharge Depths of Municipal Waste and Municipal Waste with Channelling

A visual analysis of **Figure 4-3** shows that "municipal waste" and "municipal waste with channelling" underestimate the leachate discharge depth. However, it is also seen that the two standard waste types have cumulative leachate discharge depth graphs that are similar in shape to the observed cumulative leachate discharge depth graph. The match between the observed and predicted leachate discharge depth was evaluated using the coefficient of determination (r^2), as well as the gradient (b) of the line of best fit along which the coefficient of determination is based. The range of r^2 falls between zero and one; for a strong correlation between the observed and predicted leachate discharge depths, r^2 must be close to one. For a strong agreement, b must also be close to one. A stronger agreement indicates a greater match between the observed and predicted leachate discharge. Microsoft Excel was used to obtain r^2 and b. The line of best fit, r^2, and b between the observed cumulative discharge depth and the predicted cumulative discharge depth for the two standard waste types are shown **Figure 4-4**.

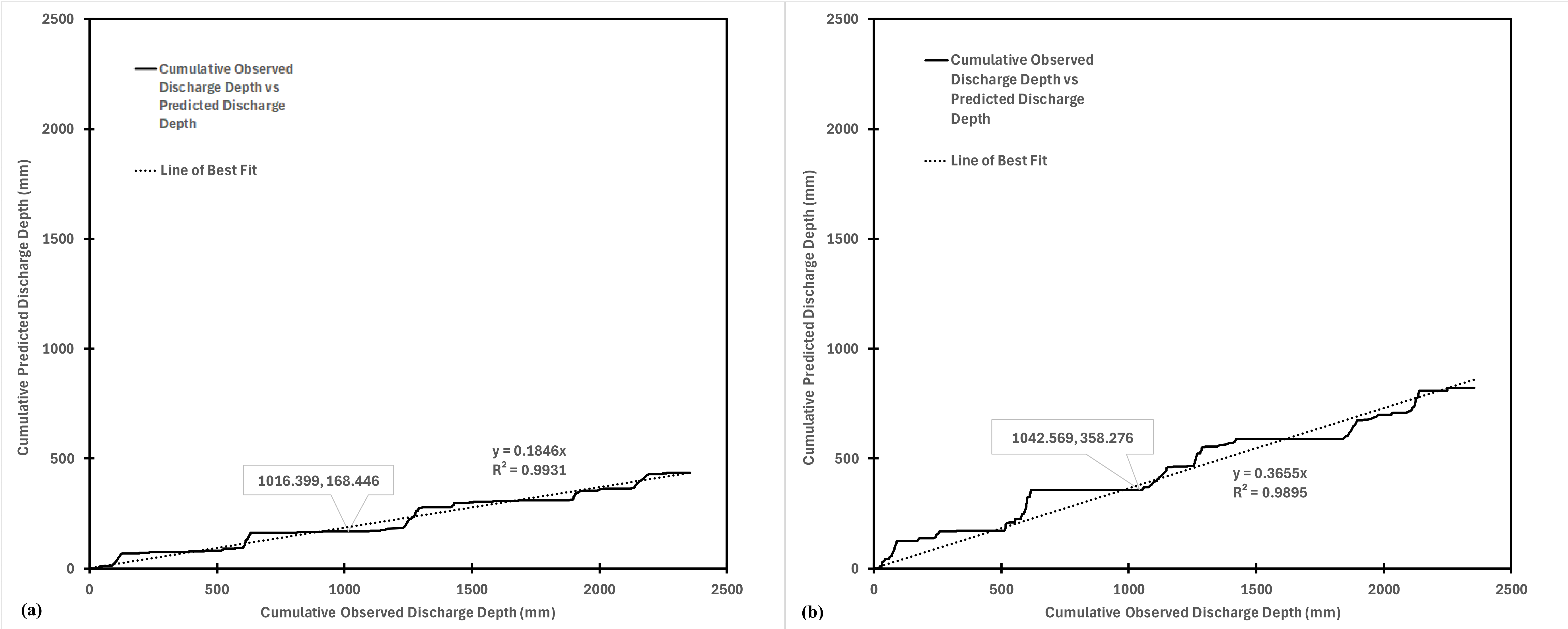


Figure 4-4: Cumulative Observed Discharge Depth Vs Predicted Discharge Depth for: (a) Municipal Waste; (b) Municipal Waste with Channelling

The intercept of the lines of best fit was set to zero for both of the graphs shown in **Figure 4-4**. The graphs show that the two standard waste types compute predicted cumulative discharge depths that have strong correlations with the observed cumulative discharge depths, with r^2 values of 0.993 and 0.990 for “municipal waste” and “municipal waste with channelling”, respectively. “Municipal waste with channelling”, with b = 0.366, has a stronger agreement than “municipal waste”, with b = 0.185; however, both still have a weak agreement and significantly underestimate the leachate discharge depth.

Given its stronger agreement, “municipal waste with channelling” was used to carry out the analysis for determining the K_s that would lead to the closest match between predicted leachate discharge and the observed leachate discharge; all of the standard waste type’s parameters were used, apart from K_s. The minimum K_s that leads to a strong agreement was found to be 5×10^4 cm/s; The line of best fit, r^2, and b between the observed cumulative discharge depth and the predicted cumulative discharge depth is shown in **Figure 4-5.**

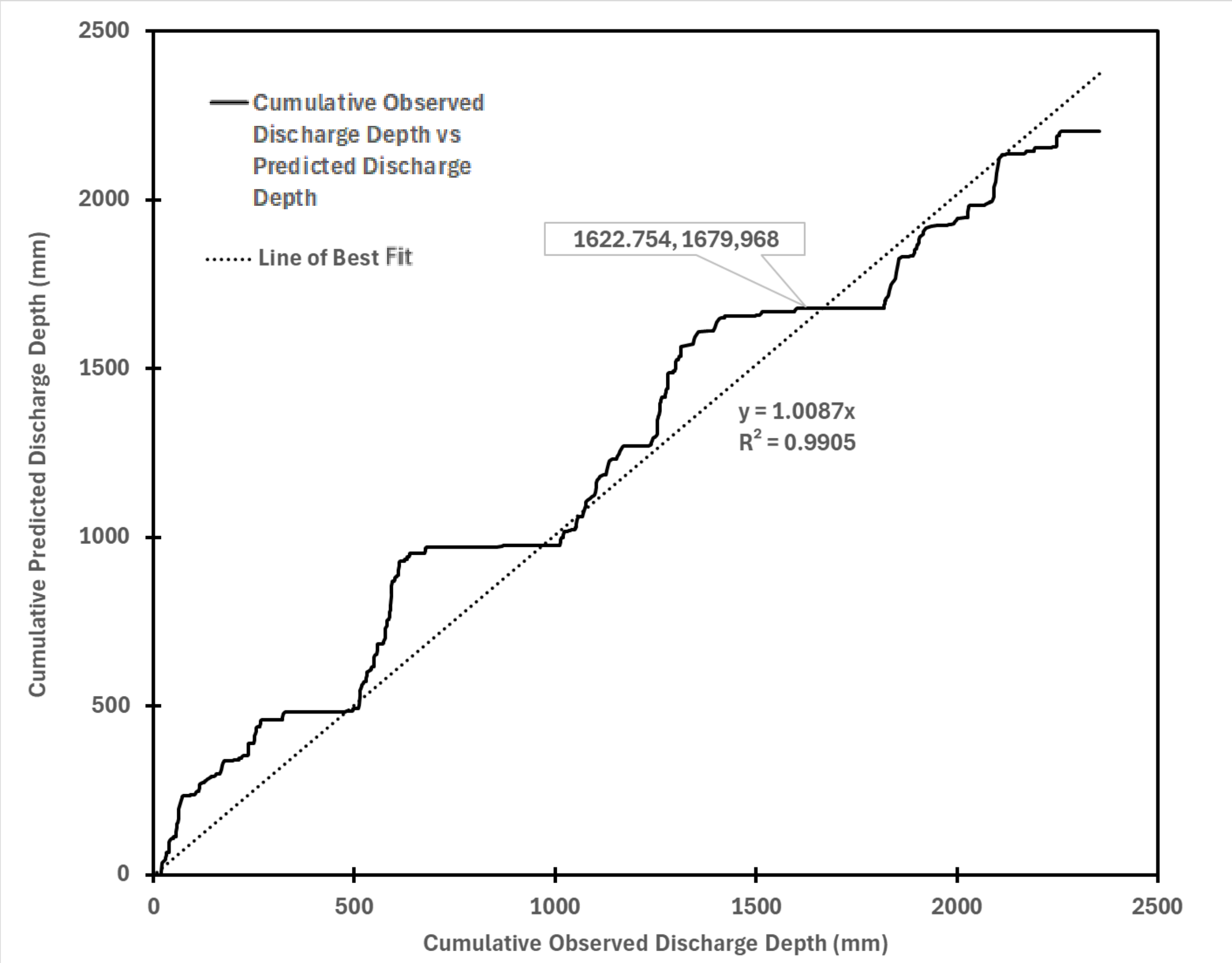


Figure 4-5: Cumulative Observed Discharge Vs Cumulative Predicted Discharge Using Municipal Waste with Channelling with an Adjusted K_s = 5 × 10^4 cm/s

The line of best fit of the graph in **Figure 4-5** has r^2 = 0.991 and b = 1.009. This indicates that there is a strong agreement between the cumulative observed and predicted discharge depths. The minimum K_s required is 10^2 times greater than the highest K_s stated in the literature. **Figure 4-6** presents the predicted monthly leachate discharge depth (when K_s = 5 × 10^4 cm/s) in comparison to the observed monthly leachate discharge depth over the entire analysis period.

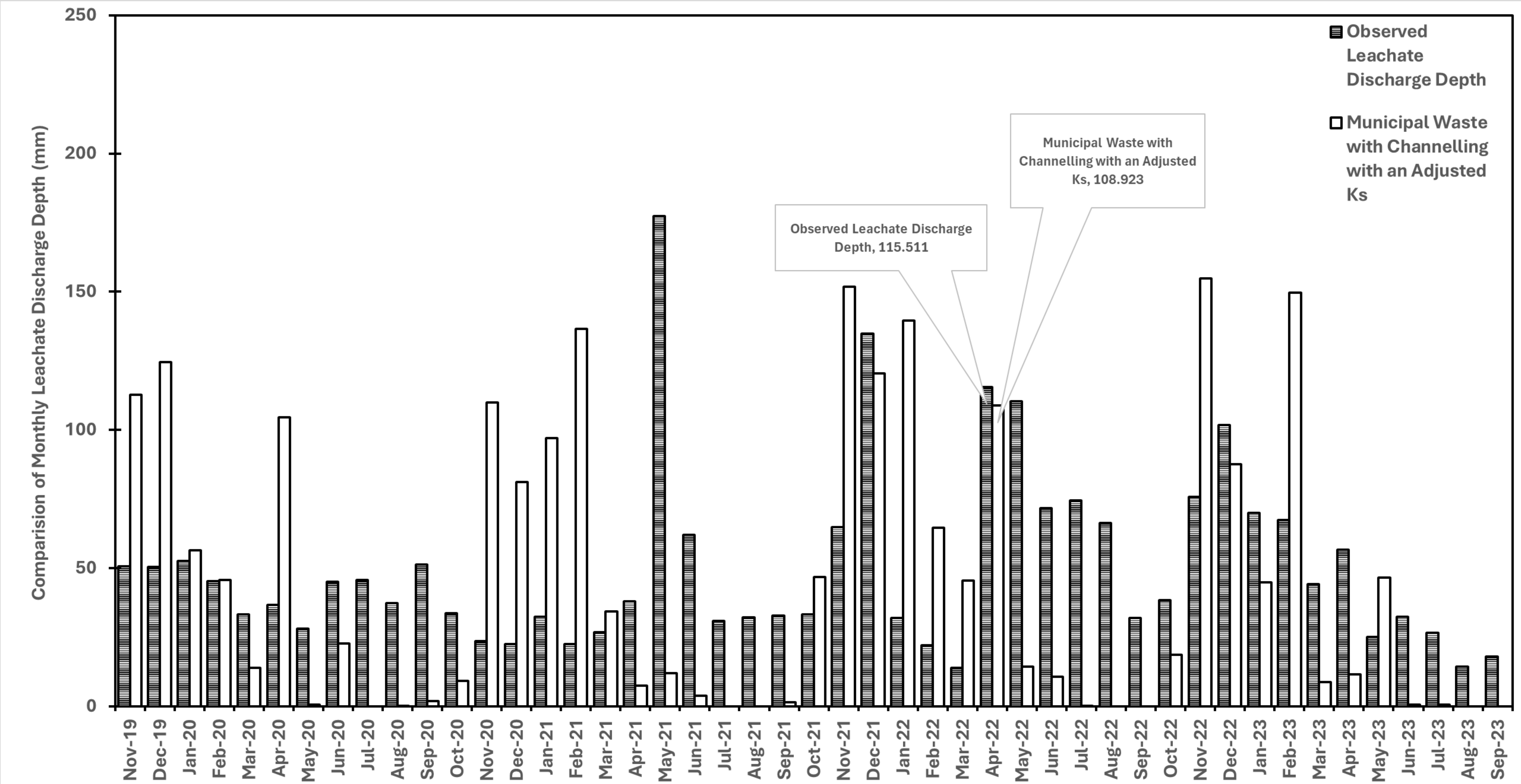


Figure 4-6: Monthly Predicted Leachate Discharge Depth and Observed Leachate Discharge Depth

The average monthly observed and predicted leachate discharge depths were very similar, calculated to be 50.1 mm/month and 46.8 mm/month, respectively. This indicates its suitability for sizing leachate dams. The predicted cumulative leachate discharge depth over the entire analysis period was 2203.6 mm compared to an observed cumulative leachate discharge depth of 2251 mm. This results in a percent error of 6.4 %. This percent error is slightly higher than reported in Fellner and Brunner (2010), which was 5.97%. **Figure 4-7** presents the monthly absolute percent error between the predicted leachate depth and the observed leachate depth for the first seven months of the analysis period.

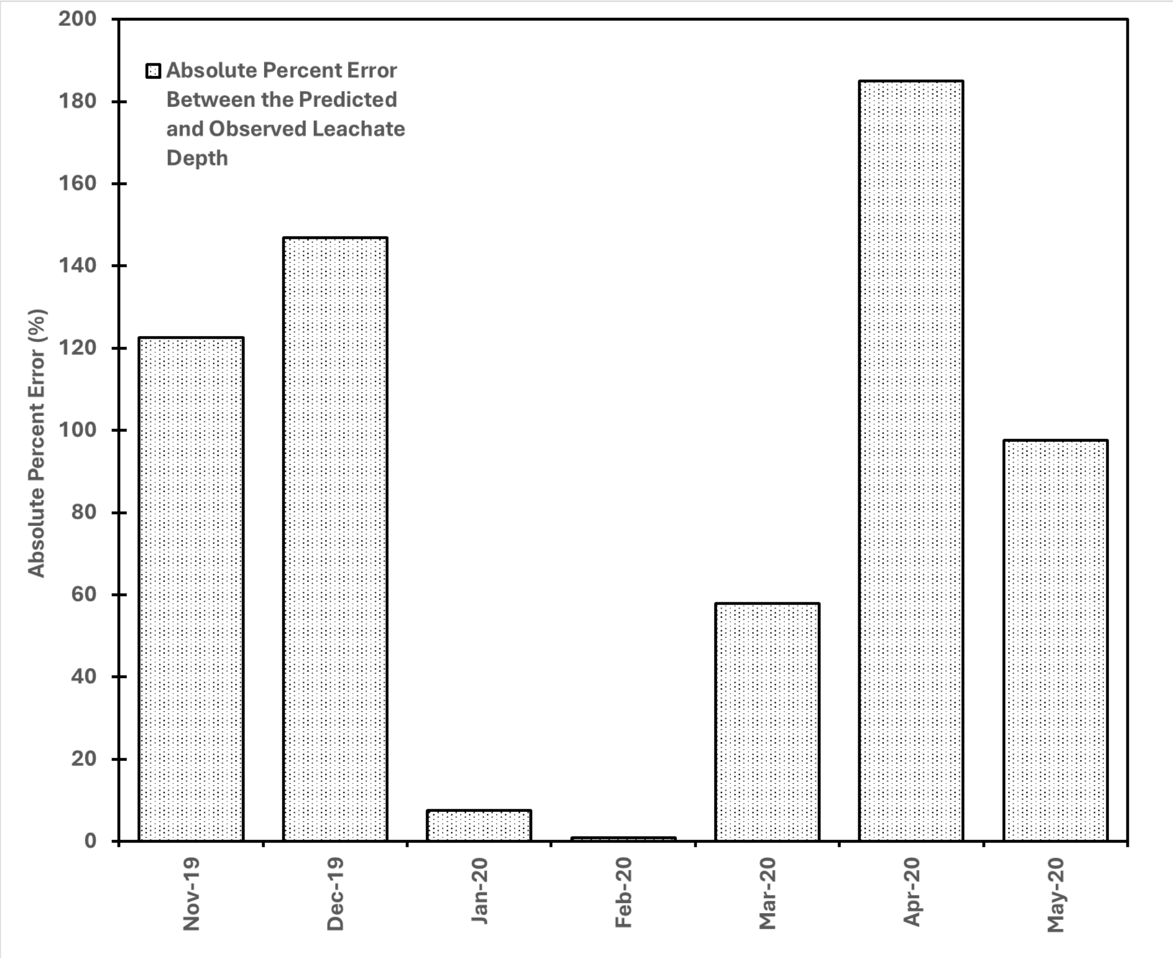
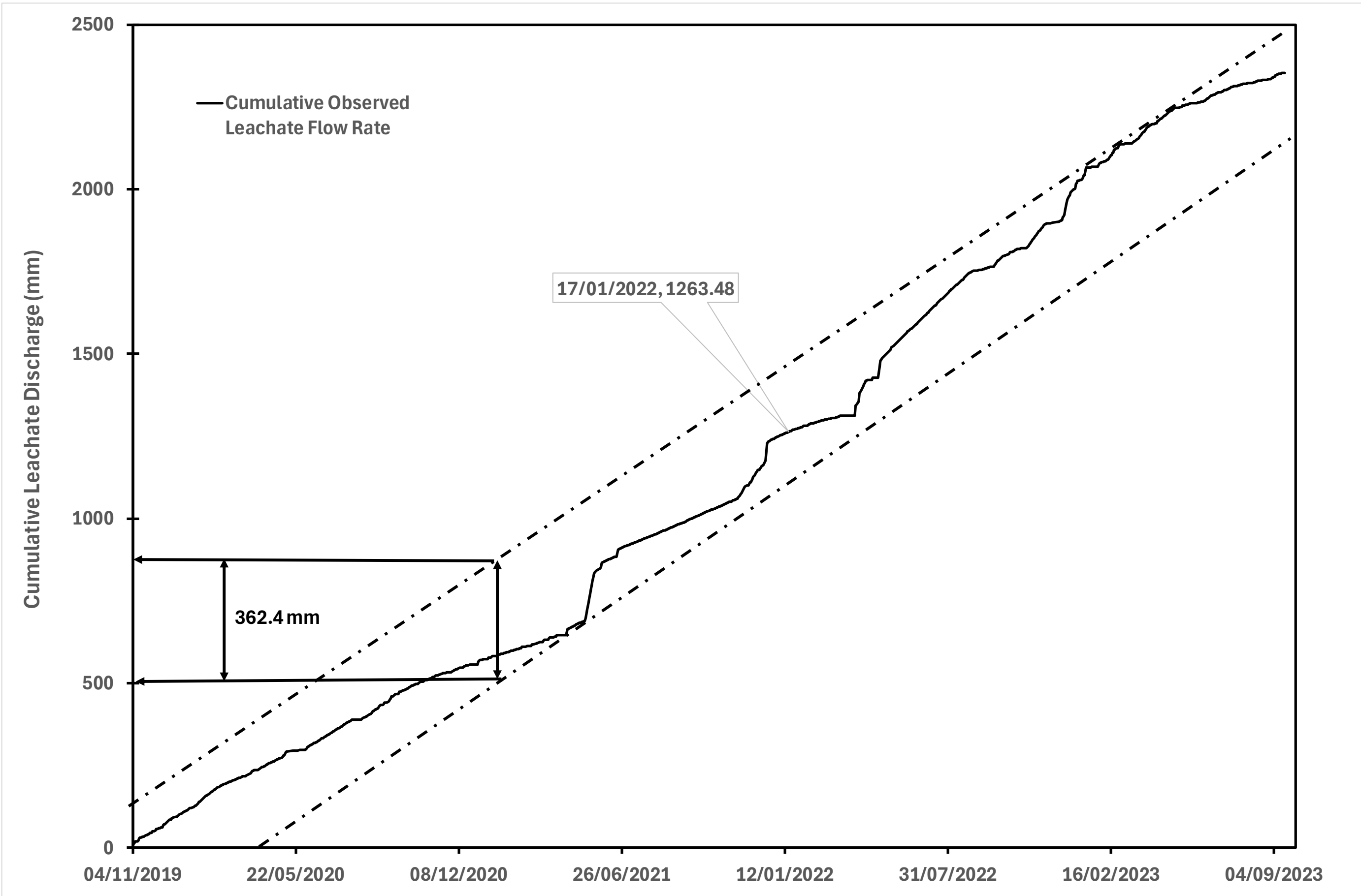
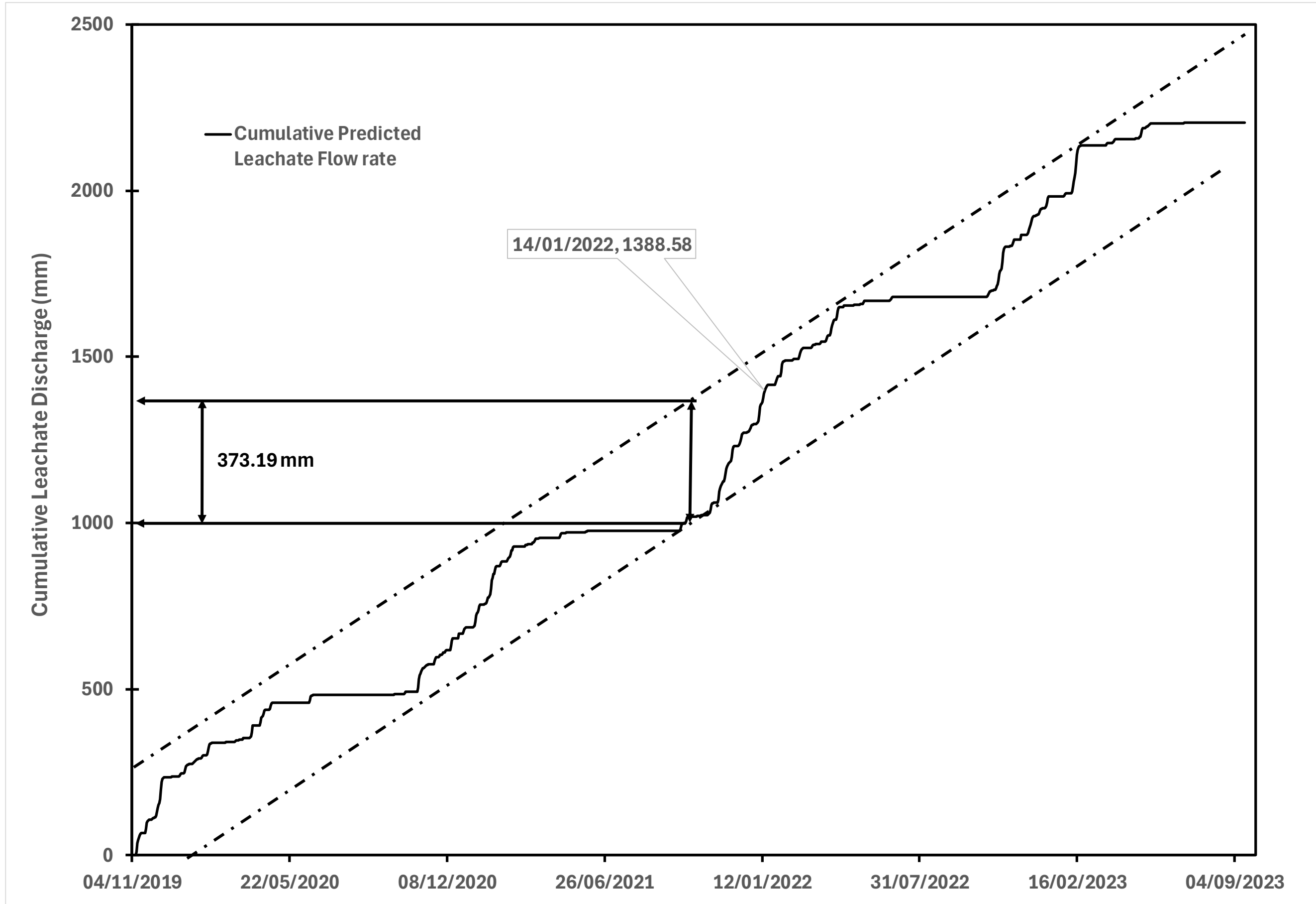


Figure 4-7: Absolute Percent Error Between Predicted and Observed Leachate Discharge.

Figure 4-7 shows that although the average monthly and total cumulative observed and predicted leachate discharges are similar, the month-to-month observed and predicted leachate discharges differ substantially. This indicates that the HELP model may not be suitable for computing monthly leachate discharges. However, given that the purpose of this research is investigate the HELP model's suitability for dam sizing, the Rippl mass curve method was applied. The Rippl mass curve method was used to compare the storage capacity required for the observed and predicted leachate discharge (when $K_s = 5 \times 10^4$ cm/s); this assumes that all other water balance components, such as evaporation and treatment rate, are equal for both. The Rippl mass curve diagrams for the observed leachate discharge depth and the predicted leachate discharge depth are presented in **Figure 4-8**.



(a)



(b)

Figure 4-8: Rippl Mass Curve Diagram for: (a) Observed Leachate Discharge and (b) Predicted Leachate Discharge

The storage depth required for the observed discharge depth was found to be 362.4 mm; this results in a required storage volume of 10 607.6 m^3. The storage depth required for the predicted discharge depth was found to be 373.2 mm; this results in a storage volume of 10 923.3 m^3. Thus, the percent error between the volume required for the observed discharge and the predicted discharge is 2.976 %. Furthermore, the average daily observed and predicted leachate discharge depths, obtained from each graph's line of best fit, are 1.769 mm/day and 1.596 mm/day, respectively. This results in average daily observed and predicted leachate discharge rates of 51.8 m^3/day and 46.7 m^3/day. Thus, the percent error between the observed average daily discharge rate and the predicted average daily discharge rate is 9.780 %. The actual leachate dam storage capacity at the landfill is approximately 99 000 m^3, which caters for multiple cells that have combined footprint of approximately 240 000 m^2. Applying the predicted leachate discharge depth to the combined footprint results in a required storage volume of 89 568 m^3. This indicates that the existing leachate dams have been oversized by 9 432 m^3. It should be noted, however, that this result is based on an analysis period that is too short to compare to the capacity of existing dams since South African regulations require that dams be sized using an analysis period of over 50 years, as discussed in **Section 2.5.3.**

Sensitivity analyses were conducted to determine the influence of the curve number and initial moisture content of the waste on the correlation of predicted discharge depths, computed for "municipal waste with channelling". The concepts of curve number and initial moisture content are discussed in **Section 2.6.1.** The results of the curve number sensitivity analysis are presented in **Table 4-1**.

Table 4-1: Curve Number Sensitivity Analysis using Municipal Waste with Channelling

Curve Number	Line of Best Fit	
	Coefficient of Determination (r^2)	Gradient (b)
75 (curve number used for this report)	0.990	0.366
20	0.990	0.370
40	0.990	0.370
60	0.990	0.369
80	0.990	0.348
95	0.984	0.100

From **Table 4-1**, it can be seen that decreasing the curve number, while keeping all other parameters the same, has a negligible effect on the predicted discharge depth. Although increasing the curve number would lead to an r^2 that is closer to one, it would also lead to a b that further from one, thus leading to a worse agreement. The results of the sensitivity analysis conducted for the initial moisture content of the waste are presented in **Table 4-2**.

Table 4-2: Waste Initial Moisture Content Sensitivity Analysis using Municipal Waste with Channelling

Initial Moisture Content in the Waste	Line of Best Fit	
	Coefficient of Determination (r^2)	Gradient (b)
0.073 (Initial Moisture Content used for this report)	0.990	0.366
0.092	0.922	0.601
0.111	0.871	0.840
0.130	1.096	0.836
0.149	0.812	1.360
0.168	0.795	0.795

It was found that increasing the initial moisture content significantly distorts the relationship between the cumulative observed and predicted discharge depths – **Figure 4-9** This is illustrated when the initial moisture content is 0.130.

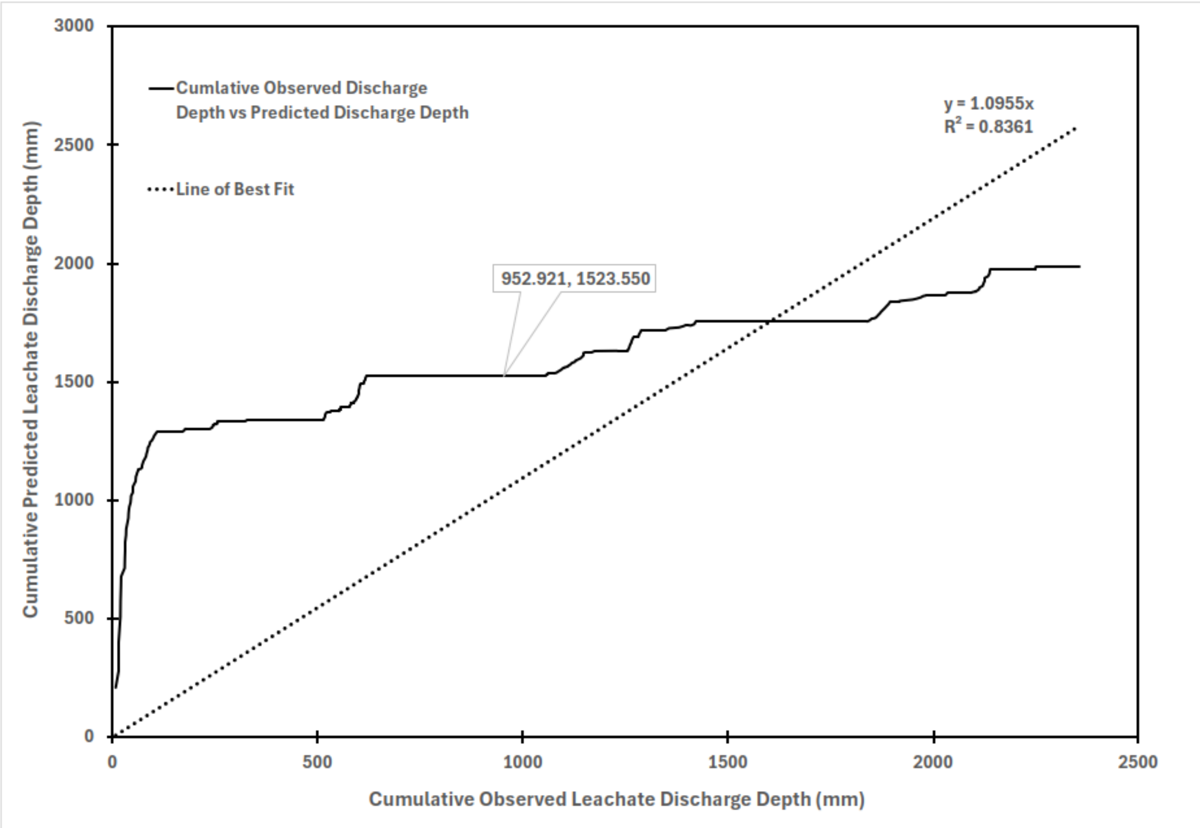


Figure 4-9: Cumulative Observed Discharge Depth Vs Predicted Discharge Depth using Municipal Waste with Channelling with an Adjusted Initial Moisture Content = 0.130

4.3 Predicting Leachate Evaporation

Water evaporation at the landfill facility, along with Dam A's leachate evaporation, TDS, and EC, were recorded and used to analyse the accuracy of the method that was derived in this research for predicting leachate evaporation, as seen in **Section 3.4**. The method was analysed by comparing the predicted leachate evaporation to the observed leachate evaporation from Dam A. **Figure 4-10** presents the observed monthly water and observed leachate evaporation, measured from two separate A-pans.

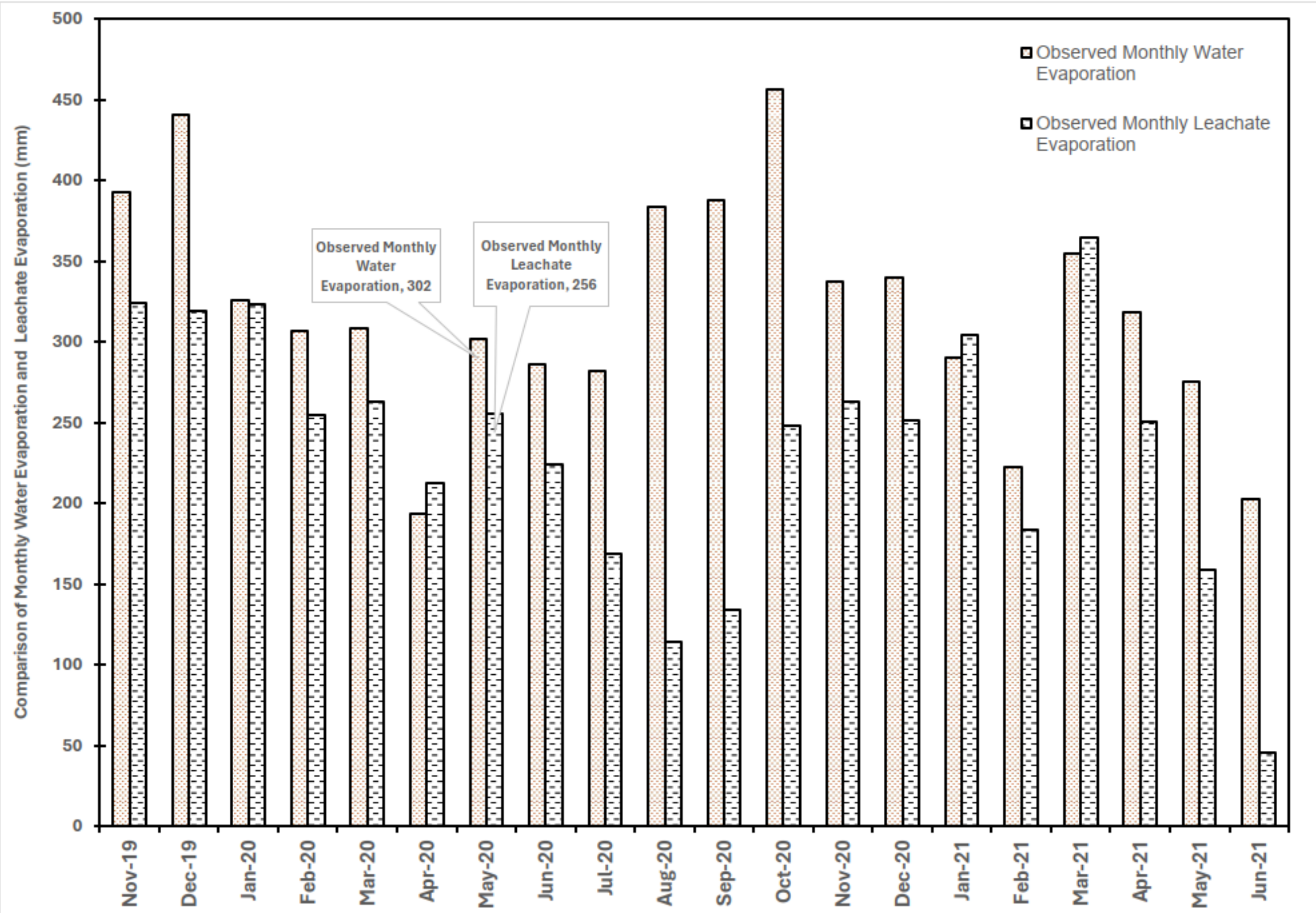


Figure 4-10: Monthly Water and Leachate Evaporation Recorded at the Landfill Facility

Figure 4-10 shows that water evaporation is generally higher than leachate evaporation, although anomalies to this trend are seen in April 2020, January 2021, and March 2022, where leachate evaporation is very similar to water evaporation albeit slightly higher. These anomalies are unusual because leachate generally evaporates at a slower rate than water due to the TDS in the leachate; this leachate in particular as an average EC of 123 000 µS/cm, as presented in **Table 3-1**, compared SANS 241's required EC of less than 12 000 µS/cm for potable water. However, since the anomalies occurred in months that are in the wet season, it is possible that excessive rainfall could have fallen into the evaporation pans and diluted the leachate to a TDS similar to water – the evaporation pans' leachate/water depth is generally kept at around 50 mm; rainfall data shows that the average monthly rainfall in January, March, and April at the landfill is 117.9 mm, 84.3 mm, and 42.3 mm, respectively. The relationship between the cumulative water evaporation and the cumulative leachate evaporation over time is presented in **Figure 4-11.**

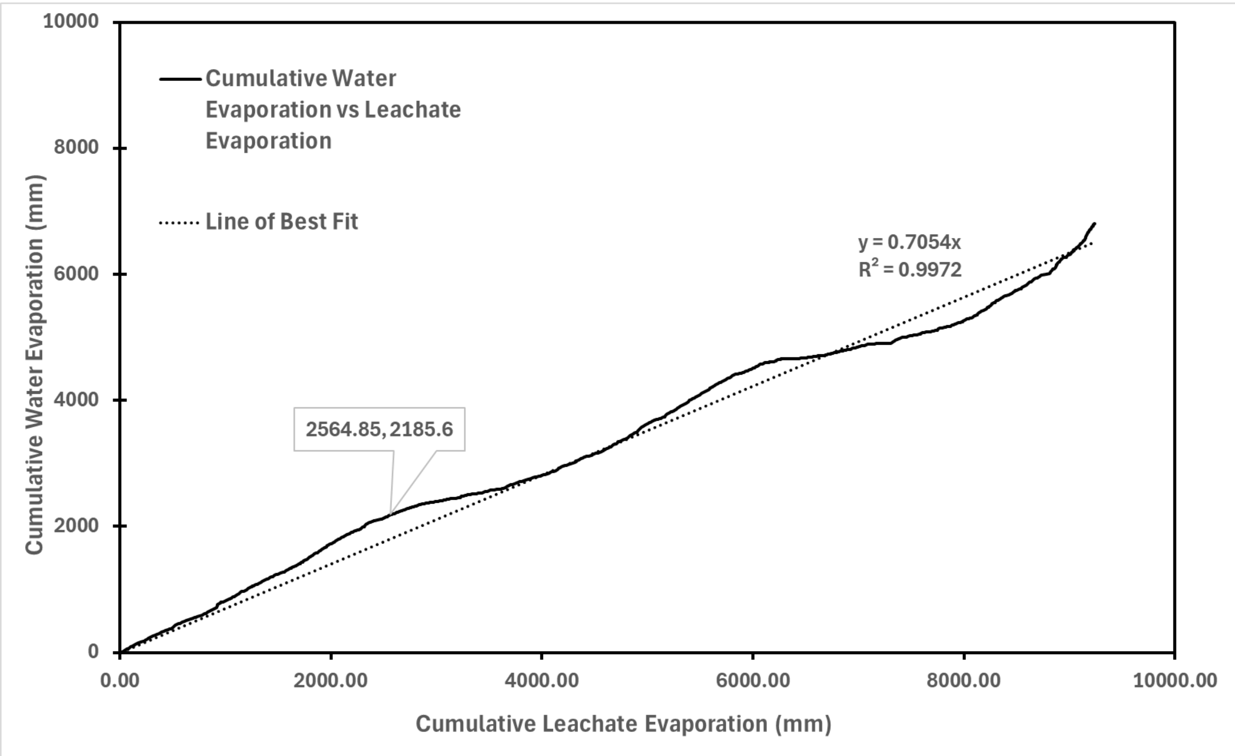


Figure 4-11: Cumulative Water Evaporation vs. Leachate Evaporation

In **Figure 4-11,** the line of best fit has an r^2 that is close to one ($r^2 = 0.997$) – this indicates a very strong correlation between water evaporation and leachate evaporation. The line of best fit of the graph has a function of $f(x) = 0.705x$, which indicates that leachate evaporation is generally equal to 70.5 % of water evaporation – i.e., leachate evaporation is generally 20.9 % less than water evaporation.

In order to assess the suitability of the derived method for predicting leachate evaporation, the cumulative comparisons are investigated because the Rippl mass curve analysis is commonly used to size dams and reservoirs. Thus, **Figure 4-12** presents a comparison of the cumulative observed leachate evaporation to what was predicted.

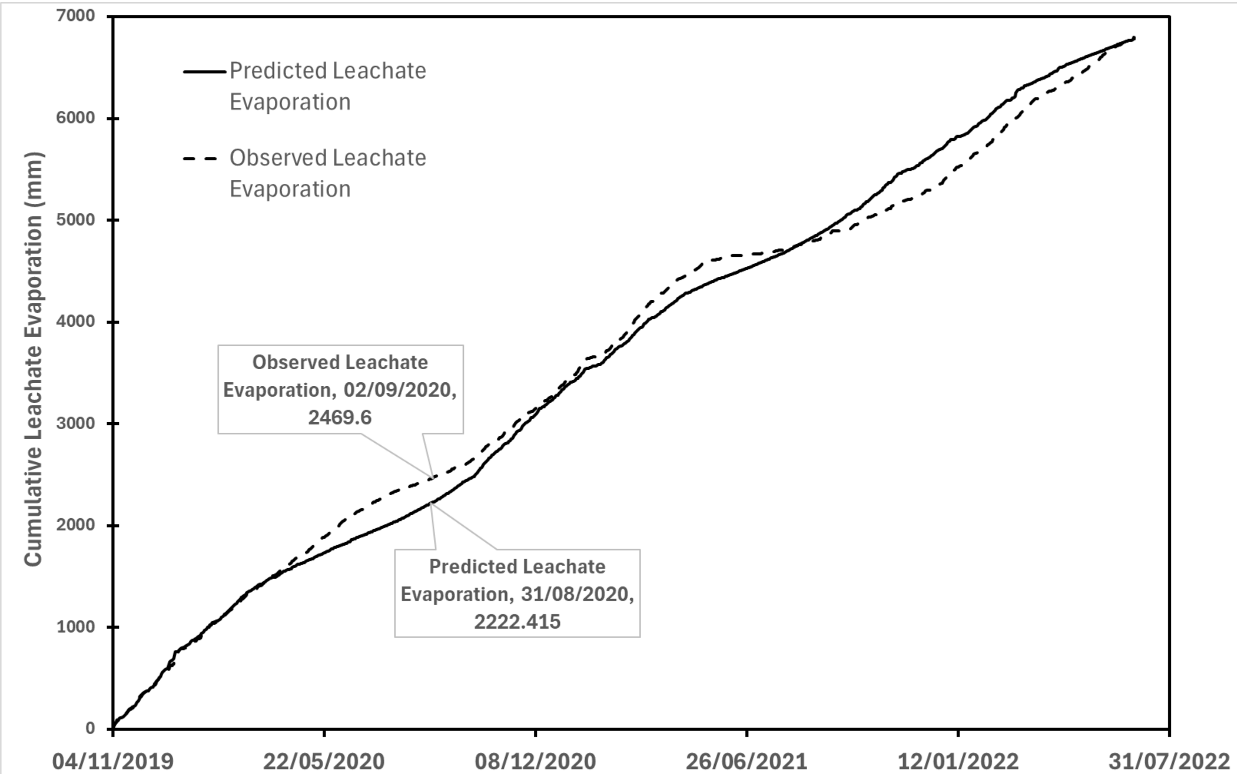


Figure 4-12: Observed Cumulative Leachate Evaporation Compared to the Predicted Cumulative Leachate Evaporation

A visual analysis of **Figure 4-12** shows that the predicted leachate evaporation is very similar to the observed leachate evaporation**.** The line of best fit, r^2, and b between the observed cumulative leachate evaporation and the predicted cumulative leachate evaporation were computed using Microsoft Excel and are shown in **Figure 4-13**.

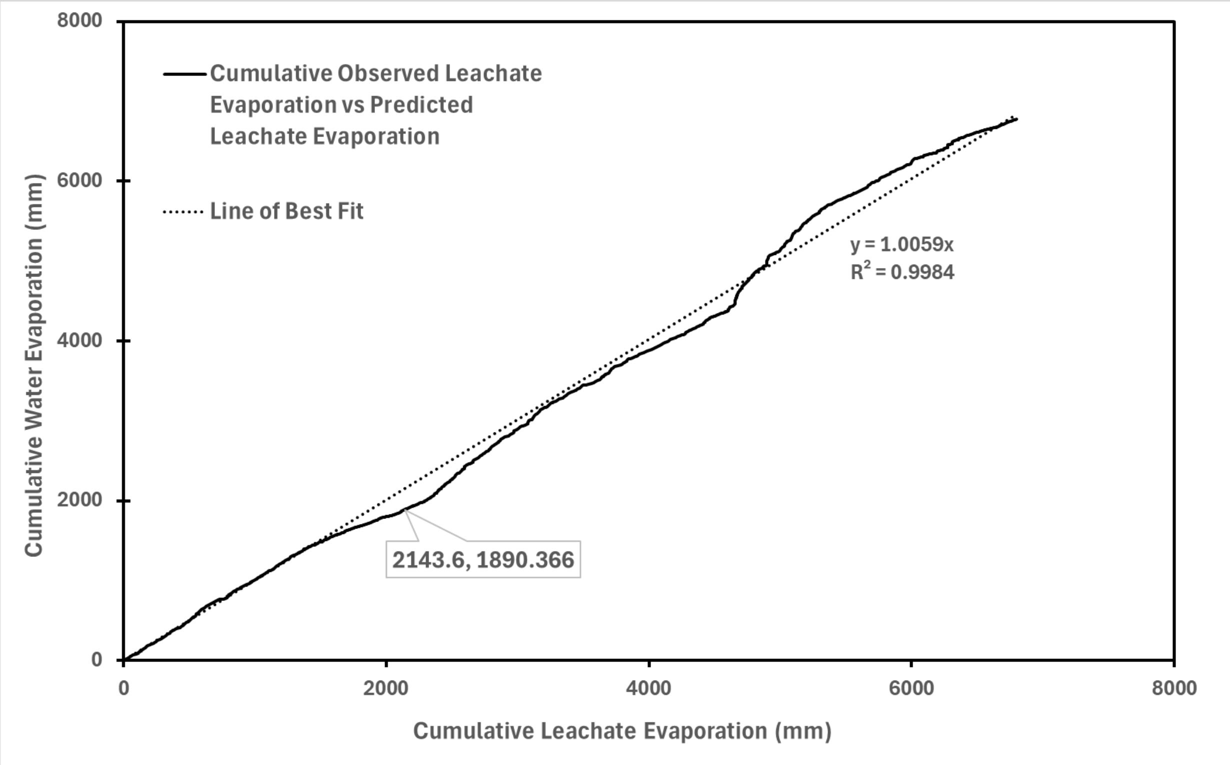


Figure 4-13: Relationship Between the Observed and Predicted Leachate Evaporation Over Time

In **Figure 4-13**, the line of best fit of the graph has an r^2 and a b that are close to one – $r^2 = 0.998$ and $b = 1.006$. This indicates a very strong agreement between the cumulative observed leachate evaporation and the predicted leachate evaporation. **Figure 4-14** presents the monthly predicted monthly leachate evaporation, in comparison to the observed monthly water and leachate evaporation.

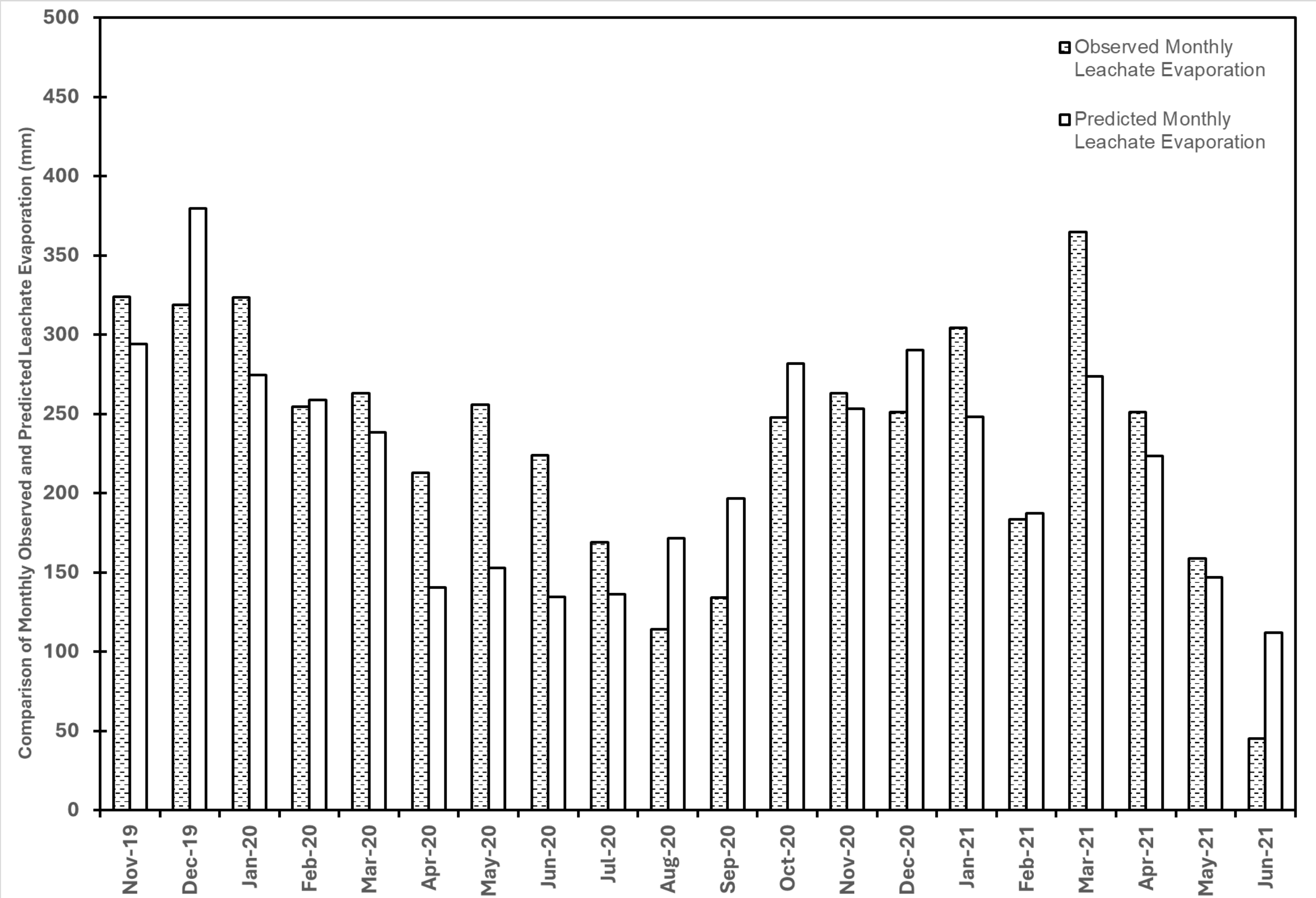


Figure 4-14: Monthly Predicted Leachate Evaporation and Observed Water and Leachate Evaporation

Figure 4-14 shows a general agreement between the predicted and observed leachate evaporation, with a slight tendency of the predicted leachate evaporation to underestimate the leachate evaporation – the percent error between the predicted leachate evaporation and the observed leachate evaporation was calculated to be 7.91 %. The figure shows that the predicted leachate evaporation is more accurate in the wet season, between October and March than in the dry season – the percent error between the predicted leachate evaporation and the observed leachate evaporation during the wet season was calculated to be 4.81 %, as opposed to a percent error of 11.70 % during the dry season.

4.4 Discussion

This section discusses the suitability of predicting leachate discharge and leachate evaporation using the HELP model and derived leachate evaporation method, respectively, for the purpose of leachate dam sizing water balances, based on the comparisons made between predicted and observed leachate discharge and evaporation values for Cell A and Dam A.

4.4.1 Suitability of the HELP Model

The HELP model's predicted leachate discharge tends to strongly correlate to the observed leachate discharge when using standard waste types available in the HELP 4.0 software. However, the model underestimated the leachate discharge when using the standard waste types.

The model's predicted leachate discharge is very sensitive to the waste's saturated hydraulic conductivity. Thus, it was found that increasing the waste's apparent saturated hydraulic conductivity led to the predicted leachate discharge correctly estimating the leachate discharge, while still having a very strong correlation to the observed leachate discharge. The waste's apparent saturated hydraulic conductivity was increased to a value 10^2 times greater than the highest K_s stated in literature, in order to correctly estimate the leachate discharge. An apparent saturated hydraulic conductivity that is so much higher can be explained by the fact that, in the literature, particle sizes larger than the size of the testing apparatus were discarded – larger particles create larger void ratios and flow paths in the waste, which generally means having a higher apparent saturated hydraulic conductivity. As an example, the particle size of the waste tested by Zeiss and Majors (1993), who recorded the highest apparent saturated hydraulic conductivity in the literature, ranged between 2.9 and 15.3 cm – this is much smaller than the particle sizes of the waste in Cell A (which comprises steel drums, metal containers, etc.). Therefore, it is reasonable to conclude that the K_s for Cell A's waste is higher than the K_s reported by Zeiss and Majors (1993). Hydraulic conductivity laboratory tests were not conducted in this research because the results would not have been representative; large objects, as steel drums and metal containers, would be too large for standard laboratory test apparatus. Further studies are required to determine the apparent saturated hydraulic conductivity applicable to landfills in which large pieces of solid waste are disposed.

After adjusting the saturated hydraulic conductivity, The HELP model's suitability in sizing leachate dams was based on the Rippl mass curve method; the percent error between the volume required for the observed leachate discharge and the predicted leachate discharge is 2.976 %. Furthermore, the percent error between the observed and predicted average daily leachate discharge is 9.780 %. Based on these results it can be concluded that, if an appropriate apparent saturated hydraulic conductivity is selected, the HELP model is suitable for use in leachate dam water balance modelling in order to design for South Africa's regulatory requirements – i.e., to ensure that yearly leachate leakage rates through a dam's liner system do not go beyond the maximum leakage rates stated in the "Minimum requirements for waste Disposal By Landfill" (1998) and to ensure that the dam is not probable to spill more than once every 50 years (Department of Water Affairs and Forestry, 2010). The latter requirement may be achieved using the HELP model when the continuous daily rainfall and evaporation/solar radiation inputs span greater than 50 years. However, the period over which the observed leachate, rainfall, and evaporation were recorded for this research was relatively short. Therefore, future studies using longer periods of analysis should be conducted in order to verify this conclusion.

4.4.2 <u>Suitability of the Derived method for Leachate Evaporation</u>

The derived method for predicting leachate evaporation computed values that have a very strong agreement with the observed leachate evaporation. The derived method also correctly estimated the leachate to a reasonable degree; the percent error between the predicted and observed leachate evaporation was found to be 7.91 %. The accuracy of the derived method also increased during the wet season, with the percent error between the predicted and observed leachate evaporation decreasing to 4.81 %. This means that the derived method was found to be more accurate during the months when leakage and spillages are more likely to occur. Furthermore, the leachate used for this research had higher TDS and COD values than typical values reported in literature (Christensen, et al., 2000; Wdowczyk & Szymanska-Pulikowska, 2020; Kulikowska, 2012). Therefore, based on these results, it can be concluded that this research's derived method for predicting leachate evaporation is suitable for use in dam sizing water balance modelling in order to design for South Africa's regulatory requirements. It is noted, however, that future studies using leachates with different chemical and biological compositions should be conducted to verify this conclusion.

5. CONCLUSION

The aim of this research was to provide a framework for sizing leachate dams and treatment infrastructure by reviewing applicable South African regulations and leachate treatment methods; and analysing methods for predicting leachate discharge and leachate evaporation, which are critical components in dam and treatment infrastructure sizing water balances.

A thorough literature review was conducted to determine the regulatory requirements that are applicable to leachate dams and leachate treatment. The South African regulatory requirements state that a leachate dam be designed with a liner system, according to the hazardousness of the waste disposed of in the landfill that is upstream of the dam, so as to prevent excessive leachate leakage into groundwater. Furthermore, leachate dams must be designed with a storage capacity that is large enough so that it is not probable that the leachate dam spills more than once every 50 years. The regulatory requirements also state that leachate must be adequately treated for permanent containment or discharge into the environment. The regulations also provide minimum requirements for treated leachate's quality, as well as its allowable discharge flow and temperature, if it is to be discharged into the environment.

A thorough literature review was conducted to determine the functions, mechanisms, and efficiencies of different treatment processes that may be used to produce leachate effluent that meets the required regulatory requirements. The literature generally recommends the use of the RO process, with a biological treatment and/or chemical treatment step preceding it in order to minimize fouling.

An analysis was conducted to verify whether the Hydrologic Evaluation of Landfill Performance model (HELP model) was suitable for use in sizing leachate dams. This was done by using the model to determine leachate discharge based on climactic parameters recorded at an existing landfill and reasonable landfill waste parameters and then comparing the leachate discharge given by the model (the predicted leachate discharge) to the leachate discharge recorded at the landfill over the same period (the observed leachate discharge). The percent error between the observed average daily leachate discharge rate and the predicted average daily leachate discharge rate is 9.780 %, thus proving this research's hypothesis of 10 % correct. For this reason, it was found that the HELP model is suitable for use in leachate dam sizing, to ensure that leachate dams fulfil South Africa's regulatory requirements on leakage and spillage. However, this conclusion is based on a relatively short period of analysis.

A method for predicting leachate evaporation in a leachate dam was derived in this research; its suitability was analysed by comparing its predicted leachate evaporation to the leachate evaporation recorded at an existing landfill. It was found that the derived method effectively predicted the leachate evaporation over a 2.7 year period when no significant change to the leachate's salinity was observed. The percent error between the predicted and observed leachate evaporation was found to be 7.91 %, thus surpassing this research's hypothesis of 10 %. Furthermore, the method was found to have a percent error of 4.81 % in the wet season (i.e., in the months between October and March at the existing landfill in this report); thus, the method is more accurate in the wet season, the season when leakage and spillages are more likely to occur given the higher volumes of precipitation. For these reasons, the derived method was found to be suitable for use in leachate dam sizing to ensure that leachate dams fulfil South Africa's regulatory requirements on leakage and spillage.

Further research is required using data recorded over longer periods in order to further verify the HELP model's suitability for leachate dam sizing according to South African regulations. The HELP model should also be verified using mono landfills, such as ash and slag disposal facilities – this would mean that the waste would be uniform and consist of smaller particles; samples can be taken to more effectively test the drainage and storage parameters of the waste for input into the HELP model. Further research is also required using leachates with different compositions in order to further verify the derived method for predicting leachate evaporation.

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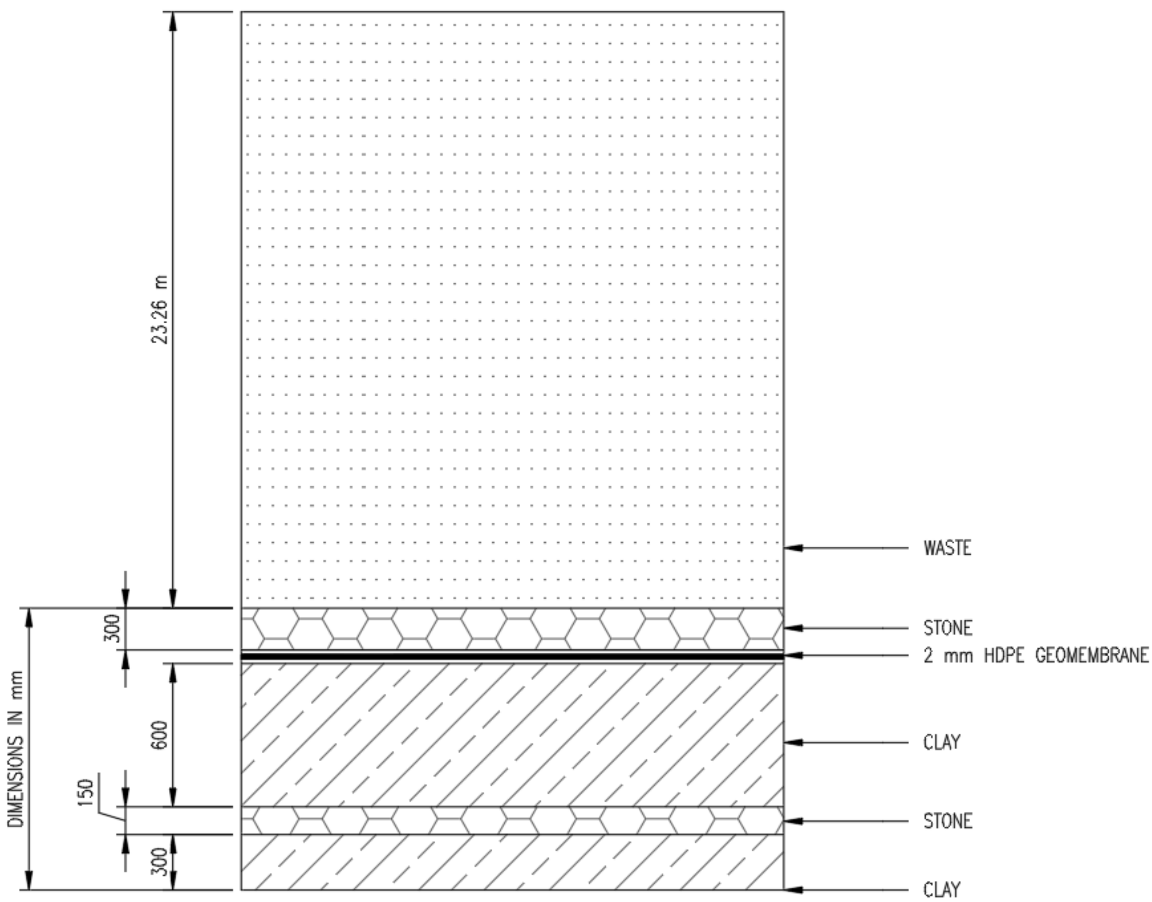
APPENDIX A – HELP MODEL INPUT PARAMETERS

Input	Valid Values	Values Used
General Information		
Latitude (Lat)	-14.32˚ to 71.25˚	Confidential
Longitude (Long)	-180˚ to 180 ˚	Confidential
Years of Simulation	1 to 100 years	4
Landfill Area	> 0 ha	2.927
Percentage of Landfill Area Subject to Runoff	0% to 100%	91.838
Specification of Initial Moisture	Yes/No	Yes
Water/Snow Storage	>= 0 mm	0
Weather		
Daily Precipitation Over Years of Simulation		1 414 days of data
Daily Temperature Over Years of Simulation		Used average daily temperature over each month
Daily Solar Radiation Over Years of Simulation		Manually calculated from 1 414 days of water evaporation data
Average Annual Wind Speed	0 km/h to 32.2 km/h	25
Average Relative Humidity for the First Quarter of a Year	0% to 100%	62.667
Average Relative Humidity for the Second Quarter of a Year	0% to 100%	57.667

Average Relative Humidity for the Third Quarter of a Year	0% to 100%	46.333
Average Relative Humidity for the Fourth Quarter of a Year	0% to 100%	57.333
Start of Growing Season	0 to 367	0
End of Growing Season	0 to 367	1 (Ground is completely bare over historic data)
Maximum Leaf Area Index (LAI)	>= 0	0
Evaporative Zone Depth	0 cm to the depth of a geomembrane	47.498
Curve Number		
Curve Number Method	Dropdown list 1 to 3	User-specified (1)
Initial Curve Number (CN_{II})	> 0	75
Waste and Barrier System Parameters and Profile		
Layer Category	• Final Cover Soil (Topmost Layer) • Vertical Percolation Layer (Soil) • Lateral Drainage Layer (Soil) • Barrier Soil Liner • Waste • Geomembrane Liner • Geosynthetic Drainage Net	See figure below
Layer Description		See figure below
Layer Thickness	> 0 cm	See figure below
Total Porosity	Determined from layer description or 0 vol/vol to 1 vol/vol if manually inputted	See table below

Field Capacity	Determined from layer description or 0 vol/vol to total porosity if manually inputted	See table below
Wilting Point	Determined from layer description or 0 vol/vol to Field Capacity if manually inputted	See table below
Saturated Hydraulic Conductivity	Determined from layer description or > 0 cm/s if manually inputted	See table below
Initial Moisture	>= wilting point and <= total porosity	See table below
Drainage Length	> 0 m	See table below
Drainage Slope	0 % to 50 %	See table below
Leachate Recirculation	0 % to 100 %	0
Recirculation to Layer	To a vertical percolation or lateral drainage layer only	0
Subsurface Inflow	>= 0 mm/year	0
Geomembrane Pinhole Density	#/hectare	0
Geomembrane Installation Defects	#/hectare	0



Layer	Design Parameters
Waste	Varies with standard waste type being analysed. Shown in the table below.
Stone	• Total Porosity (vol/vol) = 0.397 • Field Capacity (vol/vol) = 0.032 • Wilting Point (vol/vol) = 0.013 • Saturated Hydraulic Conductivity (cm/s) = 3×10^{-1} • Drainage Length (m) = 55 • Drainage Slope (%) = 4.25 • Initial Moisture (vol/vol) = 0.032
2 mm HDPE Geomembrane	• Saturated Hydraulic Conductivity (cm/s) = 2.00×10^{-13} • Geomembrane Pinhole Density (#/hectare) = 0

	• Geomembrane Installation Defects (#/hectare) = 0 • Geomembrane Placement Quality = “Good Field Placement”
Clay	• Total Porosity (vol/vol) = 0.451 • Field Capacity (vol/vol) = 0.419 • Wilting Point (vol/vol) = 0.332 • Saturated Hydraulic Conductivity (cm/s) = 6.8×10^{-7}

Waste Types	**Total Porosity (vol/vol)**	**Field Capacity (vol/vol)**	**Wilting Point (vol/vol)**	**Saturated Hydraulic Conductivity (cm/sec)**
Municipal Waste	0.671	0.292	0.077	1.0×10^{-3}
Municipal Waste with Channelling	0.168	0.073	0.019	1.0×10^{-3}
High-Density Electric Plant Coal Fly Ash	0.541	0.187	0.047	5.0×10^{-5}
High-Density Electric Plant Coal Bottom Ash	0.578	0.076	0.025	4.1×10^{-3}
High-Density Municipal Solid Waste Incinerator Fly Ash	0.450	0.116	0.049	1.0×10^{-2}

APPENDIX B – A PAN CONVERSION TO FALSE GRASSLAND

Month	Average Monthly A-Pan Evaporation at the Landfill (mm)	A-Pan to False Grass Land Evaporation Factor (Midgley, et al., 1994)	Average Monthly False Grass Land Evaporation at the Landfill (mm)
January	276.938	0.73	254.938
February	250.526	0.73	245.198
March	294.113	0.67	291.488
April	248.525	0.61	233.525
May	217.586	0.43	217.588
June	194.300	0.24	194.300
July	205.750	0.20	205.750
August	239.000	0.27	239.000
September	309.953	0.41	309.953
October	333.733	0.53	324.400
November	312.538	0.65	292.577
December	276.950	0.73	266.900

APPENDIX C – LEACHATE EVAPORATION AND LEACHATE DISCHARGE COMPUTED DATA

		Leachate Evaporation Computed Data				
Month	Year	Date	Observed Monthly Water Evaporation	Observed Monthly Leachate Evaporation	Predicted Leachate Evaporation	Percentage Error (%)
11	2019	Nov-19	393.1	324.1	294.2019139	-10.16243766
12	2019	Dec-19	440.5	319	379.5199518	15.94644801
1	2020	Jan-20	325.95	323.7	274.6741441	-17.84873346
2	2020	Feb-20	306.8	254.8	258.7797335	1.537884549
3	2020	Mar-20	309	263	238.3753584	-10.33019594
4	2020	Apr-20	193.5	213	140.3792016	-51.73187879
5	2020	May-20	302	256	152.9248218	-67.40251647
6	2020	Jun-20	286	224	134.6602075	-66.34461219
7	2020	Jul-20	282.5	169	136.1157465	-24.15903694
8	2020	Aug-20	384	114	171.6177451	33.57330275
9	2020	Sep-20	387.5	134	196.7232474	31.88400367
10	2020	Oct-20	456.9	247.9	281.9506079	12.07679889
11	2020	Nov-20	337	263	253.1859646	-3.876216209
12	2020	Dec-20	340.3	251.3	290.2559259	13.42123361
1	2021	Jan-21	290.7	304.2	248.2705478	-22.52762269
2	2021	Feb-21	223	183.5	187.4376438	2.100775361
3	2021	Mar-21	354.9	364.9	273.7845136	-33.2800001
4	2021	Apr-21	318.5	251	223.6997841	-12.20395274
5	2021	May-21	275.5	159	146.7612104	-8.339253688
6	2021	Jun-21	202.95	45.45	112.0335383	59.43179095
					Total Average	-7.911710954

	Measured Inputs										Iteration 1
Step	Date	Observed Leachate Flow Rate - Qi	Observed Precipitation	Cumulative Observed Precipitation	Observed Factored Evaporation	Cumulative Observed Factored Evaporation	Observed Precipitation	Observed Factored Evaporation	Observed Leachate Flow Rate - Qi	Cumulative Observed Leachate Flow Rate	Pi
i	(dd/mm/yyyy)	(m3)	(mm)	(mm)	(mm)	(mm)	(m)	(m)	(mm)	(mm)	(mm)
0											
1	04/11/2019	216	0	0	12.025	12.025	0	0.012025	7.379569525	7.379569525	0.0000000
2	05/11/2019	164	0	0	14.3	26.325	0	0.0143	5.603006491	12.98257602	0.0000000
3	06/11/2019	3	0	0	14.95	41.275	0	0.01495	0.102494021	13.08507004	0.0000000
4	07/11/2019	161	0	0	14.95	56.225	0	0.01495	5.50051247	18.58558251	0.0000000
5	08/11/2019	E	0	0	10.725	66.95	0	0.010725	E	18.58558251	0.0000000
6	09/11/2019	25	0	0	11.7	78.65	0	0.0117	0.854116843	19.43969935	0.0000000
7	10/11/2019	18	64.9	64.9	9.685	88.335	0.0649	0.009685	0.614964127	20.05466348	0.0000000
8	11/11/2019	22	0	64.9	7.475	95.81	0	0.007475	0.751622822	20.8062863	0.0000000
9	12/11/2019	247	2	66.9	5.2	101.01	0.002	0.0052	8.438674411	29.24496071	0.0459312
10	13/11/2019	19	9.5	76.4	4.225	105.235	0.0095	0.004225	0.649128801	29.89408951	0.1729634
11	14/11/2019	47	11.75	88.15	1.4625	106.6975	0.01175	0.0014625	1.605729665	31.49982918	0.1325313
12	15/11/2019	9	0	88.15	8.45	115.1475	0	0.00845	0.307482064	31.80731124	0.1684434
13	16/11/2019	22	0	88.15	9.1	124.2475	0	0.0091	0.751622822	32.55893406	0.1451976
14	17/11/2019	15	0	88.15	13	137.2475	0	0.013	0.512470106	33.07140417	0.1642874
15	18/11/2019	89	0	88.15	13.65	150.8975	0	0.01365	3.040655962	36.11206013	0.3051067
16	19/11/2019	E	5.2	93.35	7.605	158.5025	0.0052	0.007605	E	36.11206013	0.6602175
17	20/11/2019	57	0	93.35	12.35	170.8525	0	0.01235	1.947386402	38.05944653	1.1368251
18	21/11/2019	23	40	133.35	0	170.8525	0.04	0	0.785787496	38.84523403	2.0134008
19	22/11/2019	17	1.25	134.6	8.6125	179.465	0.00125	0.0086125	0.580799453	39.42603348	2.7333735
20	23/11/2019	41	0	134.6	6.5	185.965	0	0.0065	1.400751623	40.8267851	1.4066320
21	24/11/2019	75	8.5	143.1	8.125	194.09	0.0085	0.008125	2.56235053	43.38913563	0.3910795
22	25/11/2019	27	0	143.1	11.05	205.14	0	0.01105	0.922446191	44.31158182	0.2393729
23	26/11/2019	E	0	143.1	11.375	216.515	0	0.011375	E	44.31158182	0.2306811
24	27/11/2019	25	0	143.1	10.075	226.59	0	0.010075	0.854116843	45.16569867	0.2913357
25	28/11/2019	110	0	143.1	12.675	239.265	0	0.012675	3.75811411	48.92381278	0.2378073
26	29/11/2019	49	12.65	155.75	14.7225	253.9875	0.01265	0.0147225	1.674069013	50.59788179	0.0661164
27	30/11/2019	0	0	155.75	12.675	266.6625	0	0.012675	0	50.59788179	0.0390113
28	01/12/2019	E	0	155.75	16.79	283.4525	0	0.01679	E	50.59788179	0.0529556
29	02/12/2019	62	0	155.75	12.41	295.8625	0	0.01241	2.118209771	52.71609156	0.1700767
30	03/12/2019	92	0	155.75	12.41	308.2725	0	0.01241	3.143149983	55.85924154	0.3050156
31	04/12/2019	14	20.1	175.85	6.278	314.5505	0.0201	0.006278	0.478305432	56.33754698	0.2254594
32	05/12/2019	15	19.5	195.35	4.745	319.2955	0.0195	0.004745	0.512470106	56.85001708	0.0626833
33	06/12/2019	51	18.75	214.1	5.6575	324.953	0.01875	0.0056575	1.74239836	58.59241544	0.0174274
34	07/12/2019	10	2	216.1	0.73	325.683	0.002	0.00073	0.341646737	58.93406218	0.0048452
35	08/12/2019	41	5.1	221.2	2.628	328.311	0.0051	0.002628	1.400751623	60.3348138	0.0013470
36	09/12/2019	61	73	294.2	16.79	345.101	0.073	0.01679	2.084045097	62.4188589	0.0003744
37	10/12/2019	0	27.5	321.7	10.22	355.321	0.0275	0.01022	0	62.4188589	0.1714978
38	11/12/2019	175	9.2	330.9	2.336	357.657	0.0092	0.002336	5.978817902	68.3976768	0.3551336
39	12/12/2019	85	0	330.9	4.38	362.037	0	0.00438	2.903997267	71.30167407	0.0987361
40	13/12/2019	1	0	330.9	9.49	371.527	0	0.00949	0.034164674	71.33583874	0.0274510
41	14/12/2019	63	0	330.9	11.315	382.842	0	0.011315	2.152374445	73.48821319	0.0076320
42	15/12/2019	55	0	330.9	13.14	395.982	0	0.01314	1.879057055	75.36727024	0.0021218
43	16/12/2019	97	0	330.9	13.505	409.487	0	0.013505	3.313973352	78.68124359	0.0005898
44	17/12/2019	78	0	330.9	14.6	424.087	0	0.0146	2.664844551	81.34608814	0.0001638
45	18/12/2019	36	0	330.9	13.505	437.592	0	0.013505	1.229928254	82.5760164	0.0007606
46	19/12/2019	36	0	330.9	15.695	453.287	0	0.015695	1.229928254	83.80594465	0.2450873
47	20/12/2019	42	0	330.9	16.425	469.712	0	0.016425	1.434916297	85.24086095	0.3918087
48	21/12/2019	20	0	330.9	12.775	482.487	0	0.012775	0.683293475	85.92415442	0.8451472
49	22/12/2019	83	0	330.9	14.235	496.722	0	0.014235	2.835667919	88.75982234	1.3107694
50	23/12/2019	52	7	337.9	6.935	503.657	0.007	0.006935	1.776563034	90.53638538	1.6976495
51	24/12/2019	34	0	337.9	6.57	510.227	0	0.00657	1.161598907	91.69798428	1.9890492
52	25/12/2019	E	0	337.9	0	510.227	0	0	E	91.69798428	2.1954662
53	26/12/2019	E	0	337.9	0	510.227	0	0	E	91.69798428	2.3353251
54	27/12/2019	E	0	337.9	40.88	551.107	0	0.04088	E	91.69798428	2.4266960
55	28/12/2019	99	0	337.9	15.695	566.802	0	0.015695	3.382302699	95.08028698	2.4843195
56	29/12/2019	80	1.85	339.75	8.2855	575.0875	0.00185	0.0082855	2.733173898	97.81346088	2.5191458
57	30/12/2019	50	0	339.75	3.65	578.7375	0	0.00365	1.708233686	99.52169457	2.5388733
58	31/12/2019	45	0	339.75	9.49	588.2275	0	0.00949	1.537410318	101.0591049	2.5487306
59	01/01/2020	E	0	339.75	0	588.2275	0	0	E	101.0591049	2.5521926
60	02/01/2020	E	3.95	343.7	60.9185	649.146	0.00395	0.0609185	E	101.0591049	2.5515366
61	03/01/2020	60	11	354.7	2.555	651.701	0.011	0.002555	2.049880424	103.1089853	2.5482421
62	04/01/2020	68	2.75	357.45	0.9125	652.6135	0.00275	0.0009125	2.323197813	105.4321831	2.5432655
63	05/01/2020	56	0	357.45	4.015	656.6285	0	0.004015	1.913221729	107.3454049	2.5372228
64	06/01/2020	40	0	357.45	6.935	663.5635	0	0.006935	1.366586949	108.7119918	2.5305105
65	07/01/2020	43	0	357.45	10.22	673.7835	0	0.01022	1.46908097	110.1810728	2.5233833
66	08/01/2020	39	0	357.45	9.855	683.6385	0	0.009855	1.332422275	111.513495	2.5160050
67	09/01/2020	37	6.25	363.7	1.2775	684.916	0.00625	0.0012775	1.264092928	112.777588	2.5084808
68	10/01/2020	36	23.5	387.2	1.46	686.376	0.0235	0.00146	1.229928254	114.0075162	2.5008783
69	11/01/2020	42	0	387.2	3.285	689.661	0	0.003285	1.434916297	115.4424325	2.4932410
70	12/01/2020	49	0	387.2	8.395	698.056	0	0.008395	1.674069013	117.1165015	2.5908816
71	13/01/2020	83	1.5	388.7	4.38	702.436	0.0015	0.00438	2.835667919	119.9521695	2.6078890
72	14/01/2020	23	3	391.7	2.19	704.626	0.003	0.00219	0.785787496	120.737957	2.9080596
73	15/01/2020	18	0	391.7	7.3	711.926	0	0.0073	0.614964127	121.3529211	3.1779386
74	16/01/2020	30	0	391.7	10.585	722.511	0	0.010585	1.024940212	122.3778613	2.4267756
75	17/01/2020	34	0	391.7	12.41	734.921	0	0.01241	1.161598907	123.5394602	1.2306525
76	18/01/2020	35	0	391.7	9.49	744.411	0	0.00949	1.19576358	124.7352238	0.7352717
77	19/01/2020	63	8	399.7	4.38	748.791	0.008	0.00438	2.152374445	126.8875982	0.4785617
78	20/01/2020	41	0	399.7	7.665	756.456	0	0.007665	1.400751623	128.2883498	0.2846920
79	21/01/2020	53	0	399.7	6.935	763.391	0	0.006935	1.810727708	130.0990776	0.0791515
80	22/01/2020	79	8.5	408.2	0	763.391	0.0085	0	2.699009224	132.7980868	0.0220060
81	23/01/2020	75	0	408.2	8.03	771.421	0	0.00803	2.56235053	135.3604373	0.0061181
82	24/01/2020	86	8.25	416.45	8.76	780.181	0.00825	0.00876	2.938161941	138.2985992	0.0017009
83	25/01/2020	51	3	419.45	2.19	782.371	0.003	0.00219	1.74239836	140.0409976	0.0130984
84	26/01/2020	54	0	419.45	8.03	790.401	0	0.00803	1.844892381	141.88589	0.0243010
85	27/01/2020	55	0	419.45	12.775	803.176	0	0.012775	1.879057055	143.764947	0.0800349
86	28/01/2020	45	0	419.45	9.49	812.666	0	0.00949	1.537410318	145.3023574	0.0222516
87	29/01/2020	70	0	419.45	9.49	822.156	0	0.00949	2.391527161	147.6938845	0.0061864
88	30/01/2020	60	0	419.45	10.95	833.106	0	0.01095	2.049880424	149.7437649	0.0017199
89	31/01/2020	113	13.75	433.2	4.1975	837.3035	0.01375	0.0041975	3.860608131	153.6043731	0.0004780
90	01/02/2020	63	0	433.2	8.76	846.0635	0	0.00876	2.152374445	155.7567475	0.0001328
91	02/02/2020	35	0	433.2	10.22	856.2835	0	0.01022	1.19576358	156.9525111	0.0000368
92	03/02/2020	32	0	433.2	10.22	866.5035	0	0.01022	1.093269559	158.0457807	0.0644190
93	04/02/2020	68	0	433.2	10.585	877.0885	0	0.010585	2.323197813	160.3689785	0.0585204
94	05/02/2020	74	0	433.2	10.22	887.3085	0	0.01022	2.528185856	162.8971643	0.0376831
95	06/02/2020	62	0	433.2	10.22	897.5285	0	0.01022	2.118209771	165.0153741	0.0104767
96	07/02/2020	61	12.9	446.1	3.212	900.7405	0.0129	0.003212	2.084045097	167.0994192	0.0483160
97	08/02/2020	51	15.5	461.6	1.825	902.5655	0.0155	0.001825	1.74239836	168.8418176	0.0134324
98	09/02/2020	55	18.35	479.95	1.7155	904.281	0.01835	0.0017155	1.879057055	170.7208746	0.0037344
99	10/02/2020	52	0	479.95	2.92	907.201	0	0.00292	1.776563034	172.4974376	0.0010381
100	11/02/2020	62	3.5	483.45	4.38	911.581	0.0035	0.00438	2.118209771	174.6156474	0.0002885
101	12/02/2020	41	0	483.45	5.11	916.691	0	0.00511	1.400751623	176.016399	0.0000801
102	13/02/2020	57	0	483.45	6.205	922.896	0	0.006205	1.947386402	177.9637854	0.0000221
103	14/02/2020	63	0	483.45	8.76	931.656	0	0.00876	2.152374445	180.1161599	0.0373256
104	15/02/2020	41	0	483.45	8.395	940.051	0	0.008395	1.400751623	181.5169115	0.5397237
105	16/02/2020	44	0	483.45	9.125	949.176	0	0.009125	1.503245644	183.0201572	0.5034437
106	17/02/2020	35	0	483.45	9.855	959.031	0	0.009855	1.19576358	184.2159207	0.1652087
107	18/02/2020	23	0	483.45	8.03	967.061	0	0.00803	0.785787496	185.0017082	0.0459321
108	19/02/2020	44	0	483.45	8.395	975.456	0	0.008395	1.503245644	186.5049539	0.012770175
109	20/02/2020	47	0	483.45	7.665	983.121	0	0.007665	1.605729665	188.1106935	0.00355031
110	21/02/2020	33	0	483.45	11.315	994.436	0	0.011315	1.127434233	189.2381278	0.000986952
111	22/02/2020	39	0	483.45	9.125	1003.561	0	0.009125	1.332422275	190.5705501	0.000274273
112	23/02/2020	45	3	486.45	6.935	1010.496	0.003	0.006935	1.537410318	192.1079604	7.61302E-05
113	24/02/2020	26	0	486.45	9.49	1019.986	0	0.00949	0.888281517	192.9962419	2.10414E-05
114	25/02/2020	44	0	486.45	9.125	1029.111	0	0.009125	1.503245644	194.4994875	0.142381421
115	26/02/2020	40	0	486.45	8.76	1037.871	0	0.00876	1.366586949	195.8660745	0.427501288
116	27/02/2020	26	0	486.45	10.22	1048.091	0	0.01022	0.888281517	196.754356	0.437397389
117	28/02/2020	9	1.55	488	7.3365	1055.4275	0.00155	0.0073365	0.307482064	197.0618381	0.292523867
118	29/02/2020	53	0	488	5.84	1061.2675	0	0.00584	1.810727708	198.8725658	0.166560342
119	01/03/2020	22	0	488	9.715	1070.9825	0	0.009715	0.751622822	199.6241886	0.084753332
120	02/03/2020	13	0	488	9.38	1080.3625	0	0.00938	0.444140758	200.0683293	0.337057608
121	03/03/2020	13	0	488	10.385	1090.7475	0	0.010385	0.444140758	200.5124701	0.421561523
122	04/03/2020	63	0	488	10.05	1100.7975	0	0.01005	2.152374445	202.6648446	0.453094661
123	05/03/2020	27	0	488	10.385	1111.1825	0	0.010385	0.922446191	203.5872907	0.306563017
124	06/03/2020	46	0	488	9.38	1120.5625	0	0.00938	1.571574991	205.1588657	0.085232223
125	07/03/2020	16	0	488	8.04	1128.6025	0	0.00804	0.54663478	205.7055005	0.02369661
126	08/03/2020	15	0	488	6.365	1134.9675	0	0.006365	0.512470106	206.2179706	0.006588138
127	09/03/2020	21	0	488	7.705	1142.6725	0	0.007705	0.717458148	206.9354288	0.001831566
128	10/03/2020	33	0	488	8.375	1151.0475	0	0.008375	1.127434233	208.062863	0.000509092
129	11/03/2020	39	0	488	7.705	1158.7525	0	0.007705	1.332422275	209.3952853	0.000141416
130	12/03/2020	4	0	488	7.035	1165.7875	0	0.007035	0.136658695	209.531944	3.91924E-05
131	13/03/2020	58	8	496	2.68	1168.4675	0.008	0.00268	1.981551076	211.513495	1.07717E-05
132	14/03/2020	35	0	496	4.355	1172.8225	0	0.004355	1.19576358	212.7092586	2.87006E-06
133	15/03/2020	2	4	500	4.69	1177.5125	0.004	0.00469	0.068329347	212.777588	6.73192E-07
134	16/03/2020	60	0	500	5.36	1182.8725	0	0.00536	2.049880424	214.8274684	6.875E-08
135	17/03/2020	46	0	500	6.7	1189.5725	0	0.0067	1.571574991	216.3990434	1.93201E-19
136	18/03/2020	15	1.5	501.5	6.365	1195.9375	0.0015	0.006365	0.512470106	216.9115135	1.93201E-19
137	19/03/2020	12	0	501.5	6.7	1202.6375	0	0.0067	0.409976085	217.3214896	1.93201E-19
138	20/03/2020	E	0	501.5	6.03	1208.6675	0	0.00603	E	217.3214896	1.93201E-19
139	21/03/2020	21	0	501.5	8.04	1216.7075	0	0.00804	0.717458148	218.0389477	1.93201E-19
140	22/03/2020	7	10	511.5	5.36	1222.0675	0.01	0.00536	0.239152716	218.2781004	1.93201E-19
141	23/03/2020	E	7	518.5	2.68	1224.7475	0.007	0.00268	E	218.2781004	1.93201E-19
142	24/03/2020	128	4	522.5	1.005	1225.7525	0.004	0.001005	4.373078237	222.6511787	1.93201E-19
143	25/03/2020	E	0	522.5	4.69	1230.4425	0	0.00469	E	222.6511787	1.93201E-19
144	26/03/2020	E	0	522.5	8.04	1238.4825	0	0.00804	E	222.6511787	1.93201E-19
145	27/03/2020	E	3.5	526	4.69	1243.1725	0.0035	0.00469	E	222.6511787	5.79214E-15
146	28/03/2020	134	0	526	4.69	1247.8625	0	0.00469	4.578066279	227.229245	0.076155934
147	29/03/2020	119	0	526	6.365	1254.2275	0	0.006365	4.065596174	231.2948411	0.076671339
148	30/03/2020	27	0	526	7.035	1261.2625	0	0.007035	0.922446191	232.2172873	0.258006871
149	31/03/2020	0	0	526	7.035	1268.2975	0	0.007035	0	232.2172873	0.337948812
150	01/04/2020	83	0	526	7.015	1275.3125	0	0.007015	2.835667919	235.0529552	0.34771149
151	02/04/2020	33	7	533	3.05	1278.3625	0.007	0.00305	1.127434233	236.1803895	0.221216553
152	03/04/2020	0	0.2	533.2	3.477	1281.8395	0.0002	0.003477	0	236.1803895	0.099471684
153	04/04/2020	0	38	571.2	0	1281.8395	0.038	0	0	236.1803895	0.047675336
154	05/04/2020	0	14	585.2	0.61	1282.4495	0.014	0.00061	0	236.1803895	0.013254836
155	06/04/2020	E	0	585.2	2.135	1284.5845	0	0.002135	E	236.1803895	0.022586708
156	07/04/2020	E	0	585.2	3.66	1288.2445	0	0.00366	E	236.1803895	0.03720839
157	08/04/2020	E	0	585.2	7.015	1295.2595	0	0.007015	E	236.1803895	0.010344758
158	09/04/2020	201	0	585.2	6.71	1301.9695	0	0.00671	6.867099419	243.0474889	0.153863385
159	10/04/2020	38	0	585.2	7.015	1308.9845	0	0.007015	1.298257602	244.3457465	0.156907195
160	11/04/2020	14	0	585.2	5.49	1314.4745	0	0.00549	0.478305432	244.8240519	0.043624083
161	12/04/2020	21	0	585.2	6.405	1320.8795	0	0.006405	0.717458148	245.5415101	0.012128484
162	13/04/2020	39	0	585.2	7.32	1328.1995	0	0.00732	1.332422275	246.8739324	0.003371904
163	14/04/2020	40	0	585.2	5.795	1333.9945	0	0.005795	1.366586949	248.2405193	0.000937351
164	15/04/2020	71	32	617.2	0	1333.9945	0.032	0	2.425691835	250.6662111	0.000260483
165	16/04/2020	38	0	617.2	4.88	1338.8745	0	0.00488	1.298257602	251.9644687	7.22961E-05
166	17/04/2020	38	0	617.2	5.795	1344.6695	0	0.005795	1.298257602	253.2627263	1.99754E-05
167	18/04/2020	40	0	617.2	5.185	1349.8545	0	0.005185	1.366586949	254.6293133	0.088065629
168	19/04/2020	36	22	639.2	0	1349.8545	0.022	0	1.229928254	255.8592415	0.039446764
169	20/04/2020	18	0	639.2	3.66	1353.5145	0	0.00366	0.614964127	256.4742057	0.010967078
170	21/04/2020	2	0	639.2	3.66	1357.1745	0	0.00366	0.068329347	256.542535	0.003049003
171	22/04/2020	72	0	639.2	10.065	1367.2395	0	0.010065	2.459856508	259.0023915	0.094357536
172	23/04/2020	12	0	639.2	4.88	1372.1195	0	0.00488	0.409976085	259.4123676	0.02623368
173	24/04/2020	36	0	639.2	3.965	1376.0845	0	0.003965	1.229928254	260.6422959	0.007293508
174	25/04/2020	29	0	639.2	5.49	1381.5745	0	0.00549	0.990775538	261.6330714	0.002027657
175	26/04/2020	69	0	639.2	2.745	1384.3195	0	0.002745	2.357362487	263.9904339	0.000563616
176	27/04/2020	36	16	655.2	6.1	1390.4195	0.016	0.0061	1.229928254	265.2203621	0.000156575
177	28/04/2020	34	13	668.2	0	1390.4195	0.013	0	1.161598907	266.3819611	4.3407E-05
178	29/04/2020	40	0	668.2	1.525	1391.9445	0	0.001525	1.366586949	267.748548	1.19435E-05
179	30/04/2020	35	0	668.2	3.965	1395.9095	0	0.003965	1.19576358	268.9443116	3.19584E-06
180	01/05/2020	31	0	668.2	2.365	1398.2745	0	0.002365	1.059104886	270.0034165	0.058033906
181	02/05/2020	15	0	668.2	3.655	1401.9295	0	0.003655	0.512470106	270.5158866	0.120923441
182	03/05/2020	E	0	668.2	3.87	1405.7995	0	0.00387	E	270.5158866	0.140170052
183	04/05/2020	E	0	668.2	5.16	1410.9595	0	0.00516	E	270.5158866	0.107844646
184	05/05/2020	109	0	668.2	4.945	1415.9045	0	0.004945	3.723949436	274.239836	0.139609721
185	06/05/2020	80	0	668.2	3.655	1419.5595	0	0.003655	2.733173898	276.9730099	0.076271465
186	07/05/2020	79	0	668.2	3.44	1422.9995	0	0.00344	2.699009224	279.6720191	0.02120529
187	08/05/2020	0	0	668.2	3.655	1426.6545	0	0.003655	0	279.6720191	0.005895488
188	09/05/2020	192	0	668.2	3.44	1430.0945	0	0.00344	6.559617356	286.2316365	0.001638971
189	10/05/2020	79	0	668.2	4.085	1434.1795	0	0.004085	2.699009224	288.9306457	0.000455551
190	11/05/2020	82	0	668.2	3.655	1437.8345	0	0.003655	2.801503246	291.732149	0.00012653
191	12/05/2020	41	0	668.2	4.515	1442.3495	0	0.004515	1.400751623	293.1329006	3.50538E-05
192	13/05/2020	E	0	668.2	4.73	1447.0795	0	0.00473	E	293.1329006	9.6211E-06
193	14/05/2020	E	0	668.2	4.945	1452.0245	0	0.004945	E	293.1329006	2.55015E-06
194	15/05/2020	E	0	668.2	4.515	1456.5395	0	0.004515	E	293.1329006	5.8425E-07
195	16/05/2020	E	0	668.2	4.085	1460.6245	0	0.004085	E	293.1329006	5.03864E-08
196	17/05/2020	E	0	668.2	3.44	1464.0645	0	0.00344	E	293.1329006	1.93201E-19
197	18/05/2020	43	0	668.2	4.73	1468.7945	0	0.00473	1.46908097	294.6019816	1.93201E-19
198	19/05/2020	E	0	668.2	4.3	1473.0945	0	0.0043	E	294.6019816	1.93201E-19
199	20/05/2020	E	0	668.2	3.44	1476.5345	0	0.00344	E	294.6019816	1.93201E-19
200	21/05/2020	E	0	668.2	4.3	1480.8345	0	0.0043	E	294.6019816	1.93201E-19
201	22/05/2020	4	0	668.2	3.87	1484.7045	0	0.00387	0.136658695	294.7386402	1.93201E-19
202	23/05/2020	E	0	668.2	4.515	1489.2195	0	0.004515	E	294.7386402	1.93201E-19
203	24/05/2020	20	0	668.2	4.085	1493.3045	0	0.004085	0.683293475	295.4219337	1.93201E-19
204	25/05/2020	E	0	668.2	3.44	1496.7445	0	0.00344	E	295.4219337	1.93201E-19
205	26/05/2020	E	0	668.2	4.73	1501.4745	0	0.00473	E	295.4219337	1.93201E-19
206	27/05/2020	43	0	668.2	4.945	1506.4195	0	0.004945	1.46908097	296.8910147	1.93201E-19
207	28/05/2020	4	0	668.2	4.085	1510.5045	0	0.004085	0.136658695	297.0276734	1.93201E-19
208	29/05/2020	0	0	668.2	6.45	1516.9545	0	0.00645	0	297.0276734	1.93201E-19
209	30/05/2020	E	0	668.2	4.73	1521.6845	0	0.00473	E	297.0276734	1.93201E-19
210	31/05/2020	0	0	668.2	4.085	1525.7695	0	0.004085	0	297.0276734	1.93201E-19
211	01/06/2020	0	0	668.2	1.8	1527.5695	0	0.0018	0	297.0276734	1.93201E-19
212	02/06/2020	0	0	668.2	2.28	1529.8495	0	0.00228	0	297.0276734	1.93201E-19
213	03/06/2020	0	0	668.2	1.92	1531.7695	0	0.00192	0	297.0276734	1.93201E-19
214	04/06/2020	124	0	668.2	1.8	1533.5695	0	0.0018	4.236419542	301.2640929	1.93201E-19
215	05/06/2020	182	0	668.2	2.28	1535.8495	0	0.00228	6.217970618	307.4820635	1.93201E-19
216	06/06/2020	0	0	668.2	1.68	1537.5295	0	0.00168	0	307.4820635	1.93201E-19
217	07/06/2020	53	0	668.2	1.8	1539.3295	0	0.0018	1.810727708	309.2927913	1.93201E-19
218	08/06/2020	47	0	668.2	1.92	1541.2495	0	0.00192	1.605729665	310.8985209	1.93201E-19
219	09/06/2020	36	0	668.2	1.92	1543.1695	0	0.00192	1.229928254	312.1284592	1.93201E-19
220	10/06/2020	36	0	668.2	2.28	1545.4495	0	0.00228	1.229928254	313.3583874	1.93201E-19
221	11/06/2020	38	0	668.2	2.88	1548.3295	0	0.00288	1.298257602	314.656645	1.93201E-19
222	12/06/2020	34	0	668.2	2.64	1550.9695	0	0.00264	1.161598907	315.8182439	1.93201E-19
223	13/06/2020	40	0	668.2	2.64	1553.6095	0	0.00264	1.366586949	317.1848309	1.93201E-19
224	14/06/2020	29	0	668.2	1.56	1555.1695	0	0.00156	0.990775538	318.1756064	1.93201E-19
225	15/06/2020	31	0	668.2	1.44	1556.6095	0	0.00144	1.059104886	319.2347113	1.93201E-19
226	16/06/2020	38	0	668.2	1.8	1558.4095	0	0.0018	1.298257602	320.5329689	1.93201E-19
227	17/06/2020	29	36	704.2	14.88	1573.2895	0.036	0.01488	0.990775538	321.5237444	1.93201E-19
228	18/06/2020	34	0	704.2	0.48	1573.7695	0	0.00048	1.161598907	322.6853434	0.02761703
229	19/06/2020	47	0	704.2	1.2	1574.9695	0	0.0012	1.605729665	324.291083	0.022240079
230	20/06/2020	34	0	704.2	1.32	1576.2895	0	0.00132	1.161598907	325.4526819	0.006183185
231	21/06/2020	64	0	704.2	1.32	1577.6095	0	0.00132	2.186539119	327.639221	0.001718959
232	22/06/2020	57	0	704.2	1.8	1579.4095	0	0.0018	1.947386402	329.5866074	0.00047779
233	23/06/2020	49	0	704.2	2.16	1581.5695	0	0.00216	1.674069013	331.2606765	0.000132713
234	24/06/2020	46	0	704.2	1.68	1583.2495	0	0.00168	1.571574991	332.8322515	3.67728E-05
235	25/06/2020	46	0	704.2	1.8	1585.0495	0	0.0018	1.571574991	334.4038264	0.023099188
236	26/06/2020	54	0	704.2	1.56	1586.6095	0	0.00156	1.844892381	336.2487188	0.018596484
237	27/06/2020	50	0	704.2	1.92	1588.5295	0	0.00192	1.708233686	337.9569525	0.005170173
238	28/06/2020	41	0	704.2	2.28	1590.8095	0	0.00228	1.400751623	339.3577041	0.001437315
239	29/06/2020	41	0	704.2	2.28	1593.0895	0	0.00228	1.400751623	340.7584558	0.000399486
240	30/06/2020	42	0	704.2	1.32	1594.4095	0	0.00132	1.434916297	342.1933721	0.000110942
241	01/07/2020	39	0	704.2	1.6	1596.0095	0	0.0016	1.332422275	343.5257943	3.07201E-05
242	02/07/2020	30	0	704.2	0.8	1596.8095	0	0.0008	1.024940212	344.5507345	8.41621E-06
243	03/07/2020	61	0	704.2	2.2	1599.0095	0	0.0022	2.084045097	346.6347796	2.21516E-06
244	04/07/2020	40	0	704.2	1.6	1600.6095	0	0.0016	1.366586949	348.0013666	4.91114E-07
245	05/07/2020	36	0	704.2	1.7	1602.3095	0	0.0017	1.229928254	349.2312948	3.10104E-08
246	06/07/2020	51	0	704.2	3.3	1605.6095	0	0.0033	1.74239836	350.9736932	0
247	07/07/2020	45	0	704.2	2.3	1607.9095	0	0.0023	1.537410318	352.5111035	0.058493642
248	08/07/2020	44	0	704.2	1.9	1609.8095	0	0.0019	1.503245644	354.0143492	0.156214569
249	09/07/2020	44	0	704.2	1.8	1611.6095	0	0.0018	1.503245644	355.5175948	0.085020434
250	10/07/2020	48	0	704.2	2	1613.6095	0	0.002	1.639904339	357.1574991	0.023637727
251	11/07/2020	47	0	704.2	2.4	1616.0095	0	0.0024	1.605729665	358.7632388	0.006571767
252	12/07/2020	47	0	704.2	1.8	1617.8095	0	0.0018	1.605729665	360.3689785	0.001826994
253	13/07/2020	52	0	704.2	2.2	1620.0095	0	0.0022	1.776563034	362.1455415	0.000507826
254	14/07/2020	48	0	704.2	2.4	1622.4095	0	0.0024	1.639904339	363.7854458	0.000141064
255	15/07/2020	46	0	704.2	2.2	1624.6095	0	0.0022	1.571574991	365.3570208	3.90946E-05
256	16/07/2020	43	0	704.2	2.4	1627.0095	0	0.0024	1.46908097	366.8261018	1.07445E-05
257	17/07/2020	53	0	704.2	1.7	1628.7095	0	0.0017	1.810727708	368.6368295	2.8625E-06
258	18/07/2020	45	0	704.2	1.8	1630.5095	0	0.0018	1.537410318	370.1742398	6.7109E-07
259	19/07/2020	49	0	704.2	1.7	1632.2095	0	0.0017	1.674069013	371.8483088	6.83013E-08
260	20/07/2020	51	0	704.2	2.6	1634.8095	0	0.0026	1.74239836	373.5907072	0.096853511
261	21/07/2020	50	0	704.2	1.9	1636.7095	0	0.0019	1.708233686	375.2989409	0.140413558
262	22/07/2020	50	0	704.2	1.4	1638.1095	0	0.0014	1.708233686	377.0071746	0.131103597
263	23/07/2020	46	0	704.2	1.7	1639.8095	0	0.0017	1.571574991	378.5787496	0.111211472
264	24/07/2020	43	0	704.2	1.8	1641.6095	0	0.0018	1.46908097	380.0478305	0.092032101
265	25/07/2020	43	0	704.2	1.4	1643.0095	0	0.0014	1.46908097	381.5169115	0.076328993
266	26/07/2020	40	0	704.2	1.6	1644.6095	0	0.0016	1.366586949	382.8834985	0.06452605
267	27/07/2020	36	0	704.2	1.6	1646.2095	0	0.0016	1.229928254	384.1124267	0.056404619

											Municipal Solid Waste		Municipal Waste with Channeling	
									Inputs					
									Initial Moisture Content (IMS) - vol/vol		0.292	vol/vol	0.073	vol/vol
									Total Porosity (Φ) - vol/vol		0.671	vol/vol	0.168	vol/vol
									Field Capacity (fc) - vol/vol		0.292	vol/vol	0.073	vol/vol
									Wilting Point (wp) - vol/vol		0.077	vol/vol	0.019	vol/vol
									Saturated Permeability (Ks) - cm/s		1.00E-03	cm/s	1.00E-03	cm/s
									Depth of Soil Water Evaporation (SED/SEDMX) -		18.70013669	inches	18.70013669	inches
									Depth of Soil Water Evaporation (SED/SEDMX) -		47.49834719	cm	47.49834719	cm
									Outputs					
									Average (mm)		0.3272506		0.6338493	
									Std Deviation (mm)		0.766179621		1.554545673	
									Error Difference (%)		81.4502604		65.13649534	
									Percentage Difference (%)		137.4111165		96.59617774	
									Is Pi ≥ Qi		NO		NO	
Measured Inputs											Iteration 1		Iteration 2	
Step	Date	Observed Leachate Flow Rate - Qi	Observed Precipitation	Cumulative Observed Precipitation	Observed Factored Evaporation	Cumulative Observed Factored Evaporation	Observed Precipitation	Observed Factored Evaporation	Observed Leachate Flow Rate - Qi	Cumulative Observed Leachate Flow Rate	Pi	Cum	Pi	Cum
i	(dd/mm/yyyy)	(m3)	(mm)	(mm)	(mm)	(mm)	(m)	(m)	(mm)	(mm)	(mm)		(mm)	
268	28/07/2020	22	0	704.2	1.4	1647.6095	0	0.0014	0.751622822	384.8650495	0.051567096	75.65114151	0	172.1640288
269	29/07/2020	52	0	704.2	1	1648.6095	0	0.001	1.776563034	386.6416126	0.049566364	75.70070788	0	172.1640288
270	30/07/2020	35	0	704.2	1.1	1649.7095	0	0.0011	1.19576358	387.8373762	0.049946634	75.75065451	0	172.1640288
271	31/07/2020	E	0	704.2	1.2	1650.9095	0	0.0012	E	387.8373762	0.052261392	75.75065451	0	172.1640288
272	01/08/2020	E	0	704.2	2.43	1653.3395	0	0.00243	E	387.8373762	0.056085176	75.75065451	0	172.1640288
273	02/08/2020	E	3	707.2	3.915	1657.2545	0.003	0.003915	E	387.8373762	0.038883498	75.75065451	0	172.1640288
274	03/08/2020	E	0	707.2	3.105	1660.3595	0	0.003105	E	387.8373762	0.010810481	75.75065451	0	172.1640288
275	04/08/2020	E	0	707.2	3.105	1663.4645	0	0.003105	E	387.8373762	0.003005465	75.75065451	0	172.1640288
276	05/08/2020	E	0	707.2	3.375	1666.8395	0	0.003375	E	387.8373762	0.000835471	75.75065451	0	172.1640288
277	06/08/2020	18	0	707.2	3.51	1670.3495	0	0.00351	0.614964127	388.4523403	0.013734046	75.76438856	0	172.1640288
278	07/08/2020	40	0	707.2	3.78	1674.1295	0	0.00378	1.366586949	389.8189272	0.108457834	75.87284639	0	172.1640288
279	08/08/2020	E	0	707.2	2.43	1676.5595	0	0.00243	E	389.8189272	0.117664352	75.87284639	0	172.1640288
280	09/08/2020	E	0	707.2	2.97	1679.5295	0	0.00297	E	389.8189272	0.103417636	75.87284639	0	172.1640288
281	10/08/2020	0	0	707.2	4.05	1683.5795	0	0.00405	0	389.8189272	0.093850728	75.96669712	0	172.1640288
282	11/08/2020	46	0	707.2	2.97	1686.5495	0	0.00297	1.571574991	391.3905022	0.091510008	76.05820713	0	172.1640288
283	12/08/2020	97	0	707.2	3.24	1689.7895	0	0.00324	3.313973352	394.7044756	0.094053237	76.15226036	0	172.1640288
284	13/08/2020	E	0	707.2	3.78	1693.5695	0	0.00378	E	394.7044756	0.099053454	76.15226036	0	172.1640288
285	14/08/2020	32	0	707.2	2.7	1696.2695	0	0.0027	1.093269559	395.7977451	0.104827939	76.2570883	0	172.1640288
286	15/08/2020	28	0	707.2	2.7	1698.9695	0	0.0027	0.956610864	396.754356	0.110372607	76.36746091	0	172.1640288
287	16/08/2020	25	0	707.2	2.565	1701.5345	0	0.002565	0.854116843	397.6084728	0.115160803	76.48262171	0	172.1640288
288	17/08/2020	32	0	707.2	3.78	1705.3145	0	0.00378	1.093269559	398.7017424	0.118971083	76.6015928	0	172.1640288
289	18/08/2020	84	0	707.2	3.915	1709.2295	0	0.003915	2.869832593	401.571575	0.12176497	76.72335777	0	172.1640288
290	19/08/2020	E	0	707.2	3.645	1712.8745	0	0.003645	E	401.571575	0.123605889	76.72335777	0	172.1640288
291	20/08/2020	E	0	707.2	2.16	1715.0345	0	0.00216	E	401.571575	0.124607517	76.72335777	0	172.1640288
292	21/08/2020	78	0	707.2	2.97	1718.0045	0	0.00297	2.664844551	404.2364195	0.124902112	76.84825988	0	172.1640288
293	22/08/2020	66	0	707.2	2.7	1720.7045	0	0.0027	2.254868466	406.491288	0.124622027	76.9728819	0	172.1640288
294	23/08/2020	126	0	707.2	2.565	1723.2695	0	0.002565	4.30474889	410.7960369	0.123889701	77.09677161	0	172.1640288
295	24/08/2020	101	0	707.2	3.375	1726.6445	0	0.003375	3.450632046	414.2466689	0.122812955	77.21958456	0	172.1640288

Measured Inputs

Step	Date	Observed Leachate Flow Rate - Qi	Observed Precipitation	Cumulative Observed Precipitation	Observed Factored Evaporation	Cumulative Observed Factored Evaporation	Observed Precipitation	Observed Factored Evaporation	Observed Leachate Flow Rate - Qi	Cumulative Observed Leachate Flow Rate
i	(dd/mm/yyyy)	(m3)	(mm)	(mm)	(mm)	(mm)	(m)	(m)	(mm)	(mm)
535	21/04/2021	47	0	1457.95	7.32	3467.234	0	0.00732	1.605739665	665.2545268
536	22/04/2021	37	0	1457.95	7.015	3474.249	0	0.007015	1.264092928	666.5186197
537	23/04/2021	33	0	1457.95	7.015	3481.264	0	0.007015	1.127434233	667.646054
538	24/04/2021	37	0	1457.95	7.015	3488.279	0	0.007015	1.264092928	668.9101469
539	25/04/2021	38	0	1457.95	6.71	3494.989	0	0.00671	1.298257602	670.2084045
540	26/04/2021	35	0	1457.95	6.1	3501.089	0	0.0061	1.19576358	671.4041681
541	27/04/2021	33	0	1457.95	5.49	3506.579	0	0.00549	1.127434233	672.5316023
542	28/04/2021	37	0	1457.95	7.015	3513.594	0	0.007015	1.264092928	673.7956953
543	29/04/2021	34	0	1457.95	7.015	3520.609	0	0.007015	1.161598907	674.9572942
544	30/04/2021	37	19	1476.95	0	3520.609	0.019	0	1.264092928	676.2213871
545	01/05/2021	44	0	1476.95	3.01	3523.619	0	0.00301	1.503245644	677.7246327
546	02/05/2021	33	0	1476.95	4.085	3527.704	0	0.004085	1.127434233	678.852067
547	03/05/2021	32	0	1476.95	3.87	3531.574	0	0.00387	1.093269559	679.9453365
548	04/05/2021	36	0	1476.95	4.515	3536.089	0	0.004515	1.229928254	681.1752648
549	05/05/2021	35	0	1476.95	4.945	3541.034	0	0.004945	1.19576358	682.3710284
550	06/05/2021	32	0	1476.95	4.73	3545.764	0	0.00473	1.093269559	683.4642979
551	07/05/2021	32	0	1476.95	4.3	3550.064	0	0.0043	1.093269559	684.5575675
552	08/05/2021	35	2	1478.95	4.3	3554.364	0.002	0.0043	1.19576358	685.7533311
553	09/05/2021	34	0	1478.95	2.15	3556.514	0	0.00215	1.161598907	686.91493
554	10/05/2021	36	0	1478.95	2.365	3558.879	0	0.002365	1.229928254	688.1448582
555	11/05/2021	33	0	1478.95	3.655	3562.534	0	0.003655	1.127434233	689.2722924
556	12/05/2021	198	0	1478.95	3.44	3565.974	0	0.00344	6.764605398	696.0368978
557	13/05/2021	313	0	1478.95	4.3	3570.274	0	0.0043	10.69354288	706.7304407
558	14/05/2021	399	0	1478.95	3.44	3573.714	0	0.00344	13.63170482	720.3621455
559	15/05/2021	402	0	1478.95	5.16	3578.874	0	0.00516	13.73419884	734.0963444
560	16/05/2021	340	0	1478.95	4.73	3583.604	0	0.00473	11.61598907	745.7123334
561	17/05/2021	395	0	1478.95	4.515	3588.119	0	0.004515	13.49504612	759.2073796
562	18/05/2021	366	0	1478.95	4.3	3592.419	0	0.0043	12.50427058	771.7116502
563	19/05/2021	366	0	1478.95	3.655	3596.074	0	0.003655	12.50427058	784.2159207
564	20/05/2021	394	0	1478.95	3.225	3599.299	0	0.003225	13.46088145	797.6768022
565	21/05/2021	376	0	1478.95	4.085	3603.384	0	0.004085	12.84591732	810.5227195
566	22/05/2021	314	0	1478.95	5.16	3608.544	0	0.00516	10.72770755	821.2504271
567	23/05/2021	337	0	1478.95	3.87	3612.414	0	0.00387	11.51349505	832.7639221
568	24/05/2021	115	0	1478.95	1.935	3614.349	0	0.001935	3.928937479	836.6928596
569	25/05/2021	98	0	1478.95	2.58	3616.929	0	0.00258	3.348138025	840.0409976
570	26/05/2021	34	0	1478.95	3.225	3620.154	0	0.003225	1.161598907	841.2025965
571	27/05/2021	38	0	1478.95	3.44	3623.594	0	0.00344	1.298257602	842.5008541
572	28/05/2021	46	0	1478.95	4.73	3628.324	0	0.00473	1.571574991	844.0724291
573	29/05/2021	45	0	1478.95	3.655	3631.979	0	0.003655	1.537410318	845.6098394
574	30/05/2021	47	0	1478.95	3.87	3635.849	0	0.00387	1.605739665	847.2155791
575	31/05/2021	184	0	1478.95	3.225	3639.074	0	0.003225	6.286299966	853.5018791
576	01/06/2021	354	4.8	1483.75	0.672	3639.746	0.0048	0.000672	12.0942945	865.5961736
577	02/06/2021	36	0	1483.75	1.08	3640.826	0	0.00108	1.229928254	866.8261018
578	03/06/2021	40	1.65	1485.4	1.596	3642.422	0.00165	0.001596	1.366586949	868.1926888
579	04/06/2021	31	0	1485.4	1.2	3643.622	0	0.0012	1.059104886	869.2517936
580	05/06/2021	26	0	1485.4	1.92	3645.542	0	0.00192	0.888281517	870.1400752
581	06/06/2021	30	0	1485.4	1.68	3647.222	0	0.00168	1.024940212	871.1650154
582	07/06/2021	33	0	1485.4	1.2	3648.422	0	0.0012	1.127434233	872.2924496
583	08/06/2021	35	0	1485.4	1.56	3649.982	0	0.00156	1.19576358	873.4882132
584	09/06/2021	33	0	1485.4	1.8	3651.782	0	0.0018	1.127434233	874.6156474
585	10/06/2021	29	0	1485.4	0.72	3652.502	0	0.00072	0.990775538	875.606423
586	11/06/2021	27	0	1485.4	0.96	3653.462	0	0.00096	0.922446191	876.5288691
587	12/06/2021	29	0	1485.4	1.32	3654.782	0	0.00132	0.990775538	877.5196447
588	13/06/2021	31	0	1485.4	2.28	3657.062	0	0.00228	1.059104886	878.5787496
589	14/06/2021	34	0	1485.4	2.04	3659.102	0	0.00204	1.161598907	879.7403485
590	15/06/2021	30	0	1485.4	1.68	3660.782	0	0.00168	1.024940212	880.7652887
591	16/06/2021	28	0	1485.4	2.52	3663.302	0	0.00252	0.956610864	881.7218996
592	17/06/2021	33	0	1485.4	2.4	3665.702	0	0.0024	1.127434233	882.8493338
593	18/06/2021	24	0	1485.4	1.92	3667.622	0	0.00192	0.819952169	883.669286
594	19/06/2021	26	0	1485.4	2.16	3669.782	0	0.00216	0.888281517	884.5575675
595	20/06/2021	E	0	1485.4	1.92	3671.702	0	0.00192	E	884.5575675
596	21/06/2021	630	0	1485.4	1.92	3673.622	0	0.00192	21.52374445	906.0813119
597	22/06/2021	29	0	1485.4	1.2	3674.822	0	0.0012	0.990775538	907.0720875
598	23/06/2021	31	0	1485.4	2.16	3676.982	0	0.00216	1.059104886	908.1311923
599	24/06/2021	28	0	1485.4	1.2	3678.182	0	0.0012	0.956610864	909.0878032
600	25/06/2021	37	0	1485.4	1.92	3680.102	0	0.00192	1.264092928	910.3518961
601	26/06/2021	27	0	1485.4	3.36	3683.462	0	0.00336	0.922446191	911.2743423
602	27/06/2021	43	0	1485.4	1.44	3684.902	0	0.00144	1.46908097	912.7434233
603	28/06/2021	24	0	1485.4	1.44	3686.342	0	0.00144	0.819952169	913.5633755
604	29/06/2021	33	0	1485.4	1.92	3688.262	0	0.00192	1.127434233	914.6908097
605	30/06/2021	25	0	1485.4	1.92	3690.182	0	0.00192	0.854116843	915.5449265
606	01/07/2021	20	0	1485.4	1	3691.182	0	0.001	0.683293475	916.22822
607	02/07/2021	20	0	1485.4	1.4	3692.582	0	0.0014	0.683293475	916.9115135
608	03/07/2021	36	0	1485.4	1.6	3694.182	0	0.0016	1.229928254	918.1414417
609	04/07/2021	33	0	1485.4	1.6	3695.782	0	0.0016	1.127434233	919.268876
610	05/07/2021	27	0	1485.4	2	3697.782	0	0.002	0.922446191	920.1913222
611	06/07/2021	32	0	1485.4	1.8	3699.582	0	0.0018	1.093269559	921.2845917
612	07/07/2021	29	0	1485.4	2	3701.582	0	0.002	0.990775538	922.2753673
613	08/07/2021	28	0	1485.4	1.8	3703.382	0	0.0018	0.956610864	923.2319781
614	09/07/2021	33	0	1485.4	1.6	3704.982	0	0.0016	1.127434233	924.3594124
615	10/07/2021	36	0	1485.4	1.2	3706.182	0	0.0012	1.229928254	925.5893406
616	11/07/2021	36	0	1485.4	1.6	3707.782	0	0.0016	1.229928254	926.8192689
617	12/07/2021	15	0	1485.4	2.3	3710.082	0	0.0023	0.512470106	927.331739
618	13/07/2021	30	0	1485.4	1.2	3711.282	0	0.0012	1.024940212	928.3566792
619	14/07/2021	17	0	1485.4	1.4	3712.682	0	0.0014	0.580799453	928.9374786
620	15/07/2021	37	0	1485.4	1.2	3713.882	0	0.0012	1.264092928	930.2015716
621	16/07/2021	31	0	1485.4	0.8	3714.682	0	0.0008	1.059104886	931.2606765
622	17/07/2021	29	0	1485.4	1.4	3716.082	0	0.0014	0.990775538	932.251452
623	18/07/2021	26	0	1485.4	1.7	3717.782	0	0.0017	0.888281517	933.1397335
624	19/07/2021	26	0	1485.4	1.8	3719.582	0	0.0018	0.888281517	934.028015
625	20/07/2021	33	0	1485.4	1.5	3721.082	0	0.0015	1.127434233	935.1554493
626	21/07/2021	35	0	1485.4	1.7	3722.782	0	0.0017	1.19576358	936.3512128
627	22/07/2021	24	0	1485.4	2.2	3724.982	0	0.0022	0.819952169	937.171165
628	23/07/2021	23	0	1485.4	1.3	3726.282	0	0.0013	0.785787496	937.9569525
629	24/07/2021	46	0	1485.4	1.6	3727.882	0	0.0016	1.571574991	939.5285275
630	25/07/2021	27	0	1485.4	1.4	3729.282	0	0.0014	0.922446191	940.4509737
631	26/07/2021	12	0	1485.4	1	3730.282	0	0.001	0.409976085	940.8609498
632	27/07/2021	30	0	1485.4	1.8	3732.082	0	0.0018	1.024940212	941.88589
633	28/07/2021	30	0	1485.4	2	3734.082	0	0.002	1.024940212	942.9108302
634	29/07/2021	49	0	1485.4	2	3736.082	0	0.002	1.674069013	944.5848992
635	30/07/2021	27	0	1485.4	2.4	3738.482	0	0.0024	0.922446191	945.5073454
636	31/07/2021	30	0	1485.4	1.9	3740.382	0	0.0019	1.024940212	946.5322856
637	01/08/2021	28	0	1485.4	1.08	3741.462	0	0.00108	0.956610864	947.4888965
638	02/08/2021	19	0	1485.4	3.51	3744.972	0	0.00351	0.649128801	948.1380253
639	03/08/2021	28	0	1485.4	2.16	3747.132	0	0.00216	0.956610864	949.0946361
640	04/08/2021	28	0	1485.4	1.89	3749.022	0	0.00189	0.956610864	950.051247
641	05/08/2021	27	0	1485.4	1.35	3750.372	0	0.00135	0.922446191	950.9736932
642	06/08/2021	28	0	1485.4	1.89	3752.262	0	0.00189	0.956610864	951.9303041
643	07/08/2021	29	0	1485.4	2.43	3754.692	0	0.00243	0.990775538	952.9210796
644	08/08/2021	33	0	1485.4	2.7	3757.392	0	0.0027	1.127434233	954.0485138
645	09/08/2021	29	0	1485.4	2.43	3759.822	0	0.00243	0.990775538	955.0392894
646	10/08/2021	30	0	1485.4	2.565	3762.387	0	0.002565	1.024940212	956.0642296
647	11/08/2021	32	0	1485.4	2.295	3764.682	0	0.002295	1.093269559	957.1574991
648	12/08/2021	32	0	1485.4	1.755	3766.437	0	0.001755	1.093269559	958.2507687
649	13/08/2021	31	0	1485.4	2.43	3768.867	0	0.00243	1.059104886	959.3098736
650	14/08/2021	34	0	1485.4	1.89	3770.757	0	0.00189	1.161598907	960.4714725
651	15/08/2021	36	0	1485.4	2.025	3772.782	0	0.002025	1.229928254	961.7014008
652	16/08/2021	33	0	1485.4	1.485	3774.267	0	0.001485	1.127434233	962.828835
653	17/08/2021	30	0	1485.4	1.215	3775.482	0	0.001215	1.024940212	963.8537752
654	18/08/2021	33	0	1485.4	2.16	3777.642	0	0.00216	1.127434233	964.9812094
655	19/08/2021	31	0	1485.4	1.755	3779.397	0	0.001755	1.059104886	966.0403143
656	20/08/2021	30	0	1485.4	2.025	3781.422	0	0.002025	1.024940212	967.0652545
657	21/08/2021	32	0	1485.4	2.16	3783.582	0	0.00216	1.093269559	968.1585241
658	22/08/2021	31	0	1485.4	1.89	3785.472	0	0.00189	1.059104886	969.217629
659	23/08/2021	32	0	1485.4	2.16	3787.632	0	0.00216	1.093269559	970.3108985
660	24/08/2021	31	0	1485.4	1.89	3789.522	0	0.00189	1.059104886	971.3700034
661	25/08/2021	31	0	1485.4	1.89	3791.412	0	0.00189	1.059104886	972.4291083
662	26/08/2021	29	0	1485.4	2.16	3793.572	0	0.00216	0.990775538	973.4198838
663	27/08/2021	30	0	1485.4	2.43	3796.002	0	0.00243	1.024940212	974.4448241
664	28/08/2021	32	0	1485.4	1.89	3797.892	0	0.00189	1.093269559	975.5380936
665	29/08/2021	31	0	1485.4	1.62	3799.512	0	0.00162	1.059104886	976.5971985
666	30/08/2021	32	0	1485.4	2.97	3802.482	0	0.00297	1.093269559	977.6904681
667	31/08/2021	33	0	1485.4	2.97	3805.452	0	0.00297	1.127434233	978.8179023
668	01/09/2021	30	0	1485.4	4.1	3809.552	0	0.0041	1.024940212	979.8428425
669	02/09/2021	28	0	1485.4	4.305	3813.857	0	0.004305	0.956610864	980.7994534
670	03/09/2021	32	0	1485.4	5.125	3818.982	0	0.005125	1.093269559	981.8927229
671	04/09/2021	36	0	1485.4	4.305	3823.287	0	0.004305	1.229928254	983.1226512
672	05/09/2021	22	0	1485.4	4.51	3827.797	0	0.00451	0.751622822	983.874274
673	06/09/2021	29	0	1485.4	4.715	3832.512	0	0.004715	0.990775538	984.8650495
674	07/09/2021	29	0	1485.4	4.92	3837.432	0	0.00492	0.990775538	985.8558251
675	08/09/2021	33	0	1485.4	3.895	3841.327	0	0.003895	1.127434233	986.9832593
676	09/09/2021	12	0	1485.4	4.715	3846.042	0	0.004715	0.409976085	987.3932354
677	10/09/2021	18	0	1485.4	4.92	3850.962	0	0.00492	0.614964127	988.0081995
678	11/09/2021	37	0	1485.4	5.535	3856.497	0	0.005535	1.264092928	989.2722924
679	12/09/2021	44	0	1485.4	6.765	3863.262	0	0.006765	1.503245644	990.7755381
680	13/09/2021	64	0	1485.4	5.33	3868.592	0	0.00533	2.186539119	992.9620772
681	14/09/2021	23	0	1485.4	5.33	3873.922	0	0.00533	0.785787496	993.7478647
682	15/09/2021	38	0	1485.4	5.945	3879.867	0	0.005945	1.298257602	995.0461223
683	16/09/2021	41	0	1485.4	6.56	3886.427	0	0.00656	1.400751623	996.4468739
684	17/09/2021	21	0	1485.4	6.15	3892.577	0	0.00615	0.717458148	997.1643321
685	18/09/2021	32	0	1485.4	4.1	3896.677	0	0.0041	1.093269559	998.2576016
686	19/09/2021	21	0	1485.4	4.92	3901.597	0	0.00492	0.717458148	998.9750598
687	20/09/2021	32	0	1485.4	5.945	3907.542	0	0.005945	1.093269559	1000.068329
688	21/09/2021	35	0	1485.4	6.56	3914.102	0	0.00656	1.19576358	1001.264093
689	22/09/2021	34	0	1485.4	4.92	3919.022	0	0.00492	1.161598907	1002.425692
690	23/09/2021	26	0	1485.4	5.33	3924.352	0	0.00533	0.888281517	1003.313973
691	24/09/2021	28	0	1485.4	5.945	3930.297	0	0.005945	0.956610864	1004.270584
692	25/09/2021	36	0	1485.4	7.38	3937.677	0	0.00738	1.229928254	1005.500512
693	26/09/2021	36	0	1485.4	9.02	3946.697	0	0.00902	1.229928254	1006.730441
694	27/09/2021	36	0	1485.4	6.765	3953.462	0	0.006765	1.229928254	1007.960369
695	28/09/2021	33	0	1485.4	8.2	3961.662	0	0.0082	1.127434233	1009.087803
696	29/09/2021	48	0	1485.4	7.995	3969.657	0	0.007995	1.639904339	1010.727708
697	30/09/2021	27	7	1492.4	4.51	3974.167	0.007	0.00451	0.922446191	1011.650154
698	01/10/2021	41	22	1514.4	0	3974.167	0.022	0	1.400751623	1013.050905
699	02/10/2021	35	0	1514.4	8.48	3982.647	0	0.00848	1.19576358	1014.246669
700	03/10/2021	31	0	1514.4	1.59	3984.237	0	0.00159	1.059104886	1015.305774
701	04/10/2021	32	0	1514.4	7.685	3991.922	0	0.007685	1.093269559	1016.399043
702	05/10/2021	31	0	1514.4	7.155	3999.077	0	0.007155	1.059104886	1017.458148
703	06/10/2021	34	0	1514.4	5.83	4004.907	0	0.00583	1.161598907	1018.619747
704	07/10/2021	23	5.2	1519.6	3.286	4008.193	0.0052	0.003286	0.785787496	1019.405535
705	08/10/2021	29	20	1539.6	0	4008.193	0.02	0	0.990775538	1020.39631
706	09/10/2021	37	0	1539.6	3.445	4011.638	0	0.003445	1.264092928	1021.660403
707	10/10/2021	24	0	1539.6	3.71	4015.348	0	0.00371	0.819952169	1022.480355
708	11/10/2021	32	0	1539.6	3.975	4019.323	0	0.003975	1.093269559	1023.573625
709	12/10/2021	28	0	1539.6	8.215	4027.538	0	0.008215	0.956610864	1024.530236
710	13/10/2021	23	0	1539.6	9.275	4036.813	0	0.009275	0.785787496	1025.316023
711	14/10/2021	31	0	1539.6	11.13	4047.943	0	0.01113	1.059104886	1026.375128
712	15/10/2021	32	0	1539.6	9.805	4057.748	0	0.009805	1.093269559	1027.468398
713	16/10/2021	24	0	1539.6	6.625	4064.373	0	0.006625	0.819952169	1028.28835
714	17/10/2021	32	0	1539.6	8.745	4073.118	0	0.008745	1.093269559	1029.381619
715	18/10/2021	28	0	1539.6	5.3	4078.418	0	0.0053	0.956610864	1030.33823
716	19/10/2021	32	0	1539.6	6.36	4084.778	0	0.00636	1.093269559	1031.4315
717	20/10/2021	30	2	1541.6	7.155	4091.933	0.002	0.007155	1.024940212	1032.45644
718	21/10/2021	28	0	1541.6	7.685	4099.618	0	0.007685	0.956610864	1033.413051
719	22/10/2021	35	2.1	1543.7	7.208	4106.826	0.0021	0.007208	1.19576358	1034.608814
720	23/10/2021	34	0	1543.7	8.215	4115.041	0	0.008215	1.161598907	1035.770413
721	24/10/2021	31	0	1543.7	13.78	4128.821	0	0.01378	1.059104886	1036.829518
722	25/10/2021	28	0	1543.7	7.95	4136.771	0	0.00795	0.956610864	1037.786129
723	26/10/2021	36	3.9	1547.6	0	4136.771	0.0039	0	1.229928254	1039.016057
724	27/10/2021	37	0	1547.6	2.12	4138.891	0	0.00212	1.264092928	1040.28015
725	28/10/2021	35	0	1547.6	3.71	4142.601	0	0.00371	1.19576358	1041.475914
726	29/10/2021	32	0	1547.6	6.89	4149.491	0	0.00689	1.093269559	1042.569183
727	30/10/2021	36	1	1548.6	6.36	4155.851	0.001	0.00636	1.229928254	1043.799112
728	31/10/2021	32	0	1548.6	7.95	4163.801	0	0.00795	1.093269559	1044.892381
729	01/11/2021	29	0	1548.6	10.075	4173.876	0	0.010075	0.990775538	1045.883157
730	02/11/2021	27	0	1548.6	14.3	4188.176	0	0.0143	0.922446191	1046.805603
731	03/11/2021	32	0	1548.6	10.4	4198.576	0	0.0104	1.093269559	1047.898873
732	04/11/2021	30	0	1548.6	10.4	4208.976	0	0.0104	1.024940212	1048.923813
733	05/11/2021	32	9	1557.6	5.525	4214.501	0.009	0.005525	1.093269559	1050.017082
734	06/11/2021	19	6.75	1564.35	11.5375	4226.0385	0.00675	0.0115375	0.649128801	1050.666211
735	07/11/2021	41	0	1564.35	10.4	4236.4385	0	0.0104	1.400751623	1052.066963
736	08/11/2021	36	28.5	1592.85	0	4236.4385	0.0285	0	1.229928254	1053.296891
737	09/11/2021	44	4.95	1597.8	0	4236.4385	0.00495	0	1.503245644	1054.800137
738	10/11/2021	27	0	1597.8	8.45	4244.8885	0	0.00845	0.922446191	1055.722583
739	11/11/2021	30	0	1597.8	9.425	4254.3135	0	0.009425	1.024940212	1056.747523
740	12/11/2021	27	0	1597.8	11.7	4266.0135	0	0.0117	0.922446191	1057.669969
741	13/11/2021	40	0	1597.8	15.275	4281.2885	0	0.015275	1.366586949	1059.036556
742	14/11/2021	31	0.9	1598.7	7.41	4288.6985	0.0009	0.00741	1.059104886	1060.095661
743	15/11/2021	28	0	1598.7	7.15	4295.8485	0	0.00715	0.956610864	1061.052272
744	16/11/2021	99	0	1598.7	9.425	4305.2735	0	0.009425	3.382302699	1064.434575
745	17/11/2021	107	0	1598.7	11.05	4316.3235	0	0.01105	3.655620089	1068.090195
746	18/11/2021	48	44	1642.7	0	4316.3235	0.044	0	1.639904339	1069.730099
747	19/11/2021	167	12	1654.7	1.95	4318.2735	0.012	0.00195	5.705500512	1075.4356
748	20/11/2021	41	0	1654.7	7.8	4326.0735	0	0.0078	1.400751623	1076.836351
749	21/11/2021	141	12	1666.7	3.9	4329.9735	0.012	0.0039	4.817218996	1081.65357
750	22/11/2021	130	0	1666.7	1.95	4331.9235	0	0.00195	4.441407585	1086.094978
751	23/11/2021	151	10	1676.7	1.3	4333.2235	0.01	0.0013	5.158865733	1091.253844
752	24/11/2021	118	0	1676.7	6.825	4340.0485	0	0.006825	4.0314315	1095.285275
753	25/11/2021	71	0	1676.7	5.525	4345.5735	0	0.005525	2.425691835	1097.710967
754	26/11/2021	96	28.1	1704.8	0	4345.5735	0.0281	0	3.279808678	1100.990776
755	27/11/2021	7	10.1	1714.9	0	4345.5735	0.0101	0	0.239152716	1101.229928
756	28/11/2021	6	17	1731.9	0	4345.5735	0.017	0	0.204988042	1101.434916
757	29/11/2021	92	0	1731.9	5.2	4350.7735	0	0.0052	3.143149983	1104.578066
758	30/11/2021	150	8.95	1740.85	1.95	4352.7235	0.00895	0.00195	5.124701059	1109.702767
759	01/12/2021	26	1.6	1742.45	6.643	4359.3665	0.0016	0.006643	0.888281517	1110.591049
760	02/12/2021	147	6	1748.45	2.555	4361.9215	0.006	0.002555	5.022207038	1115.613256
761	03/12/2021	98	0	1748.45	8.76	4370.6815	0	0.00876	3.348138025	1118.961394
762	04/12/2021	223	4	1752.45	8.03	4378.7115	0.004	0.00803	7.618722241	1126.580116
763	05/12/2021	48	50	1802.45	0	4378.7115	0.05	0	1.639904339	1128.22002
764	06/12/2021	119	3.1	1805.55	8.103	4386.8145	0.0031	0.008103	4.065596174	1132.285617
765	07/12/2021	89	0	1805.55	8.395	4395.2095	0	0.008395	3.040655962	1135.326273
766	08/12/2021	152	5	1810.55	6.935	4402.1445	0.005	0.006935	5.193030407	1140.519303
767	09/12/2021	97	0	1810.55	4.38	4406.5245	0	0.00438	3.313973352	1143.833276
768	10/12/2021	113	0	1810.55	8.395	4414.9195	0	0.008395	3.860608131	1147.693885
769	11/12/2021	0	0	1810.55	9.125	4424.0445	0	0.009125	0	1147.693885
770	12/12/2021	0	0	1810.55	9.125	4433.1695	0	0.009125	0	1147.693885
771	13/12/2021	111	1.5	1812.05	5.475	4438.6445	0.0015	0.005475	3.792278784	1151.486163
772	14/12/2021	100	18.8	1830.85	0	4438.6445	0.0188	0	3.416467373	1154.902631
773	15/12/2021	110	0	1830.85	6.205	4444.8495	0	0.006205	3.75811411	1158.660745
774	16/12/2021	84	30	1860.85	7.3	4452.1495	0.03	0.0073	2.869832593	1161.530577
775	17/12/2021	175	0	1860.85	5.11	4457.2595	0	0.00511	5.978817902	1167.509395
776	18/12/2021	88	0	1860.85	8.03	4465.2895	0	0.00803	3.006491288	1170.515887
777	19/12/2021	126	4	1864.85	5.84	4471.1295	0.004	0.00584	4.30474889	1174.820635
778	20/12/2021	E	0	1864.85	7.665	4478.7945	0	0.007665	E	1174.820635
779	21/12/2021	1577	0	1864.85	8.03	4486.8245	0	0.00803	53.87769047	1228.698326
780	22/12/2021	90	0	1864.85	6.57	4493.3945	0	0.00657	3.074820635	1231.773147
781	23/12/2021	56	7	1871.85	8.395	4501.7895	0.007	0.008395	1.913221729	1233.686368
782	24/12/2021	58	0	1871.85	5.84	4507.6295	0	0.00584	1.981551076	1235.667919
783	25/12/2021	59	0	1871.85	5.84	4513.4695	0	0.00584	2.01571575	1237.683635
784	26/12/2021	32	11	1882.85	5.84	4519.3095	0.011	0.00584	1.093269559	1238.776905
785	27/12/2021	39	5.5	1888.35	4.015	4523.3245	0.0055	0.004015	1.332422275	1240.109327
786	28/12/2021	36	14	1902.35	0	4523.3245	0.014	0	1.229928254	1241.339255
787	29/12/2021	35	0	1902.35	10.22	4533.5445	0	0.01022	1.19576358	1242.535019
788	30/12/2021	3	6	1908.35	7.3	4540.8445	0.006	0.0073	0.102494021	1242.637513
789	31/12/2021	59	0	1908.35	8.03	4548.8745	0	0.00803	2.01571575	1244.653229
790	01/01/2022	35	5	1913.35	12.41	4561.2845	0.005	0.01241	1.19576358	1245.848992
791	02/01/2022	34	0	1913.35	10.95	4572.2345	0	0.01095	1.161598907	1247.010591
792	03/01/2022	37	5.8	1919.15	11.169	4583.4035	0.0058	0.011169	1.264092928	1248.274684
793	04/01/2022	37	3.7	1922.85	7.446	4590.8495	0.0037	0.007446	1.264092928	1249.538777
794	05/01/2022	37	6.5	1929.35	7.3	4598.1495	0.0065	0.0073	1.264092928	1250.80287
795	06/01/2022	54	0	1929.35	3.285	4601.4345	0	0.003285	1.844892381	1252.647762
796	07/01/2022	22	18	1947.35	0	4601.4345	0.018	0	0.751622822	1253.399385
797	08/01/2022	24	48	1995.35	0	4601.4345	0.048	0	0.819952169	1254.219337
798	09/01/2022	22	0	1995.35	8.03	4609.4645	0	0.00803	0.751622822	1254.97096
799	10/01/2022	42	0	1995.35	9.49	4618.9545	0	0.00949	1.434916297	1256.405876
800	11/01/2022	24	0	1995.35	5.11	4624.0645	0	0.00511	0.819952169	1257.225828
801	12/01/2022	35	18	2013.35	1.46	4625.5245	0.018	0.00146	1.19576358	1258.421592

Measured Inputs

Step	Date	Observed Leachate Flow Rate - Qi	Observed Precipitation	Cumulative Observed Precipitation	Observed Factored Evaporation	Cumulative Observed Factored Evaporation	Observed Precipitation	Observed Factored Evaporation	Observed Leachate Flow Rate - Qi
i	(dd/mm/yyyy)	(m3/)	(mm)	(mm)	(mm)	(mm)	(m)	(m)	(mm)
802	13/01/2022	37	19.5	2032.85	0.365	4625.8895	0.0195	0.000365	1.264092928
803	14/01/2022	24	10	2042.85	3.65	4629.5395	0.01	0.00365	0.819952169
804	15/01/2022	22	11	2053.85	0.73	4630.2695	0.011	0.00073	0.751622822
805	16/01/2022	30	0	2053.85	5.84	4636.1095	0	0.00584	1.024940212
806	17/01/2022	35	9.8	2063.65	2.044	4638.1535	0.0098	0.002044	1.19576358
807	18/01/2022	25	5.7	2069.35	4.161	4642.3145	0.0057	0.004161	0.854116843
808	19/01/2022	36	0.7	2070.05	2.701	4645.0155	0.0007	0.002701	1.229928254
809	20/01/2022	29	0	2070.05	5.11	4650.1255	0	0.00511	0.990775538
810	21/01/2022	46	0	2070.05	4.38	4654.5055	0	0.00438	1.571574991
811	22/01/2022	35	0	2070.05	9.125	4663.6305	0	0.009125	1.19576358
812	23/01/2022	23	0	2070.05	8.03	4671.6605	0	0.00803	0.785787496
813	24/01/2022	19	0	2070.05	8.76	4680.4205	0	0.00876	0.649128801
814	25/01/2022	19	0	2070.05	8.76	4689.1805	0	0.00876	0.649128801
815	26/01/2022	20	0	2070.05	8.76	4697.9405	0	0.00876	0.683293475
816	27/01/2022	24	0	2070.05	7.665	4705.6055	0	0.007665	0.819952169
817	28/01/2022	26	0	2070.05	8.76	4714.3655	0	0.00876	0.888281517
818	29/01/2022	24	20	2090.05	0	4714.3655	0.02	0	0.819952169
819	30/01/2022	27	1	2091.05	2.92	4717.2855	0.001	0.00292	0.922446191
820	31/01/2022	33	22	2113.05	16.79	4734.0755	0.022	0.01679	1.127434233
821	01/02/2022	21	0	2113.05	5.11	4739.1855	0	0.00511	0.717458148
822	02/02/2022	23	0	2113.05	5.11	4744.2955	0	0.00511	0.785787496
823	03/02/2022	8	0	2113.05	6.935	4751.2305	0	0.006935	0.27331739
824	04/02/2022	71	0	2113.05	7.3	4758.5305	0	0.0073	2.425691835
825	05/02/2022	7	56	2169.05	4.38	4762.9105	0.056	0.00438	0.239152716
826	06/02/2022	2	0	2169.05	4.015	4766.9255	0	0.004015	0.068329347
827	07/02/2022	2	0	2169.05	6.935	4773.8605	0	0.006935	0.068329347
828	08/02/2022	21	0	2169.05	6.57	4780.4305	0	0.00657	0.717458148
829	09/02/2022	20	0	2169.05	4.38	4784.8105	0	0.00438	0.683293475
830	10/02/2022	69	0	2169.05	9.855	4794.6655	0	0.009855	2.357362487
831	11/02/2022	49	0	2169.05	10.22	4804.8855	0	0.01022	1.674069013
832	12/02/2022	26	0	2169.05	10.95	4815.8355	0	0.01095	0.888281517
833	13/02/2022	11	0	2169.05	9.49	4825.3255	0	0.00949	0.375811411
834	14/02/2022	13	0	2169.05	5.475	4830.8005	0	0.005475	0.444140758
835	15/02/2022	23	0	2169.05	9.125	4839.9255	0	0.009125	0.785787496
836	16/02/2022	23	0	2169.05	12.045	4851.9705	0	0.012045	0.785787496
837	17/02/2022	24	0	2169.05	10.95	4862.9205	0	0.01095	0.819952169
838	18/02/2022	22	2.8	2171.85	5.329	4868.2495	0.0028	0.005329	0.751622822
839	19/02/2022	28	0	2171.85	5.11	4873.3595	0	0.00511	0.956610864
840	20/02/2022	24	7	2178.85	2.92	4876.2795	0.007	0.00292	0.819952169
841	21/02/2022	20	0	2178.85	7.3	4883.5795	0	0.0073	0.683293475
842	22/02/2022	23	0	2178.85	9.49	4893.0695	0	0.00949	0.785787496
843	23/02/2022	26	0	2178.85	7.665	4900.7345	0	0.007665	0.888281517
844	24/02/2022	21	0	2178.85	9.125	4909.8595	0	0.009125	0.717458148
845	25/02/2022	18	0	2178.85	8.395	4918.2545	0	0.008395	0.614964127
846	26/02/2022	17	3	2181.85	7.3	4925.5545	0.003	0.0073	0.580799453
847	27/02/2022	26	0	2181.85	7.3	4932.8545	0	0.0073	0.888281517
848	28/02/2022	12	20	2201.85	0	4932.8545	0.02	0	0.409976085
849	01/03/2022	14	7.5	2209.35	0.335	4933.1895	0.0075	0.000335	0.478305432
850	02/03/2022	22	2	2211.35	0	4933.1895	0.002	0	0.751622822
851	03/03/2022	12	13.5	2224.85	10.385	4943.5745	0.0135	0.010385	0.409976085
852	04/03/2022	34	0	2224.85	7.705	4951.2795	0	0.007705	1.161598907
853	05/03/2022	1	0	2224.85	5.695	4956.9745	0	0.005695	0.034164674
854	06/03/2022	10	0	2224.85	6.365	4963.3395	0	0.006365	0.341646737
855	07/03/2022	16	0	2224.85	5.695	4969.0345	0	0.005695	0.54663478
856	08/03/2022	17	0	2224.85	30.15	4999.1845	0	0.03015	0.580799453
857	09/03/2022	19	0	2224.85	22.78	5021.9645	0	0.02278	0.649128801
858	10/03/2022	18	0	2224.85	3.35	5025.3145	0	0.00335	0.614964127
859	11/03/2022	23	0	2224.85	3.015	5028.3295	0	0.003015	0.785787496
860	12/03/2022	E	0	2224.85	4.355	5032.6845	0	0.004355	E
861	13/03/2022	E	0	2224.85	4.69	5037.3745	0	0.00469	E
862	14/03/2022	E	0	2224.85	4.02	5041.3945	0	0.00402	E
863	15/03/2022	32	0	2224.85	0	5041.3945	0	0	1.093269559
864	16/03/2022	23	15	2239.85	11.39	5052.7845	0.015	0.01139	0.785787496
865	17/03/2022	32	6.5	2246.35	3.015	5055.7995	0.0065	0.003015	1.093269559
866	18/03/2022	21	0	2246.35	1.675	5057.4745	0	0.001675	0.717458148
867	19/03/2022	27	0	2246.35	1.675	5059.1495	0	0.001675	0.922446191
868	20/03/2022	18	0	2246.35	3.685	5062.8345	0	0.003685	0.614964127
869	21/03/2022	70	0	2246.35	2.01	5064.8445	0	0.00201	2.391527161
870	22/03/2022	E	0	2246.35	2.01	5066.8545	0	0.00201	E
871	23/03/2022	0	0	2246.35	2.345	5069.1995	0	0.002345	0
872	24/03/2022	0	0	2246.35	3.015	5072.2145	0	0.003015	0
873	25/03/2022	0	0	2246.35	3.015	5075.2295	0	0.003015	0
874	26/03/2022	0	0	2246.35	5.36	5080.5895	0	0.00536	0
875	27/03/2022	0	15	2261.35	7.705	5088.2945	0.015	0.007705	0
876	28/03/2022	0	0.5	2261.85	3.35	5091.6445	0.0005	0.00335	0
877	29/03/2022	0	0	2261.85	3.685	5095.3295	0	0.003685	0
878	30/03/2022	0	0	2261.85	3.35	5098.6795	0	0.00335	0
879	31/03/2022	0	0	2261.85	2.68	5101.3595	0	0.00268	0
880	01/04/2022	0	0	2261.85	3.05	5104.4095	0	0.00305	0
881	02/04/2022	0	0	2261.85	2.745	5107.1545	0	0.002745	0
882	03/04/2022	0	9.75	2271.6	3.2025	5110.357	0.00975	0.0032025	0
883	04/04/2022	0	18.1	2289.7	7.076	5117.433	0.0181	0.007076	0
884	05/04/2022	0	1.8	2291.5	1.708	5119.141	0.0018	0.001708	0
885	06/04/2022	0	0	2291.5	1.83	5120.971	0	0.00183	0
886	07/04/2022	0	0	2291.5	2.44	5123.411	0	0.00244	0
887	08/04/2022	0	0	2291.5	2.745	5126.156	0	0.002745	0
888	09/04/2022	899	30	2321.5	10.675	5136.831	0.03	0.010675	30.71404168
889	10/04/2022	42	20	2341.5	6.71	5143.541	0.02	0.00671	1.434916297
890	11/04/2022	67	0	2341.5	1.22	5144.761	0	0.00122	2.28903314
891	12/04/2022	132	23.55	2365.05	9.1805	5153.9415	0.02355	0.0091805	4.509736932
892	13/04/2022	113	0	2365.05	1.22	5155.1615	0	0.00122	3.860608131
893	14/04/2022	710	0	2365.05	1.525	5156.6865	0	0.001525	24.25691835
894	15/04/2022	238	0	2365.05	1.83	5158.5165	0	0.00183	8.131192347
895	16/04/2022	128	0	2365.05	2.135	5160.6515	0	0.002135	4.373078237
896	17/04/2022	120	40.5	2405.55	12.505	5173.1565	0.0405	0.012505	4.099760847
897	18/04/2022	157	20.5	2426.05	12.81	5185.9665	0.0205	0.01281	5.363853775
898	19/04/2022	187	0.3	2426.35	1.098	5187.0645	0.0003	0.001098	6.388793987
899	20/04/2022	103	0	2426.35	2.135	5189.1995	0	0.002135	3.518961394
900	21/04/2022	167	0	2426.35	2.135	5191.3345	0	0.002135	5.705500512
901	22/04/2022	41	0	2426.35	2.745	5194.0795	0	0.002745	1.400751623
902	23/04/2022	80	0	2426.35	2.44	5196.5195	0	0.00244	2.733173898
903	24/04/2022	E	0	2426.35	2.745	5199.2645	0	0.002745	E
904	25/04/2022	E	14.9	2441.25	9.15	5208.4145	0.0149	0.00915	E
905	26/04/2022	0	0.3	2441.55	1.403	5209.8175	0.0003	0.001403	0
906	27/04/2022	E	0	2441.55	1.83	5211.6475	0	0.00183	E
907	28/04/2022	0	0	2441.55	2.135	5213.7825	0	0.002135	0
908	29/04/2022	0	0	2441.55	2.44	5216.2225	0	0.00244	0
909	30/04/2022	197	0	2441.55	2.44	5218.6625	0	0.00244	6.730440724
910	01/05/2022	24	0	2441.55	2.58	5221.2425	0	0.00258	0.819952169
911	02/05/2022	0	0	2441.55	2.58	5223.8225	0	0.00258	0
912	03/05/2022	0	0	2441.55	2.15	5225.9725	0	0.00215	0
913	04/05/2022	0	0	2441.55	1.72	5227.6925	0	0.00172	0
914	05/05/2022	0	0	2441.55	2.365	5230.0575	0	0.002365	0
915	06/05/2022	0	0	2441.55	1.075	5231.1325	0	0.001075	0
916	07/05/2022	422	0	2441.55	2.15	5233.2825	0	0.00215	14.41749231
917	08/05/2022	530	0	2441.55	2.15	5235.4325	0	0.00215	18.10727708
918	09/05/2022	562	3	2444.55	3.44	5238.8725	0.003	0.00344	19.20054663
919	10/05/2022	66	0	2444.55	1.72	5240.5925	0	0.00172	2.254868466
920	11/05/2022	83	0	2444.55	1.29	5241.8825	0	0.00129	2.835667919
921	12/05/2022	84	0	2444.55	1.29	5243.1725	0	0.00129	2.869832593
922	13/05/2022	84	0	2444.55	2.15	5245.3225	0	0.00215	2.869832593
923	14/05/2022	53	0	2444.55	2.15	5247.4725	0	0.00215	1.810727708
924	15/05/2022	83	0	2444.55	3.44	5250.9125	0	0.00344	2.835667919
925	16/05/2022	90	5.45	2450	2.3435	5253.256	0.00545	0.0023435	3.074820635
926	17/05/2022	54	0	2450	0.86	5254.116	0	0.00086	1.844892381
927	18/05/2022	96	0	2450	1.72	5255.836	0	0.00172	3.279808678
928	19/05/2022	59	0	2450	0.645	5256.481	0	0.000645	2.01571575
929	20/05/2022	45	0	2450	1.935	5258.416	0	0.001935	1.537410318
930	21/05/2022	99	15	2465	3.44	5261.856	0.015	0.00344	3.382302699
931	22/05/2022	71	0	2465	0.43	5262.286	0	0.00043	2.425691835
932	23/05/2022	176	1	2466	0.86	5263.146	0.001	0.00086	6.012982576
933	24/05/2022	E	0	2466	1.29	5264.436	0	0.00129	E
934	25/05/2022	118	0	2466	0.86	5265.296	0	0.00086	4.0314315
935	26/05/2022	73	0	2466	1.075	5266.371	0	0.001075	2.494021182
936	27/05/2022	72	0	2466	1.075	5267.446	0	0.001075	2.459856508
937	28/05/2022	77	0	2466	1.505	5268.951	0	0.001505	2.630679877
938	29/05/2022	70	0	2466	1.29	5270.241	0	0.00129	2.391527161
939	30/05/2022	59	0	2466	1.505	5271.746	0	0.001505	2.01571575
940	31/05/2022	78	0	2466	0.86	5272.606	0	0.00086	2.664844551
941	01/06/2022	60	0	2466	0.6	5273.206	0	0.0006	2.049880424
942	02/06/2022	77	0	2466	0.6	5273.806	0	0.0006	2.630679877
943	03/06/2022	68	0	2466	0.48	5274.286	0	0.00048	2.323197813
944	04/06/2022	71	0	2466	0.48	5274.766	0	0.00048	2.425691835
945	05/06/2022	74	0	2466	0.48	5275.246	0	0.00048	2.528185856
946	06/06/2022	81	0	2466	0.72	5275.966	0	0.00072	2.767338572
947	07/06/2022	64	0	2466	0.48	5276.446	0	0.00048	2.186539119
948	08/06/2022	78	0	2466	0.48	5276.926	0	0.00048	2.664844551
949	09/06/2022	65	0	2466	0.72	5277.646	0	0.00072	2.220703792
950	10/06/2022	72	0	2466	0.48	5278.126	0	0.00048	2.459856508
951	11/06/2022	75	0	2466	0.72	5278.846	0	0.00072	2.56235053
952	12/06/2022	92	0	2466	0.48	5279.326	0	0.00048	3.143149983
953	13/06/2022	35	0	2466	0.48	5279.806	0	0.00048	1.19576358
954	14/06/2022	143	0	2466	0.84	5280.646	0	0.00084	4.885548343
955	15/06/2022	24	0	2466	0.6	5281.246	0	0.0006	0.819952169
956	16/06/2022	39	0	2466	0.6	5281.846	0	0.0006	1.332422275
957	17/06/2022	72	0	2466	0.48	5282.326	0	0.00048	2.459856508
958	18/06/2022	70	0	2466	0.72	5283.046	0	0.00072	2.391527161
959	19/06/2022	70	0	2466	1.2	5284.246	0	0.0012	2.391527161
960	20/06/2022	81	0	2466	1.2	5285.446	0	0.0012	2.767338572
961	21/06/2022	33	0	2466	0.84	5286.286	0	0.00084	1.127434233
962	22/06/2022	50	0	2466	0.36	5286.646	0	0.00036	1.708233686
963	23/06/2022	42	0	2466	0.36	5287.006	0	0.00036	1.434916297
964	24/06/2022	125	2	2468	0.24	5287.246	0.002	0.00024	4.270584216
965	25/06/2022	83	11	2479	0	5287.246	0.011	0	2.835667919
966	26/06/2022	70	0	2479	0.96	5288.206	0	0.00096	2.391527161
967	27/06/2022	63	0	2479	0.36	5288.566	0	0.00036	2.152374445
968	28/06/2022	78	0	2479	0.72	5289.286	0	0.00072	2.664844551
969	29/06/2022	72	0	2479	0.72	5290.006	0	0.00072	2.459856508
970	30/06/2022	70	0	2479	0.48	5290.486	0	0.00048	2.391527161
971	01/07/2022	64	0	2479	0.4	5290.886	0	0.0004	2.186539119
972	02/07/2022	64	0	2479	0.4	5291.286	0	0.0004	2.186539119
973	03/07/2022	72	0	2479	0.8	5292.086	0	0.0008	2.459856508
974	04/07/2022	71	0	2479	0.6	5292.686	0	0.0006	2.425691835
975	05/07/2022	94	0	2479	0.4	5293.086	0	0.0004	3.21147933
976	06/07/2022	70	0	2479	0.5	5293.586	0	0.0005	2.391527161
977	07/07/2022	52	0	2479	0.5	5294.086	0	0.0005	1.776563034
978	08/07/2022	87	0	2479	0.5	5294.586	0	0.0005	2.972326614
979	09/07/2022	98	0	2479	0.5	5295.086	0	0.0005	3.348138025
980	10/07/2022	35	0	2479	0.6	5295.686	0	0.0006	1.19576358
981	11/07/2022	80	0	2479	0.9	5296.586	0	0.0009	2.733173898
982	12/07/2022	68	0	2479	0.4	5296.986	0	0.0004	2.323197813
983	13/07/2022	70	0	2479	0.5	5297.486	0	0.0005	2.391527161
984	14/07/2022	57	0	2479	0.5	5297.986	0	0.0005	1.947386402
985	15/07/2022	65	0	2479	0.6	5298.586	0	0.0006	2.220703792
986	16/07/2022	62	0	2479	0.6	5299.186	0	0.0006	2.118209771
987	17/07/2022	70	0	2479	0.5	5299.686	0	0.0005	2.391527161
988	18/07/2022	87	0	2479	0.6	5300.286	0	0.0006	2.972326614
989	19/07/2022	106	0	2479	0.7	5300.986	0	0.0007	3.621455415
990	20/07/2022	46	0	2479	0.3	5301.286	0	0.0003	1.571574991
991	21/07/2022	57	0	2479	0.2	5301.486	0	0.0002	1.947386402
992	22/07/2022	78	0	2479	0.4	5301.886	0	0.0004	2.664844551
993	23/07/2022	65	0	2479	0	5301.886	0	0	2.220703792
994	24/07/2022	81	0	2479	1.5	5303.386	0	0.0015	2.767338572
995	25/07/2022	78	0	2479	0.7	5304.086	0	0.0007	2.664844551
996	26/07/2022	73	0	2479	0.5	5304.586	0	0.0005	2.494021182
997	27/07/2022	66	0	2479	0.5	5305.086	0	0.0005	2.254868466
998	28/07/2022	70	0	2479	0.6	5305.686	0	0.0006	2.391527161
999	29/07/2022	72	0	2479	0.5	5306.186	0	0.0005	2.459856508
1000	30/07/2022	54	0	2479	0.6	5306.786	0	0.0006	1.844892381
1001	31/07/2022	72	0	2479	0.6	5307.386	0	0.0006	2.459856508
1002	01/08/2022	71	0	2479	0.945	5308.331	0	0.000945	2.425691835
1003	02/08/2022	119	0	2479	0.945	5309.276	0	0.000945	4.065596174
1004	03/08/2022	35	0	2479	0.675	5309.951	0	0.000675	1.19576358
1005	04/08/2022	85	0	2479	0.675	5310.626	0	0.000675	2.903997267
1006	05/08/2022	52	0	2479	0.81	5311.436	0	0.00081	1.776563034
1007	06/08/2022	84	0	2479	1.35	5312.786	0	0.00135	2.869832593
1008	07/08/2022	59	0	2479	1.08	5313.866	0	0.00108	2.01571575
1009	08/08/2022	55	0	2479	0.945	5314.811	0	0.000945	1.879057055
1010	09/08/2022	65	0	2479	0.54	5315.351	0	0.00054	2.220703792
1011	10/08/2022	56	0	2479	0.54	5315.891	0	0.00054	1.913221729
1012	11/08/2022	61	0	2479	0.81	5316.701	0	0.00081	2.084045097
1013	12/08/2022	39	0	2479	0.81	5317.511	0	0.00081	1.332422275
1014	13/08/2022	130	0	2479	0.81	5318.321	0	0.00081	4.441407585
1015	14/08/2022	74	0	2479	0.81	5319.131	0	0.00081	2.528185856
1016	15/08/2022	51	0	2479	1.08	5320.211	0	0.00108	1.74239836
1017	16/08/2022	63	0	2479	1.215	5321.426	0	0.001215	2.152374445
1018	17/08/2022	58	0	2479	1.35	5322.776	0	0.00135	1.981551076
1019	18/08/2022	45	0	2479	0.81	5323.586	0	0.00081	1.537410318
1020	19/08/2022	67	0	2479	0.675	5324.261	0	0.000675	2.28903314
1021	20/08/2022	77	0	2479	0.675	5324.936	0	0.000675	2.630679877
1022	21/08/2022	90	0	2479	0.81	5325.746	0	0.00081	3.074820635
1023	22/08/2022	107	0	2479	1.215	5326.961	0	0.001215	3.655620089
1024	23/08/2022	70	0	2479	1.215	5328.176	0	0.001215	2.391527161
1025	24/08/2022	59	0	2479	1.35	5329.526	0	0.00135	2.01571575
1026	25/08/2022	55	0	2479	0.945	5330.471	0	0.000945	1.879057055
1027	26/08/2022	37	0	2479	0.675	5331.146	0	0.000675	1.264092928
1028	27/08/2022	43	0	2479	0.81	5331.956	0	0.00081	1.46908097
1029	28/08/2022	42	0	2479	0.81	5332.766	0	0.00081	1.434916297
1030	29/08/2022	41	0	2479	0.81	5333.576	0	0.00081	1.400751623
1031	30/08/2022	49	0	2479	0.81	5334.386	0	0.00081	1.674069013
1032	31/08/2022	E	0	2479	0.81	5335.196	0	0.00081	E
1033	01/09/2022	37	0	2479	2.05	5337.246	0	0.00205	1.264092928
1034	02/09/2022	7	0	2479	2.05	5339.296	0	0.00205	0.239152716
1035	03/09/2022	7	0	2479	1.845	5341.141	0	0.001845	0.239152716
1036	04/09/2022	12	0	2479	1.64	5342.781	0	0.00164	0.409976085
1037	05/09/2022	9	0	2479	2.87	5345.651	0	0.00287	0.307482064
1038	06/09/2022	E	0	2479	1.64	5347.291	0	0.00164	E
1039	07/09/2022	35	0	2479	2.05	5349.341	0	0.00205	1.19576358
1040	08/09/2022	11	0	2479	2.05	5351.391	0	0.00205	0.375811411
1041	09/09/2022	0	0	2479	0.82	5352.211	0	0.00082	0
1042	10/09/2022	E	0	2479	1.64	5353.851	0	0.00164	E
1043	11/09/2022	20	0	2479	1.435	5355.286	0	0.001435	0.683293475
1044	12/09/2022	39	0	2479	1.64	5356.926	0	0.00164	1.332422275
1045	13/09/2022	22	0	2479	2.05	5358.976	0	0.00205	0.751622822
1046	14/09/2022	17	0	2479	1.845	5360.821	0	0.001845	0.580799453
1047	15/09/2022	56	0	2479	1.64	5362.461	0	0.00164	1.913221729
1048	16/09/2022	9	0	2479	2.05	5364.511	0	0.00205	0.307482064
1049	17/09/2022	2	0	2479	2.05	5366.561	0	0.00205	0.068329347
1050	18/09/2022	23	0	2479	1.64	5368.201	0	0.00164	0.785787496
1051	19/09/2022	33	0	2479	1.64	5369.841	0	0.00164	1.127434233
1052	20/09/2022	20	0	2479	1.845	5371.686	0	0.001845	0.683293475
1053	21/09/2022	16	0	2479	1.845	5373.531	0	0.001845	0.54663478
1054	22/09/2022	0	0	2479	1.64	5375.171	0	0.00164	0
1055	23/09/2022	13	0	2479	2.05	5377.221	0	0.00205	0.444140758
1056	24/09/2022	19	0	2479	2.255	5379.476	0	0.002255	0.649128801
1057	25/09/2022	28	0	2479	2.05	5381.526	0	0.00205	0.956610864
1058	26/09/2022	77	0	2479	2.05	5383.576	0	0.00205	2.630679877
1059	27/09/2022	121	0	2479	2.05	5385.626	0	0.00205	4.133925521
1060	28/09/2022	104	0	2479	1.845	5387.471	0	0.001845	3.553126068
1061	29/09/2022	86	0	2479	2.255	5389.726	0	0.002255	2.938161941
1062	30/09/2022	116	0	2479	1.845	5391.571	0	0.001845	3.963102152
1063	01/10/2022	19	0	2479	1.325	5392.896	0	0.001325	0.649128801
1064	02/10/2022	74	0	2479	1.59	5394.486	0	0.00159	2.528185856
1065	03/10/2022	93	0	2479	2.12	5396.606	0	0.00212	3.177314657
1066	04/10/2022	65	0	2479	2.12	5398.726	0	0.00212	2.220703792
1067	05/10/2022	50	0	2479	3.445	5402.171	0	0.003445	1.708233686
1068	06/10/2022	57	0	2479	2.915	5405.086	0	0.002915	1.947386402

	Measured Inputs										Iteration 1
Step	Date	Observed Leachate Flow Rate - Qi	Observed Precipitation	Cumulative Observed Precipitation	Observed Factored Evaporation	Cumulative Observed Factored Evaporation	Observed Precipitation	Observed Factored Evaporation	Observed Leachate Flow Rate - Qi	Cumulative Observed Leachate Flow Rate	Pi
i	(dd/mm/yyyy)	(m³)	(mm)	(mm)	(mm)	(mm)	(m)	(m)	(mm)	(mm)	(mm)
1069	07/10/2022	43	0	2479	3.18	5408.266	0	0.00318	1.46908097	1796.925179	0
1070	08/10/2022	11	0	2479	2.65	5410.916	0	0.00265	0.375811411	1797.300991	0
1071	09/10/2022	20	0	2479	3.445	5414.361	0	0.003445	0.683293475	1797.984284	0
1072	10/10/2022	47	0	2479	2.65	5417.011	0	0.00265	1.605739665	1799.590024	0
1073	11/10/2022	38	0	2479	4.505	5421.516	0	0.004505	1.298257602	1800.888282	0
1074	12/10/2022	43	0	2479	2.65	5424.166	0	0.00265	1.46908097	1802.357362	0
1075	13/10/2022	37	0	2479	3.18	5427.346	0	0.00318	1.264092928	1803.621455	0
1076	14/10/2022	37	0	2479	2.385	5429.731	0	0.002385	1.264092928	1804.885548	0
1077	15/10/2022	114	0	2479	2.385	5432.116	0	0.002385	3.894772805	1808.780321	0
1078	16/10/2022	4	0	2479	3.18	5435.296	0	0.00318	0.136658695	1808.91698	0
1079	17/10/2022	3	0	2479	2.385	5437.681	0	0.002385	0.102494021	1809.019474	0
1080	18/10/2022	35	0	2479	2.385	5440.066	0	0.002385	1.19576358	1810.215237	0
1081	19/10/2022	30	0	2479	1.325	5441.391	0	0.001325	1.024940212	1811.240178	0
1082	20/10/2022	51	0	2479	2.385	5443.776	0	0.002385	1.74239836	1812.982576	0
1083	21/10/2022	68	0	2479	4.505	5448.281	0	0.004505	2.323197813	1815.305774	0
1084	22/10/2022	26	0	2479	2.65	5450.931	0	0.00265	0.888281517	1816.194055	0
1085	23/10/2022	39	0	2479	2.65	5453.581	0	0.00265	1.332422275	1817.526478	0
1086	24/10/2022	22	0	2479	3.18	5456.761	0	0.00318	0.751622822	1818.2781	0
1087	25/10/2022	6	14	2493	5.3	5462.061	0.014	0.0053	0.204988042	1818.483088	0
1088	26/10/2022	10	0	2493	3.71	5465.771	0	0.00371	0.341646737	1818.824735	0
1089	27/10/2022	27	8	2501	1.59	5467.361	0.008	0.00159	0.922446191	1819.747181	0
1090	28/10/2022	17	5	2506	2.12	5469.481	0.005	0.00212	0.580799453	1820.327981	0
1091	29/10/2022	18	0	2506	2.915	5472.396	0	0.002915	0.614964127	1820.942945	0
1092	30/10/2022	11	0	2506	2.915	5475.311	0	0.002915	0.375811411	1821.318756	0
1093	31/10/2022	13	0	2506	2.65	5477.961	0	0.00265	0.444140758	1821.762897	0
1094	01/11/2022	E	7.8	2513.8	0	5477.961	0.0078	0	E	1821.762897	0
1095	02/11/2022	0	0	2513.8	1.3	5479.261	0	0.0013	0	1821.762897	0
1096	03/11/2022	3	0	2513.8	0	5479.261	0	0	0.102494021	1821.865391	0
1097	04/11/2022	9	0	2513.8	1.95	5481.211	0	0.00195	0.307482064	1822.172873	0
1098	05/11/2022	22	15	2528.8	0	5481.211	0.015	0	0.751622822	1822.924496	0
1099	06/11/2022	98	0	2528.8	6.5	5487.711	0	0.0065	3.348138025	1826.272634	0
1100	07/11/2022	99	10	2538.8	3.9	5491.611	0.01	0.0039	3.382302699	1829.654937	0
1101	08/11/2022	83	32	2570.8	0	5491.611	0.032	0	2.835667919	1832.490605	0
1102	09/11/2022	102	12	2582.8	5.525	5497.136	0.012	0.005525	3.48479672	1835.975401	0.017591067
1103	10/11/2022	99	0	2582.8	4.225	5501.361	0	0.004225	3.382302699	1839.357704	0.014166103
1104	11/11/2022	103	5	2587.8	2.275	5503.636	0.005	0.002275	3.518961394	1842.876666	0.003938414
1105	12/11/2022	104	16	2603.8	3.9	5507.536	0.016	0.0039	3.553126068	1846.429792	0.001094855
1106	13/11/2022	101	50	2653.8	0	5507.536	0.05	0	3.450632046	1849.880424	0.131373877
1107	14/11/2022	89	13	2666.8	0	5507.536	0.013	0	3.040655962	1852.92108	0.262425695
1108	15/11/2022	93	0	2666.8	3.25	5510.786	0	0.00325	3.177314657	1856.098394	0.072960921
1109	16/11/2022	94	0	2666.8	1.95	5512.736	0	0.00195	3.21147933	1859.309874	0.020284875
1110	17/11/2022	99	0	2666.8	1.95	5514.686	0	0.00195	3.382302699	1862.692176	0.005639588
1111	18/11/2022	97	0	2666.8	4.55	5519.236	0	0.00455	3.313973352	1866.00615	0.001567825
1112	19/11/2022	111	2	2668.8	5.2	5524.436	0.002	0.0052	3.792278784	1869.798428	0.000435771
1113	20/11/2022	85	0	2668.8	5.2	5529.636	0	0.0052	2.903997267	1872.702426	0.000121031
1114	21/11/2022	99	0	2668.8	5.2	5534.836	0	0.0052	3.382302699	1876.084728	3.35248E-05
1115	22/11/2022	101	0	2668.8	4.875	5539.711	0	0.004875	3.450632046	1879.53536	0.070942364
1116	23/11/2022	103	2	2670.8	1.625	5541.336	0.002	0.001625	3.518961394	1883.054322	0.116441194
1117	24/11/2022	93	0	2670.8	3.9	5545.236	0	0.0039	3.177314657	1886.231636	0.193332689
1118	25/11/2022	95	5	2675.8	4.225	5549.461	0.005	0.004225	3.245644004	1889.47728	0.303145985
1119	26/11/2022	68	10	2685.8	2.6	5552.061	0.01	0.0026	2.323197813	1891.800478	0.722889752
1120	27/11/2022	69	15	2700.8	3.25	5555.311	0.015	0.00325	2.357362487	1894.157841	1.197459533
1121	28/11/2022	34	0	2700.8	1.625	5556.936	0	0.001625	1.161598907	1895.31944	1.605601886
1122	29/11/2022	68	0	2700.8	1.95	5558.886	0	0.00195	2.323197813	1897.642638	2.012518879
1123	30/11/2022	E	0	2700.8	3.25	5562.136	0	0.00325	E	1897.642638	2.101931227
1124	01/12/2022	E	0	2700.8	2.19	5564.326	0	0.00219	E	1897.642638	2.223645832
1125	02/12/2022	2	0	2700.8	2.19	5566.516	0	0.00219	0.068329347	1897.710967	2.392552621
1126	03/12/2022	5	0	2700.8	2.92	5569.436	0	0.00292	0.170823369	1897.88179	2.523833863
1127	04/12/2022	0	0	2700.8	2.555	5571.991	0	0.002555	0	1897.88179	2.35125467
1128	05/12/2022	E	0	2700.8	3.285	5575.276	0	0.003285	E	1897.88179	2.374451403
1129	06/12/2022	E	26	2726.8	0	5575.276	0.026	0	E	1897.88179	2.426003872
1130	07/12/2022	71	9	2735.8	1.825	5577.101	0.009	0.001825	2.425691835	1900.307482	2.512652437
1131	08/12/2022	E	0	2735.8	1.095	5578.196	0	0.001095	E	1900.307482	2.515712369
1132	09/12/2022	E	0	2735.8	1.825	5580.021	0	0.001825	E	1900.307482	2.452456042
1133	10/12/2022	E	0	2735.8	1.46	5581.481	0	0.00146	E	1900.307482	2.46087424
1134	11/12/2022	E	0	2735.8	1.46	5582.941	0	0.00146	E	1900.307482	2.504807875
1135	12/12/2022	E	0	2735.8	1.46	5584.401	0	0.00146	E	1900.307482	2.53438671
1136	13/12/2022	31	0	2735.8	2.19	5586.591	0	0.00219	1.059104886	1901.366587	2.522063318
1137	14/12/2022	30	4	2739.8	0.365	5586.956	0.004	0.000365	1.024940212	1902.391527	2.392939446
1138	15/12/2022	29	0	2739.8	1.095	5588.051	0	0.001095	0.990775538	1903.382303	2.41851643
1139	16/12/2022	36	16.3	2756.1	0.1095	5588.1605	0.0163	0.0001095	1.229928254	1904.612231	2.429053157
1140	17/12/2022	29	8.5	2764.6	0.9125	5589.073	0.0085	0.0009125	0.990775538	1905.603006	2.405735436
1141	18/12/2022	32	7.4	2772	0.876	5589.949	0.0074	0.000876	1.093269559	1906.696276	2.417788638
1142	19/12/2022	291	16	2788	1.46	5591.409	0.016	0.00146	9.941920055	1916.638196	2.431436307
1143	20/12/2022	12	9	2797	0.365	5591.774	0.009	0.000365	0.409976085	1917.048172	3.24709557
1144	21/12/2022	169	11.4	2808.4	0.511	5592.285	0.0114	0.000511	5.77382986	1922.822002	3.310785139
1145	22/12/2022	388	0	2808.4	0.73	5593.015	0	0.00073	13.25589341	1936.077895	2.070554802
1146	23/12/2022	396	0	2808.4	0.73	5593.745	0	0.00073	13.5292108	1949.607106	0.594183592
1147	24/12/2022	301	0	2808.4	1.095	5594.84	0	0.001095	10.28356679	1959.890673	0.233716846
1148	25/12/2022	297	0	2808.4	1.095	5595.935	0	0.001095	10.1469081	1970.037581	0.160885572
1149	26/12/2022	157	5	2813.4	1.825	5597.76	0.005	0.001825	5.363853775	1975.401435	0.142544767
1150	27/12/2022	120	0	2813.4	0.73	5598.49	0	0.00073	4.099760847	1979.501196	0.221384861
1151	28/12/2022	85	2	2815.4	0.73	5599.22	0.002	0.00073	2.903997267	1982.405193	0.657888426
1152	29/12/2022	264	2	2817.4	0.73	5599.95	0.002	0.00073	9.019473864	1991.424667	0.503431948
1153	30/12/2022	97	14.5	2831.9	0.9125	5600.8625	0.0145	0.0009125	3.313973352	1994.73864	0.699627507
1154	31/12/2022	138	5.5	2837.4	0.9125	5601.775	0.0055	0.0009125	4.714724974	1999.453365	1.981556888
1155	01/01/2023	22	1.4	2838.8	2.336	5604.111	0.0014	0.002336	0.751622822	2000.204988	1.943219896
1156	02/01/2023	22	0	2838.8	2.555	5606.666	0	0.002555	0.751622822	2000.956611	0.593875339
1157	03/01/2023	51	0	2838.8	4.745	5611.411	0	0.004745	1.74239836	2002.699009	0.527551965
1158	04/01/2023	439	0	2838.8	4.745	5616.156	0	0.004745	14.99829177	2017.697301	0.641514902
1159	05/01/2023	68	3	2841.8	1.095	5617.251	0.003	0.001095	2.323197813	2020.020499	0.422255295
1160	06/01/2023	170	0	2841.8	4.015	5621.266	0	0.004015	5.807994534	2025.828493	0.598822882
1161	07/01/2023	14	9.9	2851.7	2.8835	5624.1495	0.0099	0.0028835	0.478305432	2026.306799	0.382767581
1162	08/01/2023	22	0	2851.7	1.46	5625.6095	0	0.00146	0.751622822	2027.058422	0.177401122
1163	09/01/2023	21	31.2	2882.9	0	5625.6095	0.0312	0	0.717458148	2027.77588	0.086749441
1164	10/01/2023	20	0	2882.9	1.46	5627.0695	0	0.00146	0.683293475	2028.459173	0.024118435
1165	11/01/2023	36	0	2882.9	5.84	5632.9095	0	0.00584	1.229928254	2029.689101	0.006705416
1166	12/01/2023	63	0	2882.9	5.84	5638.7495	0	0.00584	2.152374445	2031.841476	0.001864152
1167	13/01/2023	87	0	2882.9	5.11	5643.8595	0	0.00511	2.972326614	2034.813803	0.153192383
1168	14/01/2023	256	0	2882.9	6.205	5650.0645	0	0.006205	8.746156474	2043.559959	0.189413175
1169	15/01/2023	8	0	2882.9	6.935	5656.9995	0	0.006935	0.27331739	2043.833276	0.052661575
1170	16/01/2023	295	0	2882.9	7.3	5664.2995	0	0.0073	10.07857875	2053.911855	0.014641138
1171	17/01/2023	341	0	2882.9	7.3	5671.5995	0	0.0073	11.65015374	2065.562009	0.004070486
1172	18/01/2023	20	0	2882.9	7.665	5679.2645	0	0.007665	0.683293475	2066.245302	0.001131574
1173	19/01/2023	0	0	2882.9	6.57	5685.8345	0	0.00657	0	2066.245302	0.000314482
1174	20/01/2023	E	0	2882.9	6.205	5692.0395	0	0.006205	E	2066.245302	8.72092E-05
1175	21/01/2023	14	0	2882.9	3.65	5695.6895	0	0.00365	0.478305432	2066.723608	2.41494E-05
1176	22/01/2023	19	0	2882.9	6.57	5702.2595	0	0.00657	0.649128801	2067.372737	6.5894E-06
1177	23/01/2023	30	0	2882.9	4.38	5706.6395	0	0.00438	1.024940212	2068.397677	1.70726E-06
1178	24/01/2023	13	0	2882.9	5.475	5712.1145	0	0.005475	0.444140758	2068.841818	3.49905E-07
1179	25/01/2023	E	0	2882.9	8.76	5720.8745	0	0.00876	E	2068.841818	9.41897E-09
1180	26/01/2023	E	0	2882.9	6.57	5727.4445	0	0.00657	E	2068.841818	1.93201E-19
1181	27/01/2023	E	0	2882.9	7.3	5734.7445	0	0.0073	E	2068.841818	1.93201E-19
1182	28/01/2023	E	0	2882.9	7.665	5742.4095	0	0.007665	E	2068.841818	1.93201E-19
1183	29/01/2023	E	0	2882.9	6.935	5749.3445	0	0.006935	E	2068.841818	1.93201E-19
1184	30/01/2023	E	4	2886.9	0.73	5750.0745	0.004	0.00073	E	2068.841818	1.93201E-19
1185	31/01/2023	21	6	2892.9	1.095	5751.1695	0.006	0.001095	0.717458148	2069.559276	1.93201E-19
1186	01/02/2023	154	6	2898.9	1.825	5752.9945	0.006	0.001825	5.261359754	2074.820635	1.93201E-19
1187	02/02/2023	117	0.9	2899.8	1.0585	5754.053	0.0009	0.0010585	3.997266826	2078.817902	1.93201E-19
1188	03/02/2023	70	0	2899.8	2.555	5756.608	0	0.002555	2.391527161	2081.209429	1.93201E-19
1189	04/02/2023	13	0	2899.8	2.92	5759.528	0	0.00292	0.444140758	2081.65357	1.93201E-19
1190	05/02/2023	17	0	2899.8	1.46	5760.988	0	0.00146	0.580799453	2082.23437	1.93201E-19
1191	06/02/2023	18	0	2899.8	2.19	5763.178	0	0.00219	0.614964127	2082.849334	1.93201E-19
1192	07/02/2023	36	0	2899.8	7.3	5770.478	0	0.0073	1.229928254	2084.079262	1.93201E-19
1193	08/02/2023	24	0	2899.8	4.745	5775.223	0	0.004745	0.819952169	2084.899214	1.93201E-19
1194	09/02/2023	41	1.1	2900.9	2.5915	5777.8145	0.0011	0.0025915	1.400751623	2086.299966	1.93201E-19
1195	10/02/2023	12	9.8	2910.7	0	5777.8145	0.0098	0	0.409976085	2086.709942	1.93201E-19
1196	11/02/2023	126	33	2943.7	0	5777.8145	0.033	0	4.30474889	2091.014691	1.93201E-19
1197	12/02/2023	5	10.2	2953.9	0.073	5777.8875	0.0102	7.3E-05	0.170823369	2091.185514	1.93201E-19
1198	13/02/2023	44	8	2961.9	0.365	5778.2525	0.008	0.000365	1.503245644	2092.68876	1.93201E-19
1199	14/02/2023	121	35	2996.9	1.46	5779.7125	0.035	0.00146	4.133925521	2096.822685	1.93201E-19
1200	15/02/2023	72	84.5	3081.4	12.5925	5792.305	0.0845	0.0125925	2.459856508	2099.282542	1.93201E-19
1201	16/02/2023	126	0	3081.4	21.535	5813.84	0	0.021535	4.30474889	2103.587291	2.83563E-21
1202	17/02/2023	43	12.25	3093.65	2.555	5816.395	0.01225	0.002555	1.46908097	2105.056372	0
1203	18/02/2023	175	1	3094.65	2.555	5818.95	0.001	0.002555	5.978817902	2111.03519	0
1204	19/02/2023	31	4.5	3099.15	2.555	5821.505	0.0045	0.002555	1.059104886	2112.094294	0
1205	20/02/2023	232	1.1	3100.25	2.993	5824.498	0.0011	0.002993	7.926204305	2120.020499	0
1206	21/02/2023	50	0	3100.25	6.205	5830.703	0	0.006205	1.708233686	2121.728732	0
1207	22/02/2023	45	0	3100.25	6.57	5837.273	0	0.00657	1.537410318	2123.266143	0.051513494
1208	23/02/2023	71	0	3100.25	5.84	5843.113	0	0.00584	2.425691835	2125.691835	0.21783807
1209	24/02/2023	5	0	3100.25	8.03	5851.143	0	0.00803	0.170823369	2125.862658	0.495096985
1210	25/02/2023	5	0	3100.25	8.76	5859.903	0	0.00876	0.170823369	2126.033481	0.792929076
1211	26/02/2023	210	0	3100.25	8.76	5868.663	0	0.00876	7.174581483	2133.208063	0.825791998
1212	27/02/2023	51	0	3100.25	6.935	5875.598	0	0.006935	1.74239836	2134.950461	0.889071779
1213	28/02/2023	62	0	3100.25	14.965	5890.563	0	0.014965	2.118209771	2137.068671	1.033092805
1214	01/03/2023	11	0	3100.25	7.37	5897.933	0	0.00737	0.375811411	2137.444482	1.188147483
1215	02/03/2023	4	0	3100.25	5.695	5903.628	0	0.005695	0.136658695	2137.581141	1.336771885
1216	03/03/2023	E	0	3100.25	7.705	5911.333	0	0.007705	E	2137.581141	1.475644923
1217	04/03/2023	21	0	3100.25	7.37	5918.703	0	0.00737	0.717458148	2138.298599	1.464029831
1218	05/03/2023	10	0	3100.25	7.705	5926.408	0	0.007705	0.341646737	2138.640246	1.540229221
1219	06/03/2023	0	0	3100.25	4.355	5930.763	0	0.004355	0	2138.640246	1.810328571
1220	07/03/2023	E	2.15	3102.4	7.8055	5938.5685	0.00215	0.0078055	E	2138.640246	2.061164577
1221	08/03/2023	E	1	3103.4	4.355	5942.9235	0.001	0.004355	E	2138.640246	2.249562061
1222	09/03/2023	E	0	3103.4	5.695	5948.6185	0	0.005695	E	2138.640246	2.379221439
1223	10/03/2023	E	0	3103.4	6.7	5955.3185	0	0.0067	E	2138.640246	2.497787517
1224	11/03/2023	E	0	3103.4	6.7	5962.0185	0	0.0067	E	2138.640246	2.698145858
1225	12/03/2023	E	0	3103.4	7.37	5969.3885	0	0.00737	E	2138.640246	2.594508924
1226	13/03/2023	E	0	3103.4	6.7	5976.0885	0	0.0067	E	2138.640246	2.465443251
1227	14/03/2023	58	0	3103.4	8.71	5984.7985	0	0.00871	1.981551076	2140.621797	2.372840466
1228	15/03/2023	67	0	3103.4	6.365	5991.1635	0	0.006365	2.28903314	2142.91083	2.217478136
1229	16/03/2023	71	0	3103.4	6.03	5997.1935	0	0.00603	2.425691835	2145.336522	2.155220246
1230	17/03/2023	23	0	3103.4	5.36	6002.5535	0	0.00536	0.785787496	2146.12231	2.245678639
1231	18/03/2023	45	0	3103.4	4.02	6006.5735	0	0.00402	1.537410318	2147.65972	2.3413901
1232	19/03/2023	41	0	3103.4	5.025	6011.5985	0	0.005025	1.400751623	2149.060471	2.412743943
1233	20/03/2023	66	0	3103.4	5.695	6017.2935	0	0.005695	2.254868466	2151.31534	2.459905366
1234	21/03/2023	91	0	3103.4	5.025	6022.3185	0	0.005025	3.108985309	2154.424325	2.488796877
1235	22/03/2023	55	0	3103.4	5.36	6027.6785	0	0.00536	1.879057055	2156.303382	2.505047569
1236	23/03/2023	101	0	3103.4	5.36	6033.0385	0	0.00536	3.450632046	2159.754014	2.512868437
1237	24/03/2023	70	0	3103.4	4.02	6037.0585	0	0.00402	2.391527161	2162.145542	2.515166954
1238	25/03/2023	111	5	3108.4	0.335	6037.3935	0.005	0.000335	3.792278784	2165.93782	2.513883009
1239	26/03/2023	135	7.95	3116.35	1.3065	6038.7	0.00795	0.0013065	4.612230953	2170.550051	2.510290008
1240	27/03/2023	73	0	3116.35	3.685	6042.385	0	0.003685	2.494021182	2173.044072	2.505217062
1241	28/03/2023	47	0	3116.35	4.69	6047.075	0	0.00469	1.605739665	2174.649812	2.499201783
1242	29/03/2023	39	0	3116.35	5.36	6052.435	0	0.00536	1.332422275	2175.982234	2.492592068
1243	30/03/2023	93	0	3116.35	4.69	6057.125	0	0.00469	3.177314657	2179.159549	2.485612853
1244	31/03/2023	63	0.45	3116.8	3.6515	6060.7765	0.00045	0.0036515	2.152374445	2181.311923	2.58133961
1245	01/04/2023	126	0	3116.8	5.49	6066.2665	0	0.00549	4.30474889	2185.616672	3.4269422
1246	02/04/2023	74	0	3116.8	4.575	6070.8415	0	0.004575	2.528185856	2188.144858	3.133453994
1247	03/04/2023	92	1.9	3118.7	2.684	6073.5255	0.0019	0.002684	3.143149983	2191.288008	1.721044837
1248	04/04/2023	40	12.75	3131.45	3.5075	6077.033	0.01275	0.0035075	1.366586949	2192.654595	0.478494247
1249	05/04/2023	43	0	3131.45	3.355	6080.388	0	0.003355	1.46908097	2194.123676	0.133033496
1250	06/04/2023	49	0	3131.45	4.27	6084.658	0	0.00427	1.674069013	2195.797745	0.036986585
1251	07/04/2023	33	0	3131.45	5.185	6089.843	0	0.005185	1.127434233	2196.925179	0.04581176
1252	08/04/2023	35	0	3131.45	5.185	6095.028	0	0.005185	1.19576358	2198.120943	0.031470317
1253	09/04/2023	23	0	3131.45	5.49	6100.518	0	0.00549	0.785787496	2198.90673	0.008749427
1254	10/04/2023	13	0	3131.45	5.795	6106.313	0	0.005795	0.444140758	2199.350871	0.002432439
1255	11/04/2023	14	0	3131.45	5.795	6112.108	0	0.005795	0.478305432	2199.829177	0.000676156
1256	12/04/2023	14	0	3131.45	6.1	6118.208	0	0.0061	0.478305432	2200.307482	0.000187864
1257	13/04/2023	49	0	3131.45	6.405	6124.613	0	0.006405	1.674069013	2201.981551	5.21062E-05
1258	14/04/2023	150	0	3131.45	7.32	6131.933	0	0.00732	5.124701059	2207.106252	0.170189969
1259	15/04/2023	36	0	3131.45	4.27	6136.203	0	0.00427	1.229928254	2208.33618	0.180627136
1260	16/04/2023	45	0	3131.45	5.185	6141.388	0	0.005185	1.537410318	2209.873591	0.055984824
1261	17/04/2023	73	0	3131.45	6.1	6147.488	0	0.0061	2.494021182	2212.367612	0.015565086
1262	18/04/2023	55	0	3131.45	5.185	6152.673	0	0.005185	1.879057055	2214.246669	0.004327367
1263	19/04/2023	54	0	3131.45	6.71	6159.383	0	0.00671	1.844892381	2216.091561	0.001202994
1264	20/04/2023	57	0	3131.45	7.015	6166.398	0	0.007015	1.947386402	2218.038948	0.000334338
1265	21/04/2023	61	0	3131.45	7.93	6174.328	0	0.00793	2.084045097	2220.122993	9.28298E-05
1266	22/04/2023	47	0	3131.45	6.71	6181.038	0	0.00671	1.605739665	2221.728732	2.56843E-05
1267	23/04/2023	62	0	3131.45	7.32	6188.358	0	0.00732	2.118209771	2223.846942	0.076152532
1268	24/04/2023	35	0	3131.45	4.88	6193.238	0	0.00488	1.19576358	2225.042706	0.194531885
1269	25/04/2023	39	0	3131.45	5.185	6198.423	0	0.005185	1.332422275	2226.375128	0.236816778
1270	26/04/2023	64	0	3131.45	6.1	6204.523	0	0.0061	2.186539119	2228.561667	0.248743367
1271	27/04/2023	107	0	3131.45	4.27	6208.793	0	0.00427	3.655620089	2232.217287	0.246005744
1272	28/04/2023	55	0	3131.45	4.27	6213.063	0	0.00427	1.879057055	2234.096344	0.235108929
1273	29/04/2023	56	0	3131.45	4.575	6217.638	0	0.004575	1.913221729	2236.009566	0.219377928
1274	30/04/2023	56	2.5	3133.95	4.88	6222.518	0.0025	0.00488	1.913221729	2237.922788	0.13711422
1275	01/05/2023	54	0	3133.95	1.72	6224.238	0	0.00172	1.844892381	2239.76768	0.041329505
1276	02/05/2023	57	0	3133.95	1.29	6225.528	0	0.00129	1.947386402	2241.715067	0.075338288
1277	03/05/2023	72	0	3133.95	3.225	6228.753	0	0.003225	2.459856508	2244.174923	0.084151291
1278	04/05/2023	44	0	3133.95	5.375	6234.128	0	0.005375	1.503245644	2245.678169	0.090634033
1279	05/05/2023	47	6.95	3140.9	0.6235	6234.7515	0.00695	0.0006235	1.605739665	2247.283908	0.06500037
1280	06/05/2023	14	3	3143.9	0.86	6235.6115	0.003	0.00086	0.478305432	2247.762214	0.080687475
1281	07/05/2023	9	0	3143.9	1.29	6236.9015	0	0.00129	0.307482064	2248.069696	0.056049892
1282	08/05/2023	7	31	3174.9	6.235	6243.1365	0.031	0.006235	0.239152716	2248.308849	0.076472009
1283	09/05/2023	3	5.3	3180.2	0.774	6243.9105	0.0053	0.000774	0.102494021	2248.411343	0.039322532
1284	10/05/2023	3	0	3180.2	1.935	6245.8455	0	0.001935	0.102494021	2248.513837	0.010932543
1285	11/05/2023	14	0	3180.2	1.935	6247.7805	0	0.001935	0.478305432	2248.992142	0.003039402
1286	12/05/2023	9	0	3180.2	2.15	6249.9305	0	0.00215	0.307482064	2249.299624	0.000844906
1287	13/05/2023	19	0	3180.2	3.655	6253.5855	0	0.003655	0.649128801	2249.948753	0.12029494
1288	14/05/2023	37	3	3183.2	2.365	6255.9505	0.003	0.002365	1.264092928	2251.212846	0.204279788
1289	15/05/2023	124	5.5	3188.7	1.29	6257.2405	0.0055	0.00129	4.236419542	2255.449265	0.151702756
1290	16/05/2023	0	3.9	3192.6	1.032	6258.2725	0.0039	0.001032	0	2255.449265	0.042177116
1291	17/05/2023	0	3.3	3195.9	0.989	6259.2615	0.0033	0.000989	0	2255.449265	0.225798676
1292	18/05/2023	12	5.95	3201.85	1.4835	6260.745	0.00595	0.0014835	0.409976085	2255.859242	0.110931425
1293	19/05/2023	25	2	3203.85	1.075	6261.82	0.002	0.001075	0.854116843	2256.713358	0.030841645
1294	20/05/2023	22	0	3203.85	1.935	6263.755	0	0.001935	0.751622822	2257.464981	0.00857464
1295	21/05/2023	29	0	3203.85	2.365	6266.12	0	0.002365	0.990775538	2258.455757	0.067692162
1296	22/05/2023	31	0	3203.85	2.795	6268.915	0	0.002795	1.059104886	2259.514862	0.02991661
1297	23/05/2023	34	0	3203.85	2.795	6271.71	0	0.002795	1.161598907	2260.676461	0.008317457
1298	24/05/2023	34	0	3203.85	1.935	6273.645	0	0.001935	1.161598907	2261.838059	0.002312341
1299	25/05/2023	34	0	3203.85	2.58	6276.225	0	0.00258	1.161598907	2262.999658	0.067207824
1300	26/05/2023	0	0	3203.85	2.58	6278.805	0	0.00258	0	2262.999658	0.127655014
1301	27/05/2023	0	0	3203.85	3.225	6282.03	0	0.003225	0	2262.999658	0.242291959
1302	28/05/2023	0	0	3203.85	3.01	6285.04	0	0.00301	0	2262.999658	0.365986426
1303	29/05/2023	0	0	3203.85	2.365	6287.405	0	0.002365	0	2262.999658	0.379442162
1304	30/05/2023	0	0	3203.85	3.655	6291.06	0	0.003655	0	2262.999658	0.360206353
1305	31/05/2023	0	0	3203.85	3.44	6294.5	0	0.00344	0	2262.999658	0.332862931
1306	01/06/2023	0	0	3203.85	1.68	6296.18	0	0.00168	0	2262.999658	0.305360849
1307	02/06/2023	0	0	3203.85	2.04	6298.22	0	0.00204	0	2262.999658	0.280187716
1308	03/06/2023	24	0	3203.85	1.92	6300.14	0	0.00192	0.819952169	2263.819611	0.257958193
1309	04/06/2023	20	0	3203.85	1.8	6301.94	0	0.0018	0.683293475	2264.502904	0.238628734
1310	05/06/2023	20	0	3203.85	2.04	6303.98	0	0.00204	0.683293475	2265.186197	0.221932851
1311	06/06/2023	2	0	3203.85	1.56	6305.54	0	0.00156	0.068329347	2265.254527	0.103435719
1312	07/06/2023	15	0	3203.85	1.68	6307.22	0	0.00168	0.512470106	2265.766997	0.028757647
1313	08/06/2023	17	0	3203.85	1.68	6308.9	0	0.00168	0.580799453	2266.347796	0.007995235
1314	09/06/2023	21	0	3203.85	2.16	6311.06	0	0.00216	0.717458148	2267.065255	0.002222755
1315	10/06/2023	36	0	3203.85	1.92	6312.98	0	0.00192	1.229928254	2268.295183	0.000617858
1316	11/06/2023	53	0	3203.85	1.56	6314.54	0	0.00156	1.810727708	2270.10591	0.000171656
1317	12/06/2023	73	0	3203.85	1.2	6315.74	0	0.0012	2.494021182	2272.599932	4.75999E-05
1318	13/06/2023	49	1	3204.85	1.08	6316.82	0.001	0.00108	1.674069013	2274.274001	1.31092E-05
1319	14/06/2023	37	0	3204.85	0.72	6317.54	0	0.00072	1.264092928	2275.538094	3.51994E-06
1320	15/06/2023	46	0	3204.85	1.2	6318.74	0	0.0012	1.571574991	2277.109669	8.53875E-07
1321	16/06/2023	32	0	3204.85	1.92	6320.66	0	0.00192	1.093269559	2278.202938	1.12836E-07
1322	17/06/2023	50	0	3204.85	2.52	6323.18	0	0.00252	1.708233686	2279.911172	1.93201E-19
1323	18/06/2023	124	0	3204.85	2.04	6325.22	0	0.00204	4.236419542	2284.147591	1.93201E-19
1324	19/06/2023	28	0	3204.85	1.92	6327.14	0	0.00192	0.956610864	2285.104202	1.93201E-19
1325	20/06/2023	27	0	3204.85	1.2	6328.34	0	0.0012	0.922446191	2286.026648	1.93201E-19
1326	21/06/2023	18	0	3204.85	1.32	6329.66	0	0.00132	0.614964127	2286.641613	1.93201E-19
1327	22/06/2023	17	0	3204.85	1.2	6330.86	0	0.0012	0.580799453	2287.222412	1.93201E-19
1328	23/06/2023	26	0	3204.85	1.08	6331.94	0	0.00108	0.888281517	2288.110694	1.93201E-19
1329	24/06/2023	25	0	3204.85	0.84	6332.78	0	0.00084	0.854116843	2288.96481	1.93201E-19
1330	25/06/2023	49	0	3204.85	1.68	6334.46	0	0.00168	1.674069013	2290.638879	1.93201E-19
1331	26/06/2023	42	0	3204.85	1.56	6336.02	0	0.00156	1.434916297	2292.073796	1.93201E-19
1332	27/06/2023	43	0	3204.85	1.92	6337.94	0	0.00192	1.46908097	2293.542877	1.93201E-19
1333	28/06/2023	54	0	3204.85	1.8	6339.74	0	0.0018	1.844892381	2295.387769	1.93201E-19
1334	29/06/2023	E	5.75	3210.6	1.74	6341.48	0.00575	0.00174	E	2295.387769	1.93201E-19
1335	30/06/2023	E	0	3210.6	1.92	6343.4	0	0.00192	E	2295.387769	1.93201E-19

Measured Inputs

Step	Date	Observed Leachate Flow Rate - Qi	Observed Precipitation	Cumulative Observed Precipitation	Observed Factored Evaporation	Cumulative Observed Factored Evaporation	Observed Precipitation	Observed Factored Evaporation
i	(dd/mm/yyyy)	(m3)	(mm)	(mm)	(mm)	(mm)	(m)	(m)
1336	01/07/2023	13	0	3210.6	1.2	6344.6	0	0.0012
1337	02/07/2023	25	0	3210.6	1.2	6345.8	0	0.0012
1338	03/07/2023	7	0	3210.6	1.4	6347.2	0	0.0014
1339	04/07/2023	85	0	3210.6	1.2	6348.4	0	0.0012
1340	05/07/2023	50	0	3210.6	1.4	6349.8	0	0.0014
1341	06/07/2023	E	0	3210.6	1.6	6351.4	0	0.0016
1342	07/07/2023	20	0	3210.6	1.6	6353	0	0.0016
1343	08/07/2023	12	0	3210.6	1.5	6354.5	0	0.0015
1344	09/07/2023	26	0	3210.6	1.4	6355.9	0	0.0014
1345	10/07/2023	53	0	3210.6	1	6356.9	0	0.001
1346	11/07/2023	28	0	3210.6	1.1	6358	0	0.0011
1347	12/07/2023	24	0	3210.6	1.3	6359.3	0	0.0013
1348	13/07/2023	97	0	3210.6	1.4	6360.7	0	0.0014
1349	14/07/2023	19	0	3210.6	1.3	6362	0	0.0013
1350	15/07/2023	21	0	3210.6	1.2	6363.2	0	0.0012
1351	16/07/2023	23	0	3210.6	1.5	6364.7	0	0.0015
1352	17/07/2023	21	0	3210.6	1.4	6366.1	0	0.0014
1353	18/07/2023	7	0	3210.6	1.4	6367.5	0	0.0014
1354	19/07/2023	8	0	3210.6	1.6	6369.1	0	0.0016
1355	20/07/2023	14	0	3210.6	1.3	6370.4	0	0.0013
1356	21/07/2023	13	0	3210.6	1.1	6371.5	0	0.0011
1357	22/07/2023	30	0	3210.6	1.1	6372.6	0	0.0011
1358	23/07/2023	18	0	3210.6	1.2	6373.8	0	0.0012
1359	24/07/2023	25	0	3210.6	1.2	6375	0	0.0012
1360	25/07/2023	13	0	3210.6	1.3	6376.3	0	0.0013
1361	26/07/2023	17	0	3210.6	1.2	6377.5	0	0.0012
1362	27/07/2023	13	0	3210.6	1.1	6378.6	0	0.0011
1363	28/07/2023	48	0	3210.6	1.5	6380.1	0	0.0015
1364	29/07/2023	30	0	3210.6	1.4	6381.5	0	0.0014
1365	30/07/2023	20	0	3210.6	1.3	6382.8	0	0.0013
1366	31/07/2023	E	0	3210.6	1.6	6384.4	0	0.0016
1367	01/08/2023	E	0	3210.6	1.215	6385.615	0	0.001215
1368	02/08/2023	5	0	3210.6	2.025	6387.64	0	0.002025
1369	03/08/2023	6	0	3210.6	2.025	6389.665	0	0.002025
1370	04/08/2023	12	0	3210.6	2.16	6391.825	0	0.00216
1371	05/08/2023	0	0	3210.6	1.485	6393.31	0	0.001485
1372	06/08/2023	0	0	3210.6	1.215	6394.525	0	0.001215
1373	07/08/2023	22	0	3210.6	1.485	6396.01	0	0.001485
1374	08/08/2023	12	0	3210.6	1.35	6397.36	0	0.00135
1375	09/08/2023	15	0	3210.6	1.755	6399.115	0	0.001755
1376	10/08/2023	18	0	3210.6	1.215	6400.33	0	0.001215
1377	11/08/2023	25	0	3210.6	1.35	6401.68	0	0.00135
1378	12/08/2023	28	0	3210.6	2.025	6403.705	0	0.002025
1379	13/08/2023	22	0	3210.6	2.43	6406.135	0	0.00243
1380	14/08/2023	26	0	3210.6	2.295	6408.43	0	0.002295
1381	15/08/2023	33	0	3210.6	1.485	6409.915	0	0.001485
1382	16/08/2023	26	0	3210.6	2.565	6412.48	0	0.002565
1383	17/08/2023	0	0	3210.6	2.43	6414.91	0	0.00243
1384	18/08/2023	1	0	3210.6	2.565	6417.475	0	0.002565
1385	19/08/2023	0	0	3210.6	2.43	6419.905	0	0.00243
1386	20/08/2023	20	0	3210.6	2.16	6422.065	0	0.00216
1387	21/08/2023	15	0	3210.6	1.62	6423.685	0	0.00162
1388	22/08/2023	9	0	3210.6	2.025	6425.71	0	0.002025
1389	23/08/2023	11	0	3210.6	2.16	6427.87	0	0.00216
1390	24/08/2023	5	0	3210.6	1.755	6429.625	0	0.001755
1391	25/08/2023	9	0	3210.6	1.89	6431.515	0	0.00189
1392	26/08/2023	12	0	3210.6	1.89	6433.405	0	0.00189
1393	27/08/2023	13	0	3210.6	2.16	6435.565	0	0.00216
1394	28/08/2023	19	0	3210.6	2.43	6437.995	0	0.00243
1395	29/08/2023	21	0	3210.6	2.16	6440.155	0	0.00216
1396	30/08/2023	0	0	3210.6	2.7	6442.855	0	0.0027
1397	31/08/2023	35	0	3210.6	3.105	6445.96	0	0.003105
1398	01/09/2023	37	0	3210.6	3.69	6449.65	0	0.00369
1399	02/09/2023	41	0	3210.6	2.87	6452.52	0	0.00287
1400	03/09/2023	31	0	3210.6	3.69	6456.21	0	0.00369
1401	04/09/2023	45	0	3210.6	3.28	6459.49	0	0.00328
1402	05/09/2023	48	0	3210.6	3.69	6463.18	0	0.00369
1403	06/09/2023	101	0	3210.6	4.305	6467.485	0	0.004305
1404	07/09/2023	35	0	3210.6	3.69	6471.175	0	0.00369
1405	08/09/2023	39	0	3210.6	2.87	6474.045	0	0.00287
1406	09/09/2023	16	0	3210.6	3.69	6477.735	0	0.00369
1407	10/09/2023	30	0	3210.6	3.075	6480.81	0	0.003075
1408	11/09/2023	15	0	3210.6	3.895	6484.705	0	0.003895
1409	12/09/2023	6	0	3210.6	4.51	6489.215	0	0.00451
1410	13/09/2023	14	0	3210.6	3.69	6492.905	0	0.00369
1411	14/09/2023	27	0	3210.6	3.69	6496.595	0	0.00369
1412	15/09/2023	15	0	3210.6	4.1	6500.695	0	0.0041
1413	16/09/2023	20	0	3210.6	4.51	6505.205	0	0.00451
1414	17/09/2023	8	0	3210.6	4.51	6509.715	0	0.00451