# AN EVALUATION OF HORIZONTAL SUB-DRAINAGE SYSTEMS MITIGATING LANDSLIDE HAZARD IN SHIKURUWE VILLAGE, BUDUDA DISTRICT

**CYNTHIA MAMFA MAYALA**

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# ABSTRACT

Rainfall-induced landslides pose a significant threat in BUDUDA district in Eastern Uganda, due to intense precipitation, geological instability, and increasing population density. This study assessed the suitability of horizontal sub-drainage systems to mitigate landslide risk in SHIKURUWE village. The research involved site characterization, a hydrological study, and the design of a horizontal sub-drainage system. Key findings revealed that moderately steep slopes, low permeability, and fine-grained soils contributed to water stagnation in the soil profile. High rainfall patterns were found to be influenced by global meteorological phenomenon such as the El Niño. Further, land use and soil properties significantly influenced water losses in the watershed. Finally, the introduction of a horizontal sub-drainage system down slope was observed to improve drainage in both steady state and transient conditions, hence reducing the pore water pressure, and increasing the factor of safety of the slope.

## DECLARATION

I, MAMFA MAYALA Cynthia, declare that this report entitled 'Reducing Landslide Risk in SHIKURUWE Village, BUDUDA District. An Evaluation Of Horizontal Sub-Drainage Systems' is my own original work and all sources utilized in its preparation are fully acknowledged and referenced in the report. I declare that the research was conducted in an ethical manner in accordance, and has not been submitted to any other institution for any qualification or award.

Signature..... Date.....

MAMFA MAYALA Cynthia

## APPROVAL

This is to certify that this research and design project by MAMFA MAYALA Cynthia has been conducted under my supervision and has been approved for submission to the university.

Signature..... Date.....

Dr. Eng. Morris OLENG

ACADEMIC SUPERVISOR

## DEDICATION

To my beloved parents MAMFA OBUDI Didier and MAYALA BANTEA Claudine who have been of great support throughout my academic journey. I am grateful for the unconditional love, encouragements and prayers for the success bestowed upon me. This project is dedicated to both of you, and I am certain to have made you proud.

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## LIST OF ABBREVIATIONS

AMSL: Above Mean Sea Level

ADRIRD: Average Daily Rainfall Intensity on Rainy Days

cm: centimeter

CD: Consolidated and Drained

DEM: Digital Elevation Model

HEC-HMS: Hydrologic Engineering Center-Hydrological Modelling System

LS: Linear Shrinkage

LL: Liquid Limit

m: meter

mm: millimeter

PI: Plastic Index

PL: Plastic Limit

UU: Unconsolidated and Undrained

Wc/ Mc: Moisture Content

WGS84: World Geodedic System 1984

YRI: Yearly Rainfall Intensity

# CHAPTER ONE: INTRODUCTION

## 1.1 BACKGROUND

BUDUDA District in eastern Uganda, is one of the regions most prone to rainfall-induced landslides. This vulnerability is largely due to its location within the Mount Elgon region, an extinct volcanic shield with a maximum elevation of 4,321 meters above sea level. Landslides in the area are naturally triggered by the combination of high elevation, intense precipitation, and the weathering processes typical of such geological formations (Oleng, Ozdemir and Pilakoutas, 2024). BUDUDA has an estimated land area of approximately 274 square kilometres, with Mount Elgon Park occupying about 40% of this area. It is densely populated, as any other district in the Mount Elgon region, with settlements spreading across hills, slopes, and valleys. According to preliminary results from the 2024 Uganda census, the total population of BUDUDA is estimated to be 277,475, compared to only 211683 in the 2014 census (Census, 2024). The growing population is drawn to the region due to its fertile lands and relatively reliable climate, which support intensive agriculture, its main economic activity. The district primarily cultivates Arabica coffee and bananas, which constitute the major crops (Metroeconomica and Baastel, 2015).

Climate change has significantly contributed to the increase in landslide events in the district by causing intense rainfall events. For instance, the occurrence of several major landslides recorded during 2010_2019 decade,

such as the NAMETSI and BUKALASI landslides in 2010, the BUWALUKANI landslide in 2012, and the MAROBO landslide in 2017 among others, align with the climate projections for the Lake KYOGA basin of which Mount Elgon is situated in the northern cattle corridor, where rising temperatures and increased precipitation have been observed during the same period (Obubu *et al.*, 2021).

## 1.2 **INTRODUCTION**

Landslides pose a significant concern in BUDUDA district. A comprehensive statistical analysis conducted over more than eight decades indicates that landslide hazards account for 95 percent of deaths (2,275), 60 percent of serious damage to property (352 homes), and have directly and indirectly impacted 94 percent of the population (UNDRR DesInventar Sendai, 2020). On this regard, the 2010 Uganda National Policy for Preparedness and Management outlines several essential policy actions. These include prohibiting the settlement and resettlement of individuals living in high-risk areas, promoting afforestation, and encouraging appropriate land use practices (Directorate of Relief, 2010). Despite the presence of these guidelines and several studies offering the most up-to-date landslide susceptibility maps, many residents remain hesitant to abandon the fertile lands upon which they rely for livelihood (Namuenge *et al.*, 2024).

Horizontal sub-drainage systems have a wide range of applications. They are used in civil engineering for road and highway construction, in agriculture and irrigation for optimizing crop yields, and in mining. Additionally, these

systems play a crucial role in disaster control, including landslide prevention and stabilization, as well as flood management and storm-lantern control (Tantri et al., 2023). The purpose of this project was therefore, to design a Horizontal Sub surface Drainage System with the ability of significantly draining the infiltrated water.

## 1.3 PROBLEM STATEMENT

SHIKURUWE village is situated in NAPOSHI parish in BUSHIKA Sub County, in the western part of the district. The sub county has a total population of 27,259, and a density of 1,401 people per kilometre square (Uganda Water Supply ATLAS, 2024). The sub county has known several landslides, most of which happened in 1997, provided that more than 60% of the land is located on slopes greater than 15 degrees, which is critical for accelerated mass movement. SHIKURUWE village has a couple of landslide records, of which the most recent and documented happened in 2016. The landslide scar of coordinates (x=649,193 and y=117,456) is located at an altitude of 1468 meters above sea level, on a slope of 28.26%. The scar is 86 meters long and 332 meters wide, 6.3 meters deep as seen in ***FIG 1.1***. The slope is considered abandoned as the relocation process was conducted, although agriculture is still taking place (Nantumbwe, Bob R. Nakileza et al. 2017).

A study on ground displacement in the district indicated that mitigation measures could be applied to slopes with a medium displacement rate to enhance their stability. In general, when unstable layers are washed away during a landslide, a relatively stable ground remains, and it takes time for

the remaining soil to become unstable again (Makabayi, Musinguzi and Otukei, 2021a). Hence, his study aimed to design a horizontal subsurface drainage system, and to assess its effectiveness in reducing fluctuations in water levels within the soil profile.

**Figure 1** depicts the 2016 landslide scar in SHIKURUWE village, as captured by Google Earth pro in late January 2025. The red line outlines the boundary of the scar.

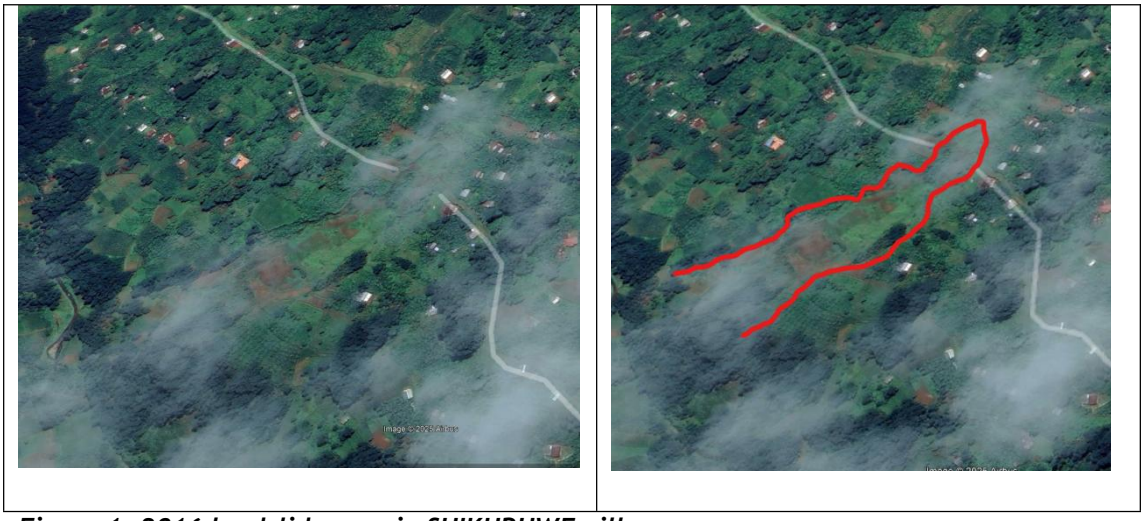


***Figure 1. 2016 landslide scar in SHIKURUWE village.***

## 1.4 OBJECTIVES

### *1.4.1 Main objective*

The main objective was to assess the suitability of horizontal sub drainage system approach in the mitigation of landslide risks.

### *1.4.2 Specific objectives*

The specific objectives were:

i. To perform a site characterizations;
ii. To conduct a hydrologic study;
iii. To design the horizontal sub drainage system.

## 1.5 RESEARCH QUESTIONS

i. What are the key soil properties to look into to obtain a better understanding of the landslide mechanism?
ii. What are the watershed characteristics, and how do they influence landslide occurrence?
iii. What are the key parameters that will guide the design of the horizontal sub drainage system, and how can the design be optimized?

## 1.6 SIGNIFICANCE

Provided the increased occurrence of rainfall-induced landslides in the district that result into significant loss of life and damage to property, there is a need for effective and sustainable mitigation measures to protect the growing population and their assets. Horizontal sub-drainage systems have the potential to reduce the risk of landslides by managing subsurface water, a key contributing factor to slope instability (Tantri *et al.*, 2023). By designing and evaluating the suitability of such a system, this study provides an insight and recommendations that can inform future landslide mitigation efforts, contributing to the safety of communities in the landslide prone areas.

## 1.7 JUSTIFICATION

Landslides are a frequent natural hazard in BUDUDA District, resulting in significant loss of life, displacement of people, and economic hardship. Over the years, these landslides have caused extensive damage to infrastructure, including roads, bridges, and buildings, which disrupts economic activity (World Bank, 2019). The region is particularly vulnerable to rainfall-induced landslides because the soil structure that promotes a high water retention. For instance, these soils have a clay content of about 30%, exhibit low drainage rates, and field capacity. This leads to stagnation when seepage water interacts with the clay layer (Makabayi, Musinguzi and Otukei, 2021b).

Sub surface drainage systems are an effective approach to mitigate slope failures linked to seepage. Taking into considerations the intensity and duration of rainfall event, the hydraulic conductivity of the soil, the positioning and spacing of the drains in relation to the depth of the groundwater level, and the soil profile among other factors, it has been demonstrated that the horizontal subsurface drainage can significantly enhance the factor of safety of a slope up to 25 percent (Tantri *et al.*, 2023).

## 1.8 SCOPE

### 1.8.1 Geographical scope

**Figure 2** shows the geographical scope of the project (black dot). The research was conducted in SHIKURUWE village of coordinates (x= 649187, y= 117488) in BUSHIKA sub county, BUDUDA district.

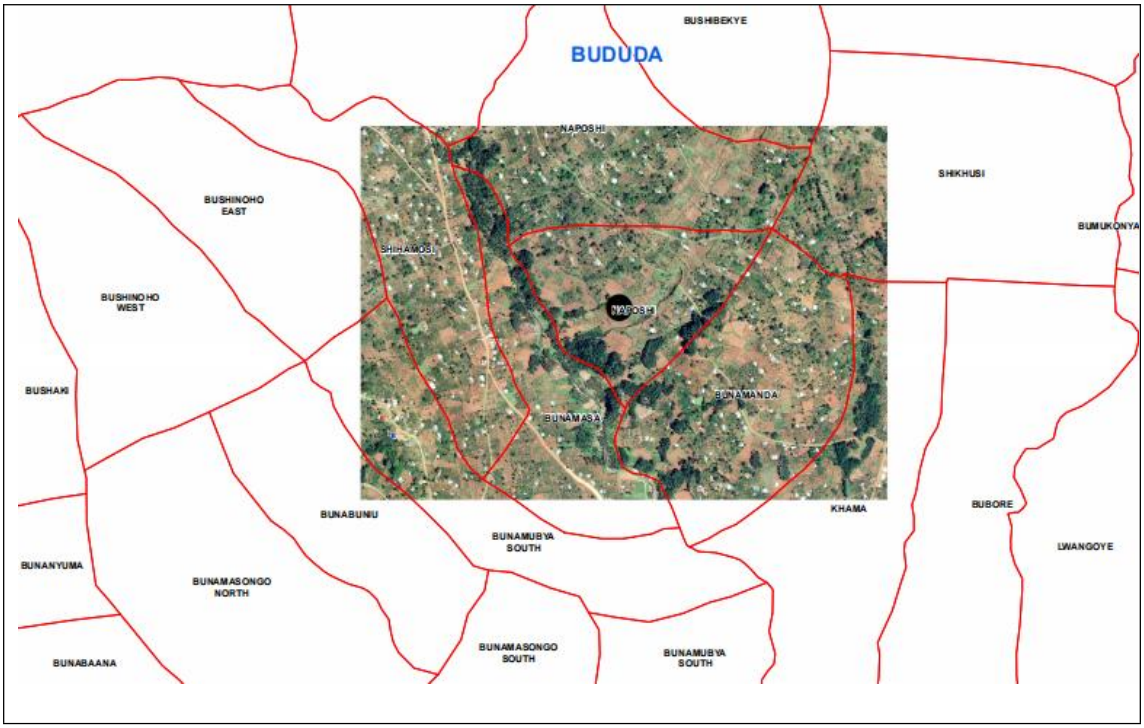



*Figure 2. Geographical scope*

### 1.8.2 Content scope

The present study focused on assessing the suitability of horizontal sub-drainage systems in the mitigation of risks associated with rainfall-induced landslides. The research involved a comprehensive analysis of the factors contributing to landslide occurrence in SHIKURUWE village, and the design of a sub-drainage system adapted to the specific conditions of the area.

The key areas of investigation within this scope included:

1. **Site characterization**

This point entailed the analysis of the site's geometry (including the slope and the topography), and the determination of soil properties (such as Atterberg limits, particle size distribution, unit weight, permeability, and shear strength).

2. **Hydrological study**

Here the aim was to understand the watershed characteristics, to analyse

the rainfall patterns, and to evaluate infiltration and water losses within the study area.

## 3. Design of sub-drainage system

A horizontal sub-drainage system was finally designed based on findings of the site characterization and the hydrological study. The aim was to determine the appropriate design parameters, and to assess the system's potential impact on groundwater levels, and slope stability.

# CHAPTER TWO: LITERATURE REVIEW

## 2.1 GENERALITIES

BUDUDA district in western UGANDA lies at the foot of the South-Western slopes of the Mount Elgon Volcano, between latitude 2°49'N and 2°55'N, longitude 34°15'E and 34°34'E (Poesen and Deckers, 2009).

### 1. GEOMORPHOLOGY

The geomorphology of the area is greatly controlled by the volcanism and doming of the country rock.

***a. Geology***

In general, BUDUDA is covered by three major rock formations (Badru *et al.*, 2022). These include:

i. Volcanic rocks and associated sediments covering more than half of the district area (229Km$^2$) in the northern and central parts;
ii. Undifferentiated gneisses including elements of P(B) and, in the north, granulite facies rocks (covering 84Km$^2$);
iii. A small portion of southern (4Km$^2$) covered with Undifferentiated gneisses including elements of P(B) and, in the north, granulite facies rocks.

***b. Slope geometry***

Slope geometry is dependant on the height and the slope angle. The critical height of slope is a function of the shear strength, density and bearing capacity of the slope foundation. Slope stability decreases with the

increase of the height, also inducing a shear stress within the toe of the slope from the added weight. On the other hand an increase in the slope angle induces a tangential stress, reducing stability (Poesen and Deckers, 2009).

### *c. Soil properties and geological discontinuities*

i. Soil properties

Seven types of soils are identified in BUDUDA district, for instance, Humose red sandy clay, Loams, Black and Grey clay often calcareous soil, Black humose sandy clay loam, Red clay loams and sandy clay Loams, Red sandy - sandy clay loams, and Red sandy clay loams occasionally lateralized (Badru *et al.*, 2022). These soil types are spread in the district as follows:

- Yellowish brown sandy clay loams with Black humose sandy clay loam is found in the northern part of the district in the forest reserve at the mountain;
- Humose red sandy clay loams covers the biggest percentage(41.7%) of the district;
- Black and grey clays often calcareous and Red sandy - sandy clay loams cover a small portion (0.01%) of the south west part of the district.

BUDUDA district has three major geological formations, which are explained by *Poesen and Deckers (2009)* as follows:

- Soils on carbonatite dome

The soils on the carbonatite dome in Bukigai are clay-rich, containing over 30% clay with a uniform color profile. There is less than 20% variation in clay content over a depth of at least 12 cm in the top 2 meters, while sand and

silt content decreases with depth. The top horizons have a reddish hue, and the B horizon features shiny ped faces.

These soils are permeable to water and plant roots up to 200 cm and experience minimal run-off erosion, unless on unprotected slopes exceeding 15%. Classified as Rhodic Nistisols, they are stable and resistant to landslides. Drilling shows that these soils extend to about 40 meters and are derived from iron-rich minerals like magnetite and haematite, giving them their distinctive red colour. Their stability is likely due to the high cohesion from cementing minerals such as calcium carbonate.

- Soils in the western zone

In the western zone, specifically along the BUDUDA and BUSHIKA transects west of the carbonatite dome, the main soil types are Cambisols, Nitisols, Acrisols, and Lixisols.

- Soils in the eastern zone

The eastern zone experienced the highest number of landslides in 1997, which were generally shallow compared to the ones observed in the western zone. In this region, the higher incidence of landslides could be associated to factors such as terraces, slope concavity, slope gradient, and high infiltration rates of top layers of the soil with high clay content in the downer layers leading to water stagnation, increasing a landslide risk.

ii. <u>Geological discontinuities</u>

A geological discontinuity is a plane or surface that marks a change in physical or chemical characteristics in a soil or rock mass. A discontinuity

can have different forms such as a bedding plane, schistosity, foliation, joint, cleavage, fracture,fissure, crack, or fault plane (Poesen and Deckers, 2009). This discontinuity controls the type of failure which may occur in a rock slope. The properties of discontinuities such as orientation, persistence, roughness and infilling are play important role in the stability of jointed rock slope. Discontinuities may occur multiple times with broadly the same mechanical characteristics in a discontinuity set, or may be a single discontinuity. This makes a soil or rock mass anisotropic.

## 2. HYDROLOGY

### *a. Climate and precipitation*

BUDUDA District has a tropical climate characterized by distinct wet and dry seasons. The wet seasons occur from March to May and from September to November, bringing heavy rainfall that averages around 1,500 mm annually. This intense precipitation, particularly during prolonged rainstorms, significantly increases the risk of landslides. The dry seasons, which last from December to February and from June to August, experience reduced rainfall, yet still present challenges due to the region's topography (Kitutu et al, 2010).

### *b. Surface water*

Surface water in BUDUDA consists of rivers, streams, and wetlands that are essential for the local ecosystem and the communities that inhabit the area. Among the primary water bodies are the MANAFWA River and the SIPI River, which provide water for domestic use, irrigation, and livestock. These rivers

originate from Mount Elgon and flow through the valleys, supporting both natural habitats and human activities (Nantumbwe, Bob R. Nakileza et al. 2017).

## 2.2 LANDSLIDE HISTORY IN BUDUDA DISTRICT

Landslides are a widespread issue around the world. In the highlands of East Africa, for example, they are primarily caused by weathering processes, various tectonic activities related to the East African Rift Valley, and the wet climates typical of tropical mountainous areas. The favorable conditions in these mountains, for instance the climate and fertile soils, have attracted populations for the culture of crops like Arabica coffee, bananas, and potatoes. Consequently, recent decades have seen a demographic boom in these mountainous areas, leading to an intensive agriculture and poor land management (Namuenge *et al.*, 2024). This has increased pressure on the naturally fragile slopes, resulting in a higher frequency of landslide events.

Landslide causes have been categorized into two main types: co-seismic and rainfall-induced, along with human activities. The combination of co-seismic and rainfall-induced landslides is more prevalent in the western part of the East African Rift Valley, particularly in the eastern part of the Democratic Republic of Congo and the western regions of Rwanda and Uganda (specifically in the KASESE and KISORO districts), while the rainfall induced landslides is more prevailing as moving away from the rift valley (Oleng, Ozdemir and Pilakoutas, 2024).

**Figure 3** depicts the landslide co-seismic and rainfall-induced susceptibility map of Uganda by Oleng, Ozdemir and Pilakoutas (2024). The combination of co-seismic and rainfall-induced landslide is more prevalent in the western part of the country, while rainfall-induced landslides occur in the eastern part.

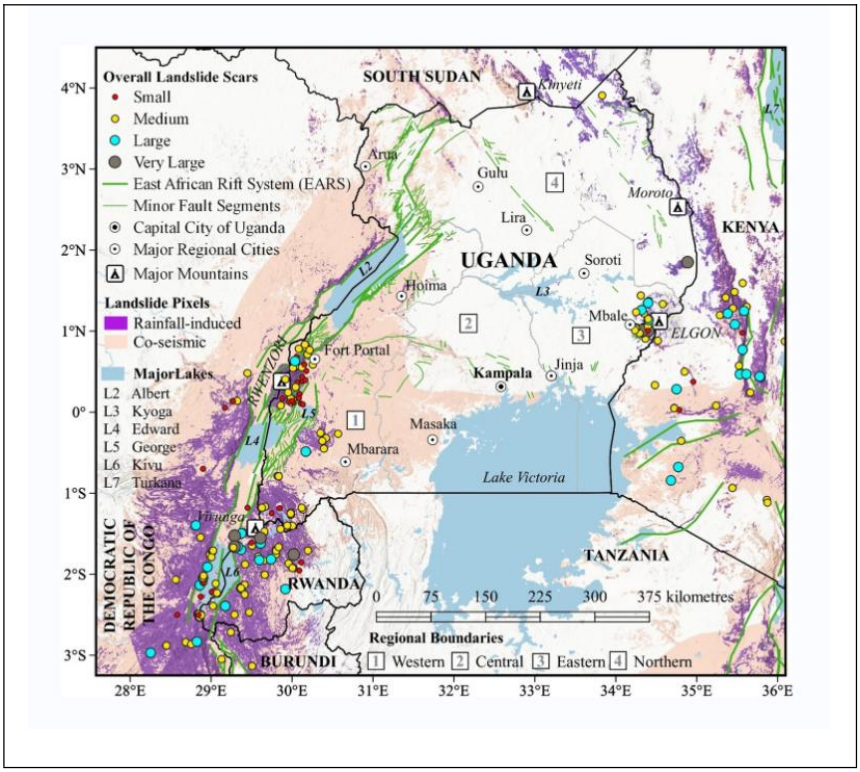



***Figure 3. Co-seismic and rainfall induced susceptibility map of Uganda.***

***Source: (Oleng, Ozdemir and Pilakoutas, 2024)***

In Uganda, landslides occur predominantly in the Western and Eastern regions, with a higher frequency observed in the Eastern part, particularly in the Mount Elgon region, due to its geological formation. The volcanic soils in this area exhibit a high infiltration rate, making them more susceptible to rainfall-induced landslides (Oleng, Ozdemir and Pilakoutas, 2024). Hence districts such as BULAMBULI, SIRONKO, MANAFWA, and BUDUDA which are located in that region have experienced significant life, environmental,

economic, and infrastructure losses over the decades. In BUDUDA district, climate change, poor land management practices, intensive agriculture, along with rising population pressure have increased the slope susceptibility to landslides (Nema, 2020).

## 2.3 MITIGATION MEASURES IN PLACE

1. Ugandan policies once prioritized disaster response and recovery, but in 2010, a new National Policy for Disaster Preparedness and Management shifted the focus to pre-disaster mitigation. This led to the creation of a Disaster Preparedness department within the Office of the Prime Minister, along with a national Disaster Risk Reduction Platform and Disaster Management Committees at district and sub-county levels (Gorokhovich *et al.*, 2013).
2. A relocation project of the victims and people exposed to danger of looming landslides was implemented by the government and development partners such as Red Cross and Oxfam in close collaboration with sub county authorities (C Namuenge, J E. Ssenku, 2024).
3. In addition to that, local populations were encouraged to actively monitor early warning signs of landslides, particularly from May to June and August to November, which are the months most prone to landslides. Signs to look for included crack formation, the sudden appearance of water during rainfall events, and small soil slips along the roads. Residents were also advised to avoid areas where water collects, known

as moisture zones, and to steer clear of steep dykes that are frequently affected by landslides ('Landslides in Uganda', no date).

4. A widespread mitigation measure at community and household level consisted of digging and constructing trenches and terrace barriers that involved using sacks filled with sand. This was conducted along with afforestation. Afforestation consisted in planting trees, especially those that can bear fruits (mangoes, avocado, oranges and lemon). This had the advantage of both address landslides and generate income at the same time by household heads and local leaders (C Namuenge, J E. Ssenku, 2024).
5. Gorokhovich *et al* (2013) proposed a cost effective scheme for MURWARWA village that involved placing vertical bars (metal or wooden) in rows along the slope, above and below the scarp. The required equipment included an optical theodolite and a surveying rod, with a benchmark bar for positioning. Regular mapping (bi-weekly or monthly) was to help detect any movements, particularly during the rainy season. In this system, an increase in movement speed was a sign to trigger evacuation warnings for the local population. Additionally, the setting up of three rain gauges monitored by local schoolchildren under teacher supervision were recommended. This data, combined with slope movement measurements, was expected to improve warnings about impending landslides (Gorokhovich *et al.*, 2013).

**Figure 4** shows the proposed cost effective scheme for MURWARWA village by Gorokhovich *et al* (2013).

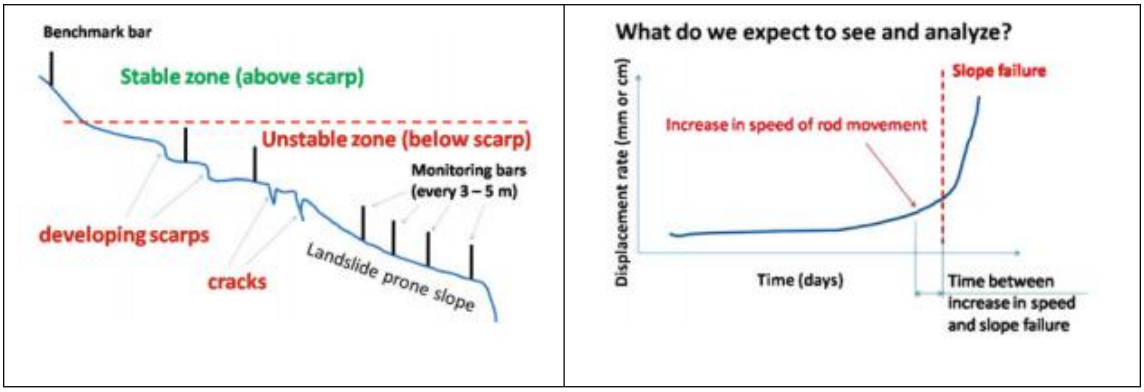



Figure 4. Landslide monitoring scheme.

***Source : (Gorokhovich et al., 2013). (b) Expected landslide behavior derived from monitoring data. Source: (Gorokhovich et al., 2013)***

## 2.4 CHALLENGES FACED IN LANDSLIDE MITIGATION

1. A delayed support from government agencies such as the office of the prime minister was observed. This made some interventions ineffective despite the fact that they could have made a considerable impact if executed in time. Furthermore, there is a limited scope of sensitization where most of the high-risk areas do not receive the service due to various challenges (C Namuenge, J E. Ssenku, 2024).
2. Poor timing, poor coordination between government, the disaster management teams, and humanitarian agencies to effectively support the landslide victims and duplication; along with proper sensitization: negligence; no clear information, no community understanding of the information. These challenges made the early warning system created in 2018 (Namono *et al.*, 2019)

## 2.5 SUB SURFACE DRAINAGE SYSTEMS

### 2.5.1 TYPES OF SUB SURFACE DRAINAGE SYSTEMS

According to H. Rahardjo, V. A. Santoso (2012), there are three main types of sub surface drainage systems, namely:

1. **Horizontal Drains**: these are installed parallel to the ground surface to lower the groundwater table and reduce pore-water pressure. They are often used in slope stabilization.
2. **Vertical Drains**: these systems consist of pipes or wells that extend downward to intercept groundwater, commonly used in soft soil areas to accelerate consolidation.
3. **French Drains** : A French drain is a trench filled with gravel or rock containing a perforated pipe that redirects surface and groundwater away from an area.

**Figure 5** depicts the types of sub-drainage systems. (a) shows the Horizontal and Vertical drains, while (b) shows the cross-section of a French drain installation.

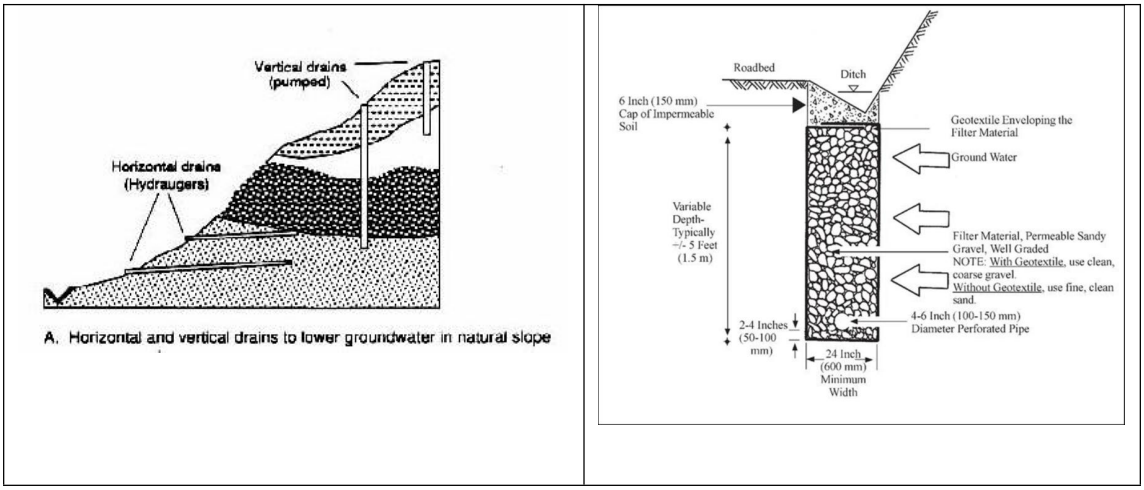



Figure 5. Types of sub drains.

*(a) Horizontal and vertical drains for sub surface drainage control. Source: (California Coastal Commission, no date). (b) French drain cross section. Source: (Rolt et al., 2020)*

### 2.5.2 DESIGN CONSIDERATIONS OF THE HORIZONTAL SUB-SURFACE DRAINAGE SYSTEMS

Water affects the slope stability in various ways including: introduction of seepage forces, increase in the weight of the slide mass, development of excess water pressure, and decrease in shear strengths (Cook, Santi and Higgins, 2008).

The design considerations of the horizontal sub surface drainage system are explained by Cook, Santi and Higgins (2008), and entail the following points:

**1. Slot size and filtering mechanism**

a. Slot size

Slots, also known as pipe perforations, allow water from the slope to enter the horizontal drain pipe, which then carries the water away. These slots are arranged in two longitudinal rows that are spaced 120° apart around the circumference of the pipe. They generally come in widths of 0.25 mm, 0.5 mm, or 1.3 mm. The wider slots are designed for use in coarse sand or gravel and can accommodate fine sand and silt without clogging. However, the narrower slots are more prone to plugging and may require regular cleaning, but they allow fewer particles to enter, making them suitable for fine-grained materials. The medium-width slots are the most commonly used.

b. Filtering mechanism

The filtering mechanism can either consist of a soil media or a geotextile

membrane.

i. Soil media

The filter requirements are given by:

- $\boldsymbol{Slot\ width} = \frac{\boldsymbol{D_{85}\ of\ soil}}{\mathbf{2}}$
- Though not common as slots, circular slots can be used to perforate the pipe, and the filter requirement for a pipe with circular holes is given by:

  $\text{Diameter hole} < \text{D}_{85}\ \text{of soil}$

ii. Filter membrane media:

This is a geotextile material that surrounds the pipe. The geotextile material is further explained under point 2.5.

**2. Drain spacing**

The spacing of drains is generally determined during installation. In practice, this process often involves a considerable amount of trial and error, and depends on site layout and accessibility (Cren- shaw and Santi, 2004). Some researchers have attempted to develop quantitative methods for estimating drain spacing, however these methods either do not offer the most economical and efficient solutions, or still require some trial and error to achieve the desired phreatic draw-down. Consequently, the conventional approach to determining drain spacing relies largely on general guidelines and engineering experience, which can be summarized as follows:

i. For parallel drains in high-permeability soils, initial drains should be spaced at 8–15-m intervals;

ii. For parallel drains in fine-grained soils, initial drains should be installed at 1–8-m intervals;

iii. Additional drains may be necessary depending on site conditions and to

tap zones that produce substantial amounts of water;

iv. For fan configurations, enough drains should be installed to result in an average spacing equivalent to the guidelines given for parallel drains.

**3. Drain length**

During their installation, drains should penetrate through the slip area to effectively remove water and enhance the stability of the slope. However, these drains should not extend more than 3 to 5 meters past the slip surface, as extending them further does not provide additional benefits beyond the point where the critical slip surface intersects the top of the slope.

**4. Drain inclination**

Horizontal drains are designed to be inclined upward from the outlet to maintain a positive hydraulic gradient, promoting more effective water flow out of the slope. The inclination angle typically ranges from 2° to 10° from the horizontal, although angles of 25° or more can be used in certain installations. Nevertheless, lower angles are generally preferred because they result in lower elevations at the back ends of the drains, which enhances the potential for groundwater draw-down that the drains can achieve.

**5. Drain configuration**

The drain configuration refers to how drains are installed within the slope profile. In general, drains are positioned at multiple levels to account for subsurface water access from various points, depending on the terrain's accessibility to those levels. This approach effectively drains perched zones and isolated water pockets. Additionally, the installation should be carried

out near the toe of the slope to help lower the groundwater table, which in turn reduces pore-water pressure (H. Rahardjo, V. A. Santoso, 2012).

The drain configuration can either be in parallel or in  in fan-shaped (array).

***a. Fan-shaped configuration***

The fan-shaped configuration (see FIG.5 (a)) exhibits several advantages among which:

i. It is not selective of the location: suitable locations for drilling are rare on sloping terrain and have to be prepared ahead of time;
ii. The installation process is faster because the time required for resetting the equipment after each drain installation is reduced;
iii. Easy collection of water from several drains at once for conveyance off the slope;
iv. High likelihood of intersecting previously unrecognized open discontinuities or perched layers of water is higher since the drains are installed at several different orientations within the slope

***b. Parallel configuration***

The advantages of parallel configuration (see FIG 5 (b)) are as follows:

i. This configuration is used often on relatively linear features such as highways, canals, and rail-roads
ii. They provide more confidence in measuring spacing of drains and in representing the slope with simplified models.

**Figure 6** shows the types of drain configuration. (a) is the plan view of a fan-shaped configuration, and (b) a side view of a parallel configuration.

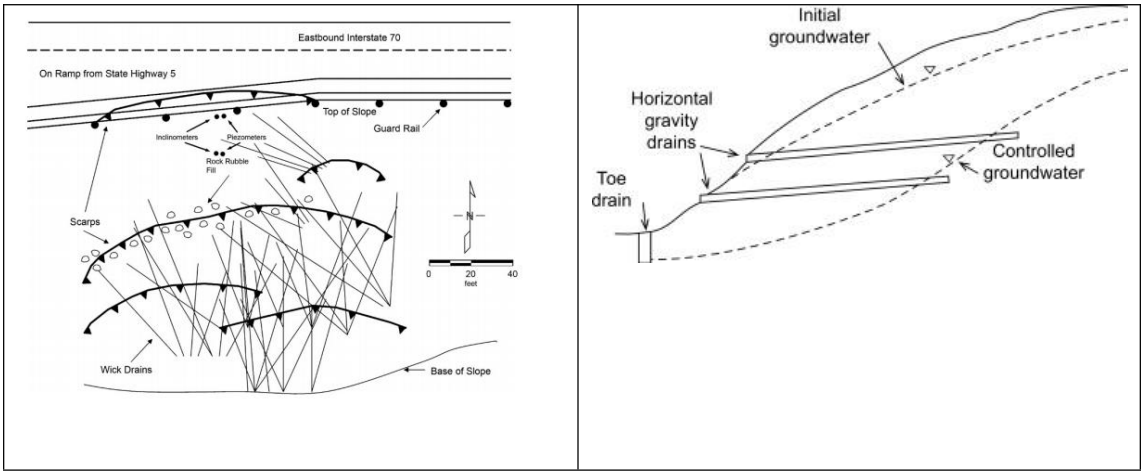



Figure 6. Drain configuration.

***(a) Drain in fan configuragion Source: Cook, D.I., Santi, P.M. and Higgins, J.D. (2008).***

***(b) Drains in parallel configuration. Source: Peter G. Nicholson (2015).***

## 6. Drain Protection and Water Redirection

After the drain has been installed, a protective sleeve of galvanized pipe is usually installed and grouted in place to protect the lower 1.5–6 m from invasion by tree roots and to prevent soil erosion at the outlet. The sleeve also protects the pipe from impact by straying vehicles, or rockfall events. A collector pipe may be attached to the sleeve to direct water to a designated discharge point off the slope. In extreme climates, drain outlets should be buried in sand or gravel to protect them from ice build-up or blockage.

## 7. Drain Markers and Location Records

Drain marking is the final step in the installation of a drain. This process involves recording the drain's location in relation to survey monuments or permanent landmarks. While drain marking is sometimes overlooked, it is a crucial step. The water discharged from a drain can often promote substantial vegetation growth, which may obscure the outlet locations. As a result, having clear drain markers and maintaining a record of drain

locations is essential for facilitating repairs and cleaning, as well as for evaluating slope stability.

## 2.6 MATERIAL

This section briefly introduces the materials used in horizontal sub-drainage systems, for instance the pipe material and the geosynthetic material.

### 2.6.1 THE GEOSYNTHETIC

Geotextile materials are fibrous materials that consist of elements such as individual fibers, filaments, and yarns among others. These constituents are long, small in cross section, and they are strong in tension. Geotechnical material are primarily characterized by their flexibility. This property is crucial as it allows good contact conditions and reduces the stress concentration in the fibers. In addition to this, they possess hydraulic functions that have a high void ration, for instance high permeability, due to the fibrous nature of the elements making it (H. Niroumand, A. Kassim, A. Ghafooripour et la; Septemner 2012). In slope stabilization, the geotextile material has the following functions:

**1. Drainage function or fluid transmission**

Here the geotextile material is placed in contact with the material of low permeability through which water is seeping slowly. Here the material gathers and conveys water within its own plane towards the outlet.

2. **Filtration**

The material acts as a filter, allowing water to pass normal to its own plane, while preventing soil particles from being carried away by the liquid current.

**3. Separation**

Here the geotechnical material is placed between two materials which have the tendency to mix when they are squeezed together under applied loads. As a separator, the geotextile must retain the soil particles and must have sufficient strength to withstand the stresses induced by the applied loads.

**4. Protection**

This is achieved as the geotextile material distributes the stresses and strains transmitted to protect the material. For example, the geotextile can be placed between two materials to preventing one material from damaging the other by exercising concentrated loads.

**5. Tension membrane**

This is achieved when the geotextile is placed between two materials having different pressures to balance the pressure difference, hence, strengthening the structure.

**6. Tensile member**

A geotextile acts as a tensile member when it provides tensile modulus and strength to a soil with which it is interacting through interface shear strength, for instance the interlocking, friction, cohesion and adhesion.

**2.6.2 PIPE**

The pipe material (pipe casing) consists of hard polyvinyl chloride pipes (PVC) or gas pipes with an internal diameter of over 40mm. The pipe can either be perforated over its whole length, or at the specific sections traversing the aquifer. Nevertheless, rigid pipes are not recommended for landslide or unstable areas considering their incapacity of accommodating

the landslide movement that is occurring in an area without separating at the joints (David L. Rpyster. No date).

## 2.7 APPLICATION OF SUB DRAINAGE SYTEMS

### 2.7.1 ROAD PROJECTS

Road slope stabilization involves stabilizing the slopes adjacent to roads to prevent landslides. Key triggers for landslides in road projects include intense rainfall, changes in water levels, and stream erosion. Other factors that contribute to slope instability are excessive slope angles or heights, inadequate drainage, weak foundations, the removal of vegetation that helps anchor the soil, increased loading on the slopes, environmental influences, poor handling of fill materials, high groundwater tables, unsuitable geological features, soil liquefaction, and wildfires (NCHRP, 2012).

Subsurface drains are designed to remove shallow groundwater located less than 15 feet (5 meters) beneath the ground surface (GSPW 2003). This includes water found within the road surface, base, and sub-grade materials. These drains, such as under-drains and French drains, serve three primary purposes: intercepting water before it reaches the road, lowering the water table, and removing excess free moisture. Additionally, subsurface drains collect seepage water from surface run-off, helping to prevent an increase in the groundwater table. (NCHRP, 2012).

### 2.7.2 SLOPE STABILIZATION

#### *1. Gully erosion control*

a. Definition

Gully erosion is one of the most damaging types of soil erosion, occurring on slopes or hillsides due to concentrated water flow. Failures of gullies and riverbanks, along with head-cut retreats, pose significant threats to agricultural land and infrastructure. Valley bottom gullies are commonly found in periodically saturated lowlands and contribute to the silting of rivers and reservoirs. Erosion from these gullies leads to irreversible changes in soil productivity, affecting food security. Controlling and rehabilitating gully erosion is a complex and costly process that requires a deep understanding of gully formation. (Zegeye *et al.*, 2021).

Bank erosion, as described by Simon et al. (1999), results from hydraulic forces at the bank toe causing undercutting and steepening, combined with gravitational forces acting on the bank mass. Rates of failure depend on bank height, angle, and soil shear strength, which is sensitive to changes in pore-water pressure (Zegeye et al., 2020).

b. Case of Ethiopia

Gully erosion is a serious concern that raised in Ethiopian highlands after deforestation in the 1980s. These highlands such as the DEBRE MAWI watershed near Lake TANA in the upper Blue Nile Basin, are characterized by shallow, highly weathered, and fractured basalt overlain by dark brown compacted clay, followed by light brown wet and sticky clay soil and then

finally by black clay and organic-rich soil sequences (Zegeye et al., 2020).

Previous attempts to stabilize gullies with gully plugs, vegetation, and reduced bank slopes have failed as vegetation does not work for gullies deeper than 3 meters. The gully plugs on the other hand, diverted water, creating new gullies (Zegeye et al., 2020).

c. Horizontal sub drainage approach

The study by Zegeye *et al. (*2021) showed that gully dewatering through the use of a horizontal subsurface system was both a economical and an effective solution. For instance, over a period of two years, the draining reduced the soil losses by about 70%, as a result of a reduction in the pore water pressure. increased the shear strength and the critical shear stress of the slope.

**Figure 7** depicts the natural dewatering of the gully after installation of the sub-drainage system.


***Figure 7. Natural dewatering of the gully the bank with installed sub-drains.***

***Source: Zegeye et al., 2021***

## 2. Residual soil slopes

Residual soils are formed from rapid in situ chemical and mechanical weathering of rock masses, primarily due to the heavy rainfall and high temperatures characteristic of tropical regions. Rainfall-induced slope failures are common in tropical and subtropical areas where residual soil is underlain by a deep groundwater table. Intense, short-duration rainfall can increase pore-water pressure, leading to a decrease in the soil's shear strength and ultimately compromising slope stability. These failures typically manifest as shallow slides, frequently observed in South-east Asia (H. Rahardjo, V. A. Santoso, 2012).The effectiveness of a horizontal drainage system is influenced by several factors, including the type, location, number, length, and spacing of the drains (Tantri *et al.*, 2023).

# CHAPTER THREE: METHODOLOGY

## 3.1 OVERVIEW AND RESEARCH DESIGN

This chapter outlined the methodology that was utilized to achieve the research objectives. These included site characterization, study of the hydrology, and the design of the horizontal sub drainage system.

The present study was an applied research, and classified as correlational as it intended to determine the relationship between water fluctuation in the soil profile and the factor of safety (FOS), the relationship between the factor of safety and the occurrence of a landslide, and ultimately, the relationship between the sub drainage system and the fluctuation of water in the soil profile.

**Table 1** summarize the specific objectives of the research, and the proposed methodology to achieve them, including the corresponding guiding standard.

***Table 1. Summary of the Objectives and Proposed Methodology used to achieve them***

| No | PROPOSED METHODOLOGY | | STANDARD/SOFTWARE |
|---|---|---|---|
| | **Objective one: To characterize the site** | | |
| **1** | Determination of the site geometry | | |
| | i. | Contour map | **QGIS** |
| | ii. | Angle map | **QGIS** |
| **2** | Determination of the soil properties | | |
| | i. | Atterberg limits | **BS 1377-2:1990** |
| | ii. | Soil classification | **BS EN ISO 17892: Part 4: 2018** |
| | iii. | Unit weight | **BS EN ISO 17892-3-2018** |

| | | | |
|---|---|---|---|
| | iv. | Coefficient of permeability | **BS EN ISO 17892-11: 2019** |
| | v. | Cohesion and angle of friction<br>● Unconsolidated and Undrained conditions;<br>● Consolidated and drained conditions. | **BS: 1377: 1990: Part 7: Clause 8**<br>**BS 1377-7:1990** |
| | **Objective two: To conduct a hydrological study** | | |
| **1** | Delineation the watershed determination of its characteristics | | **QGIS** |
| **2** | Analysis of the rainfall dataset | | **WPS-EXEL** |
| **3** | Estimation of the water losses in the watershed | | **HEC-HMS** |
| | **Objective three: To design a horizontal subdrainage system** | | |
| | Determination of the influence of the sub-drains on groundwater levels | | **MODEL MUSE** |
| | Geotechnical analysis | | **GeoStudio** |
| | Design of a drain section | | **Analytical methods** |

## 3.2 SITE CHARACTERIZATION

### *3.2.1 SITE GEOMETRY*

The site geometry encompassed the delineation of the area of interest, along with the determination of elevation contours and the slope angle.

A **Digital Elevation Model** (DEM) is a 3D computer representation of the surface of a terrain, showing the elevation of different points on the ground. These are commonly used in Geographic Information System (GIS), and are a

common basis for digitally produced maps. DEMs can be created from various sources such as satellite imagery, aerial photography, and ground-based surveys. They have a wide range of applications including creation of topographic maps, watershed modelling, and flood simulations (F. Hutchinson and C. Gallant.2000.). The resolution of a DEM refers to the size of the grid cells that make up the model. The higher the resolution, the more details it will contain.

A DEM of resolution 30 meters was obtained from the USGS platform, and was used to generate the topographic maps, and to delineate the watershed in the area of interest. During the site visit, the coordinates of a point in the area of interest were obtained with the Handy GPS application as seen in ***FIG.8(a)***. The application has an accuracy of 1 meter, and it provides data in forms of '*Northings* and *Eastings'(MINNA CLARKE ELLIPSOID)*. Care should be put on the specification of the coordinate reference system (CRS), which in this case was the commonly used '*World Geodedic System 1984 (WGS84)'*. This collected data was converted into degrees prior to its use in QGIS. A polygon shape file of the area of interest was finally generated in delineating the area over an open street-map. The acquired DEM was clipped in accordance with the area of interest extent, and the contour and slope maps were finally generated.

### *3.2.2 SOIL PROPERTIES*

This activity entailed the determination of all the key parameters related to the slope stability. These included the atterberg limits, the particle size distribution, the unit weight, the coefficient of permeability, and the

strength parameters.

## SAMPLING PROCEDURE AND SAMPLE PRESERVATION

The sampling procedure was conducted in SHIKURUWE village, on a slope with a 2016 landslide scar (Nantumbwe, Bob R. Nakileza et al. 2017). Sampling was performed in the mid-slope, on a 15 by 10 area. The procedure followed recommendations highlighted by (Budhu, no date). Soil samples were obtained from 3 trial pits of dimension 1*1*1 meter, two along the slope and 10 meters apart, and the third 15meters away in the horizontal direction. An equivalent of 20 kilograms were extracted from each pit, and preserved into three air-tight polythene bags. At the lab, the three samples were labeled 163, 164, and 165 respectively.

**Figure 8(a)** shows the Handy-GPS interface. The app shows the UTM coordinates (Easting: 649187, Northing: 117488) based on the WGS84 datum, with an accuracy of +/-1 meter. The reported altitude is 1455 meters. **Figure 8(b)** shows a soil sample packed in layers of air-tight polythene bags to prevent excessive loss of moisture during transportation from the site to the laboratory.


*Figure 8. (a) Handy GPS interface; (b) sample preservation*

## 1. ATTERBERG LIMIT

Atterberg limit tests was performed in accordance with the BS 1377-2:1990 standard. Atterberg limits are a set of tests performed to determine the physical properties of fine grained soils such as clay and silts (GEOTECHNICAL ENGINEERING BUREAU. 2015). They consist of three tests that measure the moisture content of a soil at different states.

i. Liquid limit: this is the moisture content at which a soil changes from a liquid state to a plastic state.

ii. Plastic limit: this is the moisture content at which a soil changes from a semi-solid state to a solid state. This is determined by measuring the moisture content at which soil can be molded into a ball.

iii. Shrinkage limit: this is the moisture content at which soil changes from a semi solid to a solid state. This is determined by measuring the moisture content at which a soil stops shrinking.

**Figure 9** depicts the Atterberg Limits graph, that illustrates the relationship between the soil moisture content (Wc), and the total volume. Four distinct states of soil consistency are noticed as the water content increases: brittle (solid), semi-solid, plastic, and liquid.

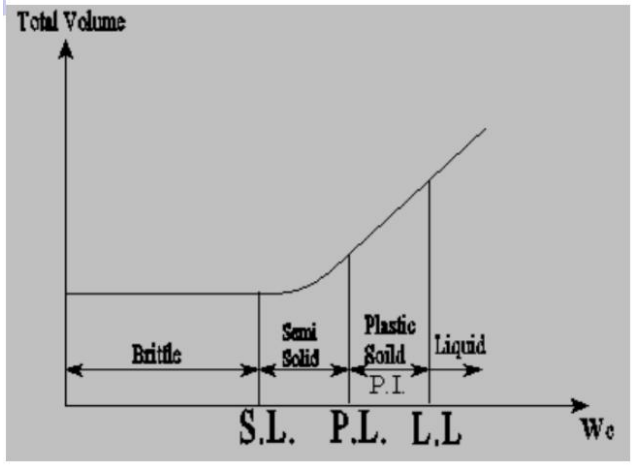



*Figure 9. Atterberg limit graph*

**Sample preparation**

The sample was oven-dried at 110° for 24 hours. It was then crushed and particles retained at the 425mm sieve were removed. A specimen of about 400g was then transferred onto a glass plate and water was added to form a thick homogeneous paste using palette knives. The paste was placed in a airtight container for 24 hours to allow a thorough penetration of water into the specimen.

### *a. LIQUID LIMIT*

The liquid limit was determined by cone penetrometer method, which is based on the measurement of penetration into the soil of a standardized cone.

Apparatus

- A glass plate
- Palette knives
- Penetrometer
- A stainless steel cone, 35,mm long with a polished surface
- A damp cloth
- A wash bottle
- A metal cup of 55mm diameter and 40mm depth

Test procedure

- The 400g of damp specimen was placed on glass plate, and water was gradually added until sufficient to reach a first reading with the cone penetrometer reading about 15mm. The paste was mixed for about 8 minutes using the palette knives;
- A portion of the mixture was put into the metal cup with a palette knife and trimmed until a smooth level surface was achieved;
- The cone was lowered until it almost touched the soil surface in the metal cup, then it was released for a period of 5 seconds. The dial gauge was lowered to contact the cone shaft and the reading was taken slightly above 15mm for the samples.

- The cone was then lifted and cleaned carefully;
- Moisture content samples were picked from the area penetrated by the cone and weighed and taken into the oven for drying.
- For the readings less than 0.5mm, the soil was removed from the metal cup and remixed to achieve consistent results.
- The procedure was repeated for penetrometer readings of 18mm, 20mm, and 25mm. more water was added for each reading, such that the approximately a rage of 15-25mm readings were covered.
- The metal cup was washed and dried for every addition of water.

Calculation

**Equation 1** shows the obtention of moisture content of the soil specimen expressed in percentage, which was the ratio of the mass of water that was evaporated from the soil sample during the oven-drying process ($\boldsymbol{m_2 - m_3}$), over the mass of dry sample ($\boldsymbol{m_3 - m_1}$). Therefore,

$$\boldsymbol{M_c = \frac{m_2 - m_3}{m_3 - m_1} * 100}$$

***Equation 1 Moisture content for Liquid Limit***

Where

$\mathbf{m_1}$: mass of the container in g

$\mathbf{m_2}$: mass of the container and the wet soil in g

$\mathbf{m_3}$: mass of the container and dry soil in g

***b. PLASTIC LIMIT***

The plastic limit test was done as a continuation of the liquid limit test. The specimen from the three test pits were prepared the same way as for liquid

limit.

Apparatus

- A 3mm diameter rod
- Palette knives
- Glass plate
- Water

Test procedure

- About 40g of paste was placed on a glass plate and allowed to dry partially until it became plastic enough to be shaped into a ball;
- The soil was then molded between the fingers and rolled between the palms of the hands until the soil dries sufficiently to be able to form cracks on its surface;
- The soil was divided into sub specimen of about 20g and then 3mm diameter threads were formed with forward and backward movement of the hands. These were measured by the rod to ensure that they were 3mm;
- The first crumbling point was the plastic limit. The crumbled threads were then gathered and transferred to labeled containers for moisture content determination.
- The procedure was repeated for the three samples form the three trial pits.

Calculations

**Equation 2** shows the obtention of moisture content of the soil specimen

expressed in percentage, which is the ratio of the mass of water that was evaporated from the soil sample during the oven-drying process ($\boldsymbol{m_2 - m_3}$), over the mass of dry sample ($\boldsymbol{m_3 - m_1}$), therefore,

$$\boldsymbol{M_c = \frac{m_2 - m_3}{m_3 - m_1} * 100}$$

***Equation 2. Moisture Content for plastic limit***

Where

**$m_1$ :** mass of the container in g

**$m_2$:** mass of the container and the wet soil in g

**$m_3$**: mass of the container and dry soil in g

The plastic index was finally obtained from the liquid limit and the plastic limit values.

**Equation 3** shows the formula for the Plastic Limit, calculated as the difference between the Liquid Limit and the Plastic Limit of the soil sample.

$$\boldsymbol{PI = LL - PL}$$

***Equation 3. Plastic index***

Where

**PI**: plastic index

**LL**: liquid limit

**PL**: plastic limit

### *c. LINEAR SHRINKAGE*

The linear shrinkage test measures the total linear shrinkage from linear measurements on a bar of the soil that passed the 425mm sieve at the moisture content of the liquid limit. It is also done as a continuation of the

liquid limit and the plastic limit tests and the sample is prepared as part of the liquid limit test.

Apparatus

- Glass plate
- Palette knives
- Oven
- Clean water
- A linear shrinkage mold
- Grease
- Vernier calipers

Test procedure

- The mould was cleaned thoroughly and a light film of grease was applied to its inner face to prevent the soil from sticking to the surface of the mold;
- The paste for linear shrinkage was removed at the moisture content where the penetrometer reading was 20mm during the liquid limit test;
- The paste was then placed in the shrinkage mould and a palette knife was used to achieve a smooth level surface. The molds were left to air dry for a day and then were placed in the oven at $105^0$C;
- The mould was then cooled and the length of the bar was measured using the Vernier caliper.

Calculations

**Equation 4** shows the calculation for Linear Shrinkage expressed as a percentage reduction in length due to drying.

$$LS = (1 - \frac{L_D}{L_0}) * 100$$

*Equation 4. Linear Shrinkage*

Where

$L_0$: initial length in mm

$L_D$: length of the oven dried specimen in mm

## 2. SOIL CLASSIFICATION

The soil was classified by the particle size distribution test, in accordance with BS EN ISO 17892: Part 4: 2018.

a. Moisture content

A mass of wet soil + tin was measured in labeled tins of known mass and then oven-dried at 110° for 24-hours. The mass of dry soil+ tin was then determined.

**Equation 5** shows the obtention of the initial moisture content of the specimen, which was the ratio of the mass of water that was evaporated from the soil sample during the oven-drying process ($w_1 - w_2$), over the mass of dry sample ($w_2$).

$$Mc = \frac{w_1 - w_2}{w_2} * 100$$

*Equation 5. Initial moisture content for particle size distribution*

Where

$w_1$ : mass of the wet soil + the tin in g

$w_2$: mass of the dry soil + the tin in g

This operation was repeated twice for every specimen in triplicate.

b. Wet sieving

A dry specimen of about 1.5 kg was weighed and recorded as **A**, and then soaked in water for a minimum of 12-hours, to allow larger particles to soften prior to the wet sieving process .

The wet sieving procedure entailed washing thoroughly the soil specimen through a series of two sieves until water coming out of the sieves was relatively clean.

The finer sieve had a diameter of 75μm, meaning that only particles of diameter less than 75μm (silt) were allowed to pass through. The other sieve, also referred to as the 'guard sieve', had a diameter of 600μm. Its purpose was to prevent damaging the finer sieve if used alone. After sieving, the specimen was oven-dried at 110° for 24-hours.

This procedure was done in triplicate for every sample.

c. Dry sieving

The weight of the dry specimen was recorded as **B**, then the specimen was passed through a series of different sieve sizes as per standard , and the mass retained at each sieve recorded.

d. Determination of the mass that passed the 75μm sieve (Pan+C)

The soil particles that passed through the 75μm sieve are referred to as fine-grained, and they encompass silt and clay particles.

**Equation 6** shows the obtention of the mass of fine-grained particles, which was the sum of the mass retained on the pan after dry-sieving, and C, the difference in mass due to sample washing.

$$\boldsymbol{Mass_{fine-grained} = Pan + C}$$

***Equation 6. Determination of the mass that passed the 75μm sieve***

Where

***Pan:*** mass of soil retained on the pan after the dry sieving process

***C:*** mass of dry sample (D) - dry mass after washing (B)

**Equation 7** shows the obtention of the mass of dry sample (D), using the initial dry mass before washing (A), over the moisture content Mc expressed in percentage.

$$\boldsymbol{D = \frac{Dry\ mass\ before\ washing\ (A)\ * 100}{100\ +\ M_C}}$$

***Equation 7. Determination of the dry mass sample***

## 3. UNIT WEIGHT

The bulk unit weight of the soil was indirectly determined by the specific gravity test in accordance with (BS EN ISO 17892-3-2018).

a. Sample preparation

The oven-dried sample was crushed and passed through a 2mm sieve, after which it was divided into three specimen of about 100g for the test in triplicate.

b. Aparatus used

- A weighing scale;
- Nine clean and dry pyconometers of capacity 250ml and a lid;
- A beaker of capacity 100ml.

c. Testing procedure

The label and the weight of the empty pyconometer with the lid was recorded. In a beaker, a 50mg of the specimen was measured, and then poured into the pyconometer. The mass of the pyconometer plus the sample plus the lid was then recorded.

Water was poured into the pyconometer up to a level slightly above the

level of the soil specimen, and then vigorously mixed until dissolution of the soil. The solution was allowed to settle for a minimum of 12-hours. After that period of time, the pyconometer was entirely filled with water, closed with the lid, and the solution briefly mixed to allow an even dispersal of particles in water. The weight of the pyconometer with the lid plus the solution (water+specimen) was recorded.

**Equation 8** shows the obtention of specific gravity (G) which is dimensionless, from the ratio of mass of dry soil ( $\boldsymbol{m_2 - m_1}$ ) over the difference between the mass of water ($\boldsymbol{m_4 - m_1}$) and the mass of wet soil ($\boldsymbol{m_3 - m_2}$).

$$\boldsymbol{G = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)} * 1000}$$

***Equation 8. Determination of the soil density***

Where

$m_1$: mass of pyconometer (g);

$m_2$ : mass of pyconometer and dry soil (g);

$m_3$ : mass of pyconometer, soil, and water (g);

$m_4$ : mass of pyconometer full of water only (g).

## 4. COEFFICIENT OF PERMEABILITY

The permeability test is a test conducted to determine the coefficient of permeability (K), which is the rate of flow under laminar flow conditions

through a unit cross sectional area of porous medium under unit hydraulic gradient (B. Ahmed, August 2021). The falling head permeability test is commonly used in connection with the studies where the drainage and settlement of soft foundations are involved. This test can also serve as a check on the consolidation test results.

There are two types of permeability tests, for instance the constant head permeability test, and the falling head permeability test.

- The constant head permeability test is performed on coarse materials such as sand. Here water is forced by a known constant pressure through a soil sample of known dimensions, and the rate of flow is then determined. The type of sample used is undisturbed, and remolded prior to testing. During sample preparation, water is added to bring the sample slightly below the apparent optimum moisture content (OMC), or sufficient water to enable a good compaction using the 45.4 kg compaction method.
- The falling head permeability test on the other hand, is performed on fine-grained materials such as clay. Here water is forced by a falling head through a soil sample of known dimensions, and the rate of flow is determined. Undisturbed samples are required for this test, however, remolded specimens can also be used, though they cannot be as accurate as undisturbed samples.

The coefficient of permeability (K) was determined by the falling head permeability test in accordance with the BS EN ISO 17892-11: 2019 standard, since the soil sample was a clay type. The test was performed on remolded specimen, hence an adequate compaction was necessary prior to the test.

a. Sample preparation

**i. Apparatus used**

- Permeameter with its accessories;
- Weighing scale;
- 2 mm sieve
- Measuring jar
- Trimming knife
- Tins for moisture content test
- Oven
- Metallic rings of dimensions D6mm, h4mm
- Protective glass plates

ii. **Procedure**

- The soil sample is preferably dried and sieved to remove particles retained on the 2mm sieve. An alternative is to work at the moisture content of the sample which was previously determined in other tests. In this case, the specimen was ensured to be composed of fine particles by further crushing any larger particles, and an amount of 2.5 kg was taken;
- Water was gradually added to the specimen until the optimum moisture content was attained for compaction;
- The weight of the empty mould, as well as the one of two empty tins per specimen was recorded according to their respective label;
- The permeameter was assembled. The compaction method utilized was the 4.5 kg, which is suitable for soil particles up to medium particle size. This method entails compacting the specimen in 5layers with 27 blows

each, with a 4.5 kg hammer in a 1 liter mould;

- After compaction, the mould was trimmed, and the weight of the mould plus the compacted specimen recorded. Some of the trimmed compacted soil was recovered to determine the moisture content. Hence, the mass of the tin plus the wet specimen was taken and recorded, and the specimen oven-dried at 110° for 24 hours ;
- The compacted specimen was mechanically recovered from the oiled mould;
- The weight of the empty ring was taken and recorded according to the respective label;
- The specimen was divided into two, and a half was kept as reserve. The metallic ring was ensured to be inserted evenly into the compacted soil, trimmed at both ends, and the weight of the ring plus the specimen recorded, then two glass plates were placed at both ends of the specimen to prevent a loss of moisture, finalizing the sample preparation process.

b. Apparatus used for the permeability test

- Thermometer
- Filter papers
- Rings
- Porous stone
- Stand pipe
- Measuring cylinder
- Water supply

c. Test procedure

The apparatus was loaded, by placing a filter paper and then the ring, and another filter paper on top. The ring was then fastened to prevent any water from spilling out. The water head was measured at a known starting point.

Before starting the flow measurements, the soil sample was saturated and the stand pipes were filled with de-aired water to given level, (in this case it was 90ml).

The soil sample, a cylindrical core was placed in a test chamber with the water above it.

The test then started by allowing water to flow through the sample until the water in the stand pipe reached a lower limit. The reading was recorded when the difference in the level was about 20ml.

The starting time and the ending time were recorded for the three specimens, and then converted into seconds.

**Equation 9** shows the obtention of the discharge (Q) in cubic centimeter, which was the product of the cross-sectional area of the tube ($\boldsymbol{\pi R^2}$) and the head difference ($\boldsymbol{h_0 - h_1}$).

$$\boldsymbol{Q\ (cm^3) = \pi R^2 (h_0 - h_1)}$$

***Equation 9. Calculation for discharge in falling head permeability test***

Where

$\boldsymbol{h_0}$ : initial height of water

$\boldsymbol{h_1}$ : final height of water

***R***: diameter of the tube

This was performed several times until a consistent value is reached for the value of k (m/s) in the table.

Calculations

The information collected included the following:

- Initial water head ($h_0$) in the stand pipe
- Final water head ($h_1$) in the standpipe after a set time.
- Time (t) it takes for the water level to fall from $h_0$ to $h_1$
- Length of the soil sample which is the same as the ring dimensions
- Cross sectional area of the stand pipe through which the water flows

**Equation 10** shows the obtention of the coefficient of permeability K from Darcy's law for falling head permeability test, which related the dimensions of the testing apparatus (area of burette, length of soil column, and area of soil column), and the change in water over time to quantify the ability of the soil to transmit water.

$$K = \frac{aL}{At} \, ln\frac{h_0}{h_1}$$

***Equation 10. Determination of the coefficient of permeability***

where

***K*** :coefficient of permeability

***a*** :area of the burette

***L*** :length of the soil column

***A*** :area of the soil column

$\boldsymbol{h_0}$ :initial height of water

$\boldsymbol{h_1}$ :final height of water $(\mathrm{h}_0 - \Delta h)$

$\boldsymbol{t}$ :time required to get head drop

## 5. COHESION AND ANGLE OF FRICTION

Cohesion and angle of friction are fundamental soil parameters that describe the soil's resistance to forces that cause it to slide or deform, known as the shear strength. Cohesion represents the internal bond of the soil, stemming from the attraction of fine particles such as clay, while the angle of friction reflects the resistance to sliding due to the interlocking and friction between particles (ABG. No date). These soil parameters can be determined in either unconsolidated and undrained, or consolidated and drained conditions.

### *a. UNCONDOLIDATED AND UNDRAINED CONDITONS*

The Triaxial test provides undrained stress-strain response of a cylindrical soil specimen under triaxial compression loading without consolidating the specimen (Andrew Lees,2020). It also provides the undrained shear strength parameters by performing the tests on different confining pressures. Initially, a confining pressure ($\boldsymbol{\sigma_3}$) is applied through water around the specimen in triaxial cell. The drainage valve is closed throughout the test, which does not allow the consolidation of the specimen. The specimen is then subjected

to shearing by applying the constant rate of deformation under undrained compression loading conditions. The excess pore water pressure is not measured during shearing; hence the shear strength parameters are analyzed in total stress conditions only.

**Sample preparation**

The testing specimen consisted into a reconstituted sample of 38.1mm in diameter and 76.2mm long ($\mathrm{H} = 2\mathrm{D}$) .

**Figure 10** shows a typical testing specimen for triaxial test, which has a diameter of 38.1mm and a height of 76.2mm.

***Figure 10. Testing specimen for triaxial test***

i. Apparatus

- Loading frame capable of generating constant rate of movement;
- Proving ring (Capacity ranging from 1 kN to 50 kN);
- Bottom platen of required diameter made with Perspex glass (diameter of the plate is selected according to the diameter of the sample);
- Top cap of required diameter made with Perspex glass with a circular

groove to accommodate the plunger of triaxial cell;

- Dial gauge (0.01 mm accuracy);
- Hardened Steel ball;
- Triaxial cell, in which using water hydro-static pressure can be applied to the specimen and having a central plunger that can be connected to proving ring to measure the vertical load/pressure. The cell (made of Perspex) is usually designed with a non-ferrous metal top and base connected by tension rods;
- Bottom base plate with a pedestal of diameter similar to the diameter of specimen and valve arrangements to apply cell pressure;
- Air-water interface system (Cylinder filled with water and a balloon inside it which applies air pressure to the water filled in cylinder);
- Air Compressor;
- Constant pressure system with regulators, valves and pressure meter to control the cell pressure;
- De-aeration tank;
- Latex rubber membrane;
- Rubber O-rings;
- Membrane Stretcher (An open-ended cylindrical section former, required inside diameter fitted with a small rubber tube on its side).

ii. <u>Test procedure</u>

- The bottom plate was placed on the pedestal of base plate of triaxial

cell, then the specimen was placed on top of it;

- The top cap was placed on the specimen;
- The specimen arrangement was sealed properly with the latex rubber membrane and rubber O-rings using the membrane stretcher;
- The cell was placed such that properly set up and uniformly clamped down to prevent leakage of pressured water during the test;
- The plunger was moved down and set up on the circular groove of the top cap, and the ball was then placed on the top of plunger;
- The center-line of the specimen was adjusted such that the proving ring, the steel ball, plunger and specimen were in the same line;
- The cell was filled with water with bleed valve open, then closed when the cell was completely filled;
- The air water interface was then regulated using valves and regulator of constant pressure system, and the pressure was applied to water with the balloon in interface system;
- The valve connecting the pressure to the cell was opened to apply the required cell pressure (50 kPa, 100 kPa and 150 kPa…). The pressure gauge was monitored such that to make any necessary adjustment to keep the pressure constant during the test;
- A small deformation was applied to the system until the underside of the hemispherical seating of the proving ring, through which the loading was applied, just touched the steel ball on cell piston. This procedure is

called the *docking of triaxial system;*

- After docking a dial gauge was fixed to measure the vertical compression of the specimen;
- The position of the gear was adjusted on the load frame to give suitable rate of deformation;
- The load was applied, and the readings of the proving ring and compression dial for every 25 divisions in compression dial gauge were automatically recorded by the machine;

The loading continued until failure or 20% axial strain a picture of the failure pattern of the specimen was finally taken as illustrated by ***FIG.3.5***.

### *b. CONSOLIDATED AND DRAINED CONDITIONS*

This test was used to determine the shear strength parameters of soil under consolidated drained conditions primarily the cohesion and the angle of internal friction. The soil sample was consolidated under a known normal stress and then sheared at a slow rate to ensure drainage and prevent pore pressure buildup. This test followed BS 1377-7:1990.

**Sample preparation**

Representative soil samples were taken that were large enough to meet the test's size dimensions. The sample was carefully trimmed into a shape that fit the shear box ensuring a smooth and uniform surface, the moisture content of the samples was determined by oven drying to obtain dry weigh,

which was needed for calculations.

*i.* *Apparatus*

- A shear box;
- Loading frame;
- Normal load application system linear displacement transducer;
- Sample cutting tools.

*ii.* *Test procedure*

- The trimmed sample was placed inside the shear box, ensuring the top and bottom surfaces were level;
- The sample was carefully paced between the halves of the shear box and were aligned properly for the test;
- A normal load ($\sigma_3$) was applied to the top of the top sample by placing a known weight or load on the top of the shear box;
- The normal stress was applied to avoid sudden disturbance of the sample;
- The sample was allowed to consolidate under the applied normal load. During this phase, the pore pressure dissipated and the sample reached a state where volume change stopped that is full consolidation.
- The consolidation phase ensured that the sample was drained. For clay soils, consolidation may take several hours or days;

- The settlement of the sample was monitored to ensure proper drainage and consolidation;
- After the consolidation was complete, the shearing phase began. The top half of the shear box was displaced horizontally by the shear apparatus causing the soil sample to shear along a horizontal plane;
- A slow, controlled shear by moving the top part of the box at a constant rate. The shear force was applied gradually, ensuring that drainage of the pore water occurs;
- The shear force ($\tau$) was recorded continuously throughout the test using a load cell attached to the shear box. The horizontal displacement (strain) was recorded using a displacement transducer;
- The test continued until failure was observed. This typically occurs when the shear force reaches a peak and then drops indicating failure;
- The test stopped once significant displacement occurred or when the shear stress started to level off;
- The test was repeated with different normal stresses for example 50 kpa, 100 kpa, 200 kpa. And a failure envelope was plotted from the results.

*iii. Results*

The failure data from the test was used to plot the shear stress versus normal stress for the samples. From the data points, a Mohr-Coulomb failure envelope was generated providing the cohesion and the angle of friction of the soil. The intercept of the Mohr-Coulomb failure envelope gives the

cohesion (c). The slope of the failure envelope gives the angle of internal friction ( $\varphi$).

## 3.3 STUDY OF THE HYDROLOGY

A spatial analysis was conducted using QGIS, utilizing a DEM to examine the topography, land use, and land cover. Subsequently, a hydrological analysis was carried out with the Hydrologic Modelling System (HEC-HMS). The aim of this objective was to determine the distribution of water in the various elements of the watershed.

### 1. WATERSHED DELINEATION

Watershed delineation entailed the identification of the river network that drains the study area, along with the specific drainage basin. The largest river in the area being TSUTSU river, the information about its catchment area was extracted from the DEM previously acquired using, QGIS. The large catchment was then divided into four sub catchments, and the outlet of the respective sub-catchment determined.

### 2. RAINFALL

A twenty five-years daily rainfall dataset was acquired from a weather station in BUDUDA district (coordinates x= 34.33 and y=1.017), and plotted. In the context of risk aversion, the design had to account for the worst case scenario of inflow, which in this case corresponded to the highest daily

rainfall value in the dataset (UNISDR, 2017). In addition to this, further statistical analysis were performed to determine the monthly rainfall frequency pattern, the yearly rainfall intensity, as well as the rainfall return time.

**Figure 11** shows the plotted graph of the 25-years daily rainfall dataset. The precipitation was recorded in inches, then converted to millimeters for a easier analysis. The orange arrow points at the highest rainfall value (1330.96mm) that was recorded on July 7th, 2007.

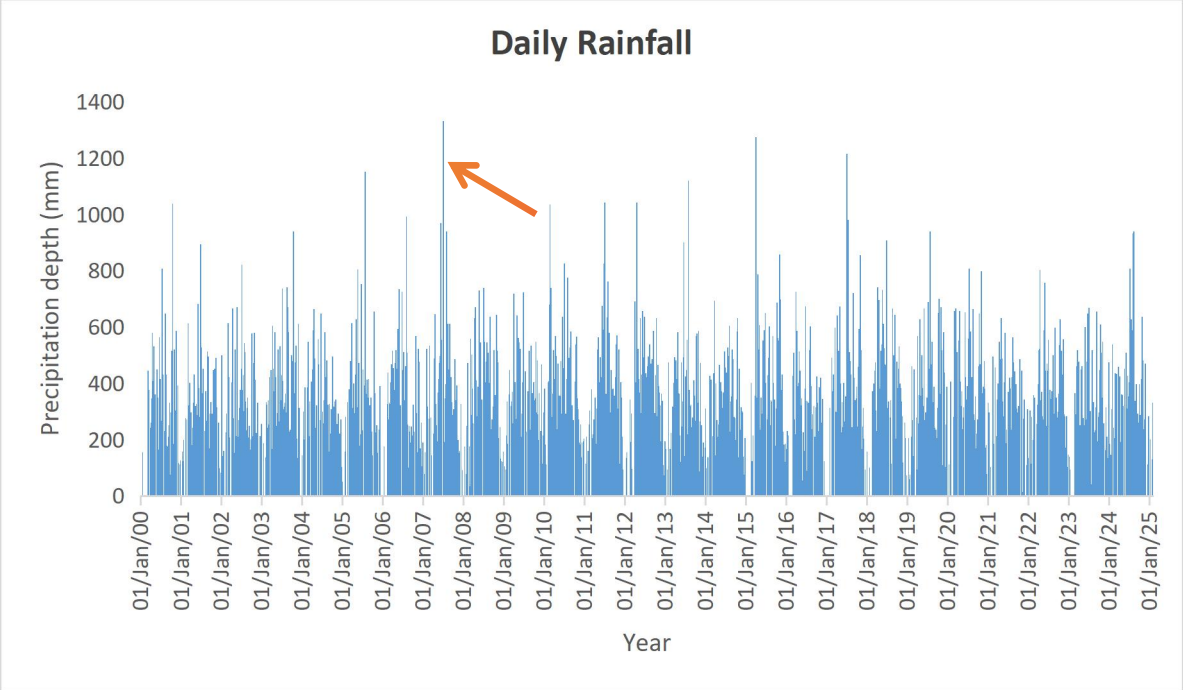



***Figure 11. Daily rainfall data for 25 years.***

### a. MONTHLY RAINFALL PATTERN

The monthly rainfall pattern corresponds to the average monthly rainfall throughout the data set.

**Table 2** shows the derivation of the average monthly rainfall data from

statistical analysis in WPS-EXCEL.

*Table 2. Average monthly rainfall values*

| Month | Rainfall depth (mm) |
|---|---|
| January | 20695.92 |
| Febuary | 43995.34 |
| March | 76928.98 |
| April | 124452.38 |
| May | 123134.12 |
| June | 107579.16 |
| July | 121699.02 |
| August | 125168.66 |
| September | 93685.36 |
| October | 125364.24 |
| November | 85450.68 |
| December | 31193.74 |
| **Grand Total** | **1079347.6** |

## b. YEARLY RAINFALL INTENSITY

**Table 3** shows the yearly rainfall intensity (YRI), along with the average daily rainfall intensity on rainy days (ADRIRD), and maximum daily rainfall intensity were generated from statistics in WPS-EXCEL.

*Table 3. Yearly intensity, Average daily rainfall intensity on rainy days, and maximum daily rainfall intensity.*

| Year | Yearly rainy day count | Yearly rainfall | YRI | ADRIRD | Max daily intensity |
|---|---|---|---|---|---|
| 2000 | 169 | 39695.12 | 108.7537534 | 234.8823669 | 1038.86 |
| 2001 | 187 | 40152.32 | 110.0063562 | 214.7182888 | 894.08 |
| 2002 | 189 | 38336.22 | 105.0307397 | 202.8371429 | 820.42 |
| 2003 | 200 | 43395.9 | 118.8928767 | 216.9795 | 939.8 |
| 2004 | 173 | 37467.54 | 102.6507945 | 216.5753757 | 662.94 |
| 2005 | 172 | 39235.38 | 107.4941918 | 228.1126744 | 1150.62 |
| 2006 | 199 | 43157.14 | 118.2387397 | 216.8700503 | 993.14 |
| 2007 | 204 | 43883.58 | 120.2289863 | 215.1155882 | 1330.96 |
| 2008 | 209 | 44932.6 | 123.1030137 | 214.9885167 | 739.14 |
| 2009 | 178 | 39921.18 | 109.3730959 | 224.2762921 | 723.9 |
| 2010 | 227 | 48541.94 | 132.9916164 | 213.8411454 | 1036.32 |
| 2011 | 216 | 51833.78 | 142.0103562 | 239.9712037 | 1041.4 |
| 2012 | 202 | 46075.6 | 126.2345205 | 228.0970297 | 1041.4 |
| 2013 | 209 | 45156.12 | 123.7153973 | 216.0579904 | 1120.14 |
| 2014 | 219 | 42418 | 116.2136986 | 193.6894977 | 693.42 |
| 2015 | 189 | 43461.94 | 119.0738082 | 229.9573545 | 1275.08 |
| 2016 | 169 | 35689.54 | 97.77956164 | 211.1807101 | 726.44 |

| | | | | | |
|---|---|---|---|---|---|
| 2017 | 194 | 45605.7 | 124.9471233 | 235.0809278 | 1216.66 |
| 2018 | 184 | 43883.58 | 120.2289863 | 238.4977174 | 906.78 |
| 2019 | 214 | 44820.84 | 122.7968219 | 209.4431776 | 939.8 |
| 2020 | 203 | 47073.82 | 128.9693699 | 231.8907389 | 807.72 |
| 2021 | 185 | 40576.5 | 111.1684932 | 219.3324324 | 632.46 |
| 2022 | 217 | 46814.74 | 128.2595616 | 215.736129 | 802.64 |
| 2023 | 194 | 41541.7 | 113.8128767 | 214.1324742 | 668.02 |
| 2024 | 218 | 44800.52 | 122.7411507 | 205.5069725 | 939.8 |

## c. RAINTALL RETURN PERIOD

The rainfall return period refers to the probability that a particular rainfall event will occur again in a near future, and it is mostly considered in the modelling process when design for the worst case scenario (M. Amoakowaash, L. Kofiste, A. Omari-sasu et al. 2021). The exceedance probability on the other hand, refers to the probability that a given rainfall magnitude will be exceeded in any given year. Rainfall events with a high return time depict a lower exceedance probability, while the ones with a low return time have a higher exceedance probability.

**Table 4** shows the maximum rainfall, the return period, and the Exeedance probability generated through statistical analyses in WPS-EXCEL.

***Table 4. Rainfall return period computation***

| Year | Maximum rainfall (mm) | Rank | Return period (years) | Exeedance probability |
|---|---|---|---|---|
| 2007 | 1330.96 | 1 | 26 | 0.038461538 |
| 2015 | 1275.08 | 2 | 13 | 0.076923077 |
| 2017 | 1216.66 | 3 | 8.666666667 | 0.115384615 |
| 2005 | 1150.62 | 4 | 6.5 | 0.153846154 |
| 2013 | 1120.14 | 5 | 5.2 | 0.192307692 |
| 2011 | 1041.4 | 6 | 4.333333333 | 0.230769231 |
| 2012 | 1041.4 | 7 | 3.714285714 | 0.269230769 |
| 2000 | 1038.86 | 8 | 3.25 | 0.307692308 |
| 2010 | 1036.32 | 9 | 2.888888889 | 0.346153846 |
| 2006 | 993.14 | 10 | 2.6 | 0.384615385 |
| 2003 | 939.8 | 11 | 2.363636364 | 0.423076923 |
| 2019 | 939.8 | 12 | 2.166666667 | 0.461538462 |
| 2024 | 939.8 | 13 | 2 | 0.5 |
| 2018 | 906.78 | 14 | 1.857142857 | 0.538461538 |
| 2001 | 894.08 | 15 | 1.733333333 | 0.576923077 |
| 2002 | 820.42 | 16 | 1.625 | 0.615384615 |
| 2020 | 807.72 | 17 | 1.529411765 | 0.653846154 |
| 2022 | 802.64 | 18 | 1.444444444 | 0.692307692 |
| 2008 | 739.14 | 19 | 1.368421053 | 0.730769231 |

| | | | | |
|---|---|---|---|---|
| 2016 | 726.44 | 20 | 1.3 | 0.769230769 |
| 2009 | 723.9 | 21 | 1.238095238 | 0.807692308 |
| 2014 | 693.42 | 22 | 1.181818182 | 0.846153846 |
| 2023 | 668.02 | 23 | 1.130434783 | 0.884615385 |
| 2004 | 662.94 | 24 | 1.083333333 | 0.923076923 |
| 2021 | 632.46 | 25 | 1.04 | 0.961538462 |

## 3. HYDROLOGICAL MODEL

The purpose of the hydrological model was to understand the movement of water in the watershed.

Hydrological Modelling System (HEC-HMS) 4.12 program is a product developed by the US Army Corps of research and development program, and produced by the Hydrologic Engineering Center (HEC) (Feldman, 2000). The program works on the principle of watershed run-off process which begins with the precipitation falling onto the vegetation, land surface and water bodies, only to be returned to the atmosphere in the form of evaporate-transpiration. A portion of the precipitation on the vegetation falls onto the land surface, joining the precipitation that had already fallen onto the surface. On the surface, a portion infiltrates the ground, while the rest joins the stream. The precipitation that infiltrated the ground is stored in the upper or saturated soil layer. This either further gets carried to the surface by capillary action, or flows horizontally as inter-flow, or further percolates

vertically to join the aquifers as groundwater. All of the water previously mentioned eventually flow towards the stream (Vijayaprakash, M. 2020).

**Figure 12** depicts the principle of watershed run-off process used by HEC-HMS, how water precipitation enters the watershed, how it moves through the different elements of the watershed, and how it returns back to the atmosphere.

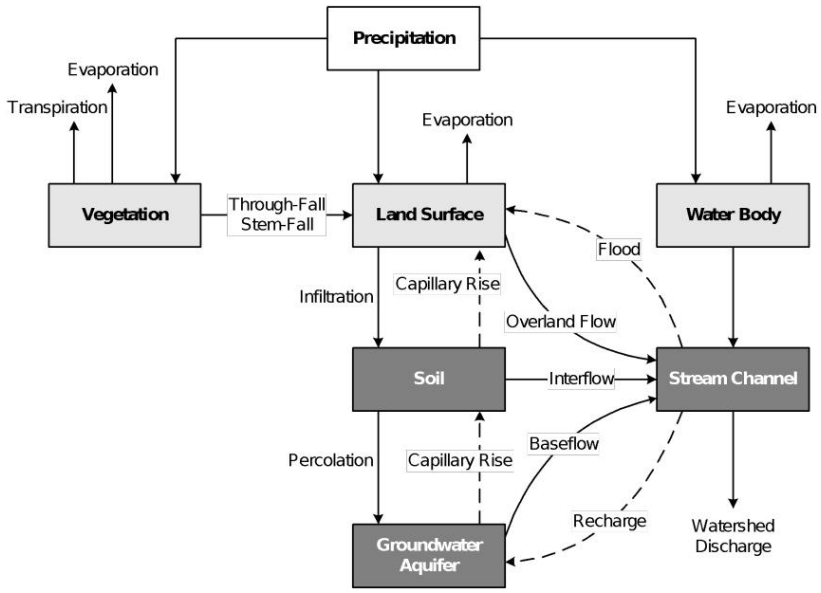



***Figure 12. System diagram of the runoff process at local scale***

***(Source: Ward,1975)***

## a. MODEL DOMAIN AND CONCEPTUAL MODEL

The model domain shown in ***FIG 12***, had HEC-HMS grid cells equivalent to the DEM resolution (30m by 30m). The previously delineated watershed was divided into three sub-catchments of which the characteristics are displayed in ***Table 5***.

i. The basin model consisted of three sub-basins (where the slope of

interest was located in sub-basin 3), two reaches, and three junctions (where the junction 3 is the outlet of the watershed). Every sub-basin accounted for the canopy interception, the surface, and the soil moisture, and was assumed to have a linear reservoir;

ii. The meteorologic model considered the specified hydrograpth and an annual evaporation for all the sub-basins;

iii. The model had a control specification with a starting and ending dates corresponding to the ones in the time-series data, together with a time interval which was taken as an hour;

iv. In the time-series data, the precipitation gage was a 24-hours data set corresponding to the peak rainfall value of the 25-years rainfall data.

**Figure 13** depicts the model developed with HEC-HMS. The active cells in color scale of assigned land surface elevations, with dimension 30 m by 30 m. The watershed was divided into 3 sub-basins, and different icons represent the sub-basins, the reaches, and the junctions respectively.

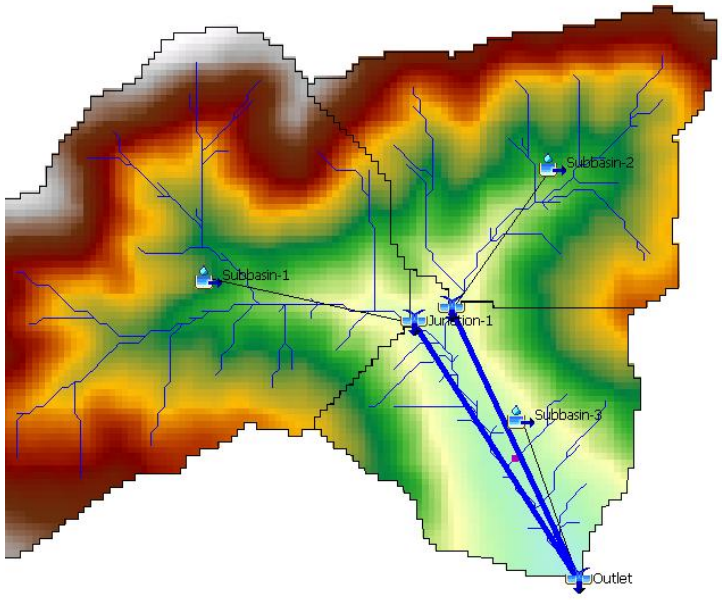



*Figure 13. HEC-HMS Model grid for the watershed.*

**Table 5** shows the characteristics for every sub catchment of the watershed, for instance the surface area, the longest river path, and the slope.

*Table 5. Characteristics of the different sub-catchments*

| Sub-catch | Surface ($Km^2$) | Longest river path (Km) | Slope $\frac{m}{m}$ |
|---|---|---|---|
| 1 | 3.3 | 3999.615 | 0.093 |
| 2 | 1.9 | 3410.236 | 0.1 |
| 3 | 1.5 | 1611 | 0.33 |

b. **BASIN MODEL**

This encompassed the identification of the basin constituents (sub basins, outlets here referred to as junctions, and reaches), linking them from upstream to downstream, and defining their respective parameters. Hence, our basin model flow was as follow:

Sub basin1 → junction1 → reach1 → outlet

Sub basin2 → junction2→ reach2→ outlet

Sub basin 3 → outlet

BASIN CONSTITUENT PARAMETERS

i. SUB BASIN

The sub basin comprised the watershed area, the vegetation, the slope, the water loss type, and the transformation method.

- ***Vegetation: Simple canopy method***

Simple canopy method requires an initial, and a maximum storage value to be assigned to the sub-basin.

The initial storage was assumed to be 40%, provided that it rained the day before the considered simulation day. The maximum storage value on the other hand, is dependant on the type of vegetation.

**Table 6** explains estimation of the maximum storage value in relation to the vegetation type, according to Buchhorn et al (2019).

***Table 6. Land cover and Interception storage values***

| *Vegetation type* | *Max storage* |
|---|---|
| Herbaceous vegetation | 2.0 |
| Cropland | 2.0 |
| Urban area | 0.5 |
| Water bodies | 0.0 |

| | |
|---|---|
| Evergreen needle leaf | 2.0 |
| Deciduous broad leaf forest | 2.0 |
| Mixed forest | 3.0 |

Considering that the vegetation type of the area is primarily herbaceous vegetation (banana plantations) and cropland (coffee and cassava), the maximum storage was taken as 2.0.

- ***Surface: simple surface method***

The simple surface method also requires the user to define the initial, and maximum storage value.

The initial storage value was assumed to be 60% for the same reasons stated before. The maximum storage value is dependent on the slope of the terrain. The slope of the terrain was previously extracted from the DEM under site characterization, where the maximum value was 28.26%.

**Table 7** gives an insight of the maximum storage values estimation based on the type of surface slope (Vijayaprakash, M. 2020).

***Table 7. Slope and Surface storage values***

| *Category* | *Type of surface Slope (%)* | *Surface Storage (mm)* |
|---|---|---|
| Paved Impervious | NA | 3.18-6.35 |
| Flat, Furrowed | 0-5 | 50.8 |
| Moderate to Gentle Slopes | 5-30 | 6.35-12.70 |
| Steep, Smooth Slopes | >30 | 1.02 |

From the table, the slope of 28.26% fell under the category of 'Moderate to Gentle slopes'. A linear interpolation was applied to determine the maximum storage corresponding to the slope of interest.

**Equation 11** is an application of linear interpolation, considering the value above ($\boldsymbol{S_{30}}$), and below ($\boldsymbol{S_5}$) the one for the slope ($\boldsymbol{S_x}$).

$$\frac{\boldsymbol{S_{30} - S_x}}{\boldsymbol{S_{30} - S_5}} = \frac{\boldsymbol{Slope_{30} - Slope_x}}{\boldsymbol{Slope_{30} - Slope_5}}$$

***Equation 11. Linear interpolation for maximum surface storage***

$$\frac{12.70 - S_x}{12.70 - 6.35} = \frac{30 - 28.26}{30 - 5}$$

$$12.70 - S_x = 0.44196$$

$$\mathbf{S_x\ (mm) = \ 12.258}$$

- ***Loss: SMA method***

Provided our interest in the effects of rain on the soil, the selected loss method was the Soil Moisture Accounting (SMA). This method requires several parameters to calculate the loss from three layers (soil, GW1,and GW2).

1. Initial storage condition

Based on the rule, the soil layer was assigned 50%, groundwater layer 1 as 20 % and groundwater layer 2 as 30% (Vijayaprakash, M. 2020).

2. Infiltration rate

The infiltration rate only pertains only to the top soil, which consists of a clay layer.

**Equation 12** shows the obtention of the maximum infiltration rate, which

was the average of the infiltration rate values obtained from the falling head permeability test for the three trial pits.

$$\boldsymbol{Max\ IR\ (mm/hr)\ =\ \frac{IR_1\ +IR_2\ +IR_3}{3}}$$

***Equation 12. Maximum infiltration rate***

Therefore,

$$\boldsymbol{Max\ IR\ (mm/hr)\ =\ \frac{9.39\ +367.1\ +444.67}{3}=\ 273.68}$$

3. Soil storage condition

This included the calculation of soil storage, tension storage and soil percolation.

i. Soil maximum storage

**Equation 13** shows the obtention of the soil maximum storage, which was the product of the soil depth and the porosity, where the porosity was obtained from the bulk density and the specific gravity. The soil depth was taken to be 1 meter, with respect to the depth of sampling excavation.

$$\boldsymbol{Max\ soil\ strorage\ (mm)=\ soil\ depth\ *\ porosity}\ (\%)$$

***Equation 13. Maximum soil storage***

Where

$$\boldsymbol{Porosity\ (n)=}\ 1-\ \frac{\rho_{bulk}}{2.7}*\ 100$$

$$=1-\ \frac{1.933*9.81}{2.7}*100=\ 28.40\%$$

Therefore,

$$\boldsymbol{Max\ soil\ storage\ (mm)=\ 1000\ *\ \frac{28.40}{100}=\ 284}$$

ii. Tension storage

**Equation 14** shows the obtention of the tension storage, which was the product of the soil depth, and the field capacity, where the field capacity was taken as 40% for clay soils (Vijayaprakash, M. 2020).

$$\boldsymbol{Tension\ (mm) = \ soil\ depth\ *\ field\ capacity\ (\%)}$$

***Equation 14. Tension storage***

Therefore,

$$\boldsymbol{Tension\ (mm) = \ 1000\ *\ \frac{0.4}{100} = \ 40}$$

iii. Percolation

The percolation in the soil layer was taken to be 40% of the infiltration rate, and 10% for GW1 and GW2 respectively (Vijayaprakash, M. 2020). Hence,

$$\boldsymbol{Soil\ percolation\ (mm/hr)\ = 273.68 * \frac{40}{100} = \ 109.472}$$

$$\boldsymbol{GW1/GW2\ percolation\ (mm/hr)\ = 273.68 * \frac{10}{100} = \ 27.368}$$

- ***Transformation: Unit Clark transform method***

The time of concentration (Tc) and storage coefficient (R) are the essential parameters for this method. Tc represents the time required to travel from the farthest point of the watershed to the outlet, while R represents the amount of water stored within the watershed during runoff. These parameters are dependent on the characteristics of the watershed (Timothy Melching, Charles S Kocher et al. 2000).

**Table 8** summarizes the characteristics of the watershed used in the computation of the time of concentration, and the storage coefficient, for

instance the longest river path, and the slope.

*Table 8. Key parameters for Unit Clark transformation method*

| *Sub-basin* | *Longest flow length (Km)* | *Slope* ($\frac{m}{Km}$) |
|---|---|---|
| 1 | 3.99 | 92.6 |
| 2 | 3.4 | 100 |
| 3 | 1.6 | 33.33 |

**Equation 15** shows the obtention of Tc and R when the longest flow path and the slope are known (Timothy Melching, Charles S Kocher et al. 2000).

$$T_c = 1.54 * L^{0.875} * S^{-0.181}$$

$$R = 16.4 * L^{0.342} * S^{-0.790}$$

*Equation 15. Time of concentration and Storage coefficient*

where

***L:*** longest flow length in kilometers;

***S:*** main-channel slope determined from elevations at points that represent 10 and 85 percent of the distance along in meters per kilometer.

**Table 9** summarizes the different values of Tc and R for the different sub basins.

*Table 9. Values for time of concentration and storage coefficient*

| *Sub basin* | *Tc (hr)* | *R (hr)* |
|---|---|---|
| 1 | 2.28 | 0.74 |
| 2 | 1.95 | 0.66 |

| | | |
|---|---|---|
| 3 | 1.23 | 1.21 |

ii. JUNCTION

The junctions are the sub basin outlets determined when delineating the watershed. They should be linked to the other basin components, specifying the downstream element immediately following it.

iii. REACH

Reaches are related to the rivers of the system. The flow routing selected was the Muskingum model, for which the main parameters are K (hr) and X. A number of sub reaches was also determined, which were dependent on K and the running time-frame.

### c. METEOROLOGICAL COMPONENT

The distribution of precipitation over the basin was performed using specified hydrograpth method, and the evapo-transpiration method taken as 'annual evapo-transpiration', where the rate was taken as 4mm/day.

### d. TIME SERIES

The time series component contains the precipitation gages. A precipitation gage consists of a time series gage where the data source, unit, and time interval are specified, a time window to specify the start day and start hour, as well as the end date and end hour. Finally it has a table allowing to enter

the rainfall data corresponding to the time window specifications, and graph to visualize the plotted graph for the entered data.

Daily rainfall was acquired for 25 years (Jan 1$^{rst}$ 2000- Feb 5$^{th}$ 2025), and plotted to determine the peak rainfall. The peak daily rainfall has a value of 1330.96mm, and was considered as the design time frame in the context of risk aversion.

e. **CONTROL**

The principle is to control the simulation run. This is done by specifying time to start and stop the simulation, along with the time interval. The start date/time and the end date/time is specified in the time window. This runs both for event and continuous simulation.

The conceptual model model was set to run for 24 hours (03 Jul. 2007 00:00-03 Jul. 2007 23:00), with a time interval of an hour.

## 3.4 DESIGN OF THE HORIZONTAL SUB DRAINAGE SYSTEM

Two software were simultaneously utilized to understand the effect of drains on the slope stability: MODEL MUSE enabled the groundwater modelling, and the determination of the groundwater levels with and without sub-drains, while GeoStudio 2024 2.4 used the piezometric line previously obtained together with geotechnical parameters of the slope to determine the factor of safety, which is the indicator of the slope stability.

### i. MODEL MUSE

MODFLOW-6 program in MODEL MUSE is a widely accepted, finite-difference, public domain groundwater flow model produced by the United States Geologic Survey (USGS).

**Equation 16** shows the basic governing equation for transient groundwater flow in a saturated antisotropic porous medium. The sum of rate of change of change of flow in the x ($\frac{\delta}{\delta x}(K_x \frac{\delta h}{\delta x})$), y ($\frac{\delta}{\delta y}(K_y \frac{\delta h}{\delta y})$), and z ($\frac{\delta}{\delta z}(K_z \frac{\delta h}{\delta z})$) directions is equal to rate of change of storage within the porous medium ($S_s \frac{\delta h}{\delta t}$) (R. Carrol, T. Badger. 2013).

$$\frac{\delta}{\delta x}(K_x \frac{\delta h}{\delta x}) + \frac{\delta}{\delta y}(K_y \frac{\delta h}{\delta y}) + \frac{\delta}{\delta z}(K_z \frac{\delta h}{\delta z}) = S_S \frac{\delta h}{\delta t}$$

***Equation 16. Governing groundwater flow equation used in MODFLOW***

Where

$K_x, K_y, K_z$: hydraulic conductivity in the x,y, and z direction respectively;

$\frac{\delta h}{\delta x}, \frac{\delta h}{\delta y}, \frac{\delta h}{\delta z}$: hydraulic gradient in the x, y, and z directions respectively;

$S_S$: specific storage

$\frac{\delta h}{\delta t}$ : the rate of change of hydraulic head with respect to time.

### ii. GeoStudio

GeoStudio is an integrated geotechnical analysis software suite for analyzing slope stability, groundwater flow, and heat and mass in soil and rock. Its strength is in limit equilibrium slope stability analysis for civil and mining engineering projects, hence making it a powerful toll in solving slope stability, groundwater flow, and environmental challenges (GeoStudio

official website, 2021).

### 3.4.1 INFLUENCE OF THE SUB-DRAINS SYSTEM ON GROUNDWATER LEVEL

### 1. SITE DESCRIPTION

The slope of the topography for which the system is being designed is relatively uniform from the slope crest to the base of the slope at approximately 27.73% (15.5°). The subsurface conditions are assumed to consist of a single layer reaching up to 275 meters in thickness. This is the sub-catchment 2 earlier delineated under section section 3.3(1). However, it was previously merged with sub-catchment 1 provided its small extent.

**Figure 14** shows the topography of model for groundwater modelling. The grid cells of the watershed equal to the resolution of the DEM (30m by 30m), and they are coloured with respect with the assigned values for elevation.

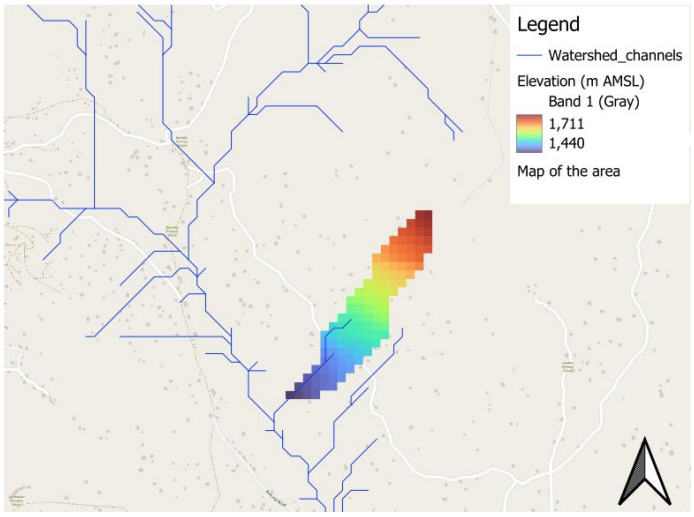



*Figure 14. Topography of site*

## 2. MODEL DOMAIN AND CONCEPTUAL MODEL

### a. MODEL DOMAIN

The model domain is defined in FIG. 14 with MODFLOW cells 5 m by 5 m in the x-y direction, which is rotated (-33°) so that the grid is parallel to the slope.

### b. CONCEPTUAL MODEL

#### i. Hydrologic parameters

The hydrologic parameters include specifying the coefficient of permeability in the x, y, and z directions ($K_x$, $K_y$, and $K_z$), along with the specific yield ($S_y$)and the initial head of the system.

- $K_y$ and $K_z$ were assumed to be equal to $K_x$ (isotropic condition, VKA=1), where $K_x$ was obtained from:

$$K_x = K\frac{m}{s} \Big/ \frac{1}{3600 * 24}\ \frac{m}{day}$$

$$K_x = 1.545 * 10^{-7} * 3600 * 24 \frac{m}{day}$$

$$K_x = 0.0133\ \frac{m}{day}$$

- The specific yield $S_y$ was taken as 0.01 for clay soils (A. I. Joghnson. 1967).
- The initial head of the each grid cell was considered to be equal to its top elevation.

#### ii. Layer definition

This is a single layer model where the maximum thickness is 275 meters at the highest elevation (1711m AMSL) and minimum thickness is 6 meters at

the lowest elevation (1440m AMSL). The bottom of the modeled layer is at 1436 meters above mean sea level.

iii. Boundary conditions

- **Specified head boundary condition (CHD)**

The specified head boundary conditions are typically applied to the cells for which MODFLOW does not need to solve heads. Specified head cells are assigned a head value for a specific period of time for which head does not change. These conditions anchor the solution, and they represent features such as lakes, rivers, or distant observed heads. However, they should be positioned at a region sufficiently far from the region to be investigated has they can sometimes introduce inaccuracies. For most slope stability problems, the specified head boundary is likely assigned to the up and down-gradient model boundary locations (R. Carrol, T. Badger. 2013).

Considering the fact that there was no data about the ground water of the slope, the model domain comprised the whole watershed to avoid the need to designate water flux across the boundary conditions. This means that water was assumed to only enter the system from precipitation, with all water flowing towards the watershed outlet at lower elevation.

- Specified flux (RCH)

Specified flux boundary conditions are utilized in the event that the discharge is known. In this case, MODFLOW still solves for head where this flux is specified. There are several types of flux conditions among which no

flow, inter-basin flow, pumping/injection flow, and groundwater recharge, which was our interest.

**Equation 17** shows the principle of application of the recharge flow rate to the cell in Model muse, which is function of the recharge flux and the area of the cell.

$$\boldsymbol{Qr_{i,j}} = \boldsymbol{R_{i,j}}\Delta\boldsymbol{r_j}\Delta\boldsymbol{c_i}$$

***Equation 17. Recharge flow rate estimation in ModelMuse***

Where

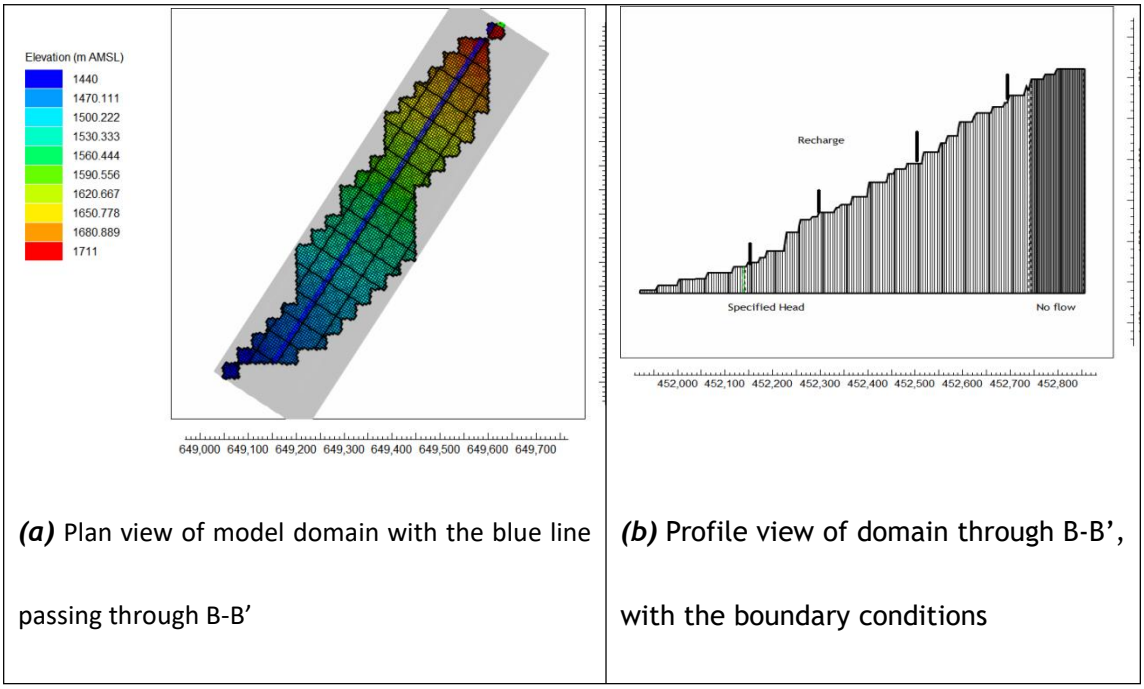
$\boldsymbol{Qr_{i,j}}$ is the recharge flow rate applied to cell i,j ($L^3/T$)

$\boldsymbol{R_{i,j}}$ is the recharge flux (L/T) input by the user

$\Delta\boldsymbol{r_j}\Delta\boldsymbol{c_i}$ is the area of the cell ($L^2$)

The recharge was set to be uniformly distributed across the domain.

**Figure 15** show the model domain. (a) Plan view showing the modeled grid , the active cells in color scale of assigned land surface elevations. The cell dimension is 5m by 5m. (b)The cross section B-B' depicts a single layer model (maximum thickness 275m and minimum thickness 6m), as well as no flow cells, specified boundary (green vertical line) condition and recharge (black vertical lines) which is applied uniformly across the domain.




***(a)*** Plan view of model domain with the blue line passing through B-B'

***(b)*** Profile view of domain through B-B', with the boundary conditions

***Figure 15. Model domain.***

## 3. DRAIN CONFIGURATION

Drains are also assigned to the cells of the domain through a boundary condition (DRN).

In MODFLOW, drains are designed to remove water from the aquifer based on the difference between head in the aquifer, and the drain's elevation. This implies that flow into the drain and out of the aquifer only occurs when the levels in the aquifer are higher then the drain, and drop to zero when heads drop below the drain elevation (R. Carrol, T. Badger. 2013).

Two drain arrays in a fan-shaped configuration were considered. Drain array 1 consisted of 8 drains drilled at an angle of approximately 6° from each other, with a length of 100 meters, and at lower elevation of 1469m AMSL. Drain array 2 on the other hand, consisted of 4 drains drilled at an angle of

approximately 12° from each other, with a length of about 200 meters, and at lower elevation of 1469m AMSL.

Ideally, drains should have been positioned below the lowest elevation (1440m AMSL), however, the shape of the domain was such that it would not permit a proper positioning of the drains to spread effectively. Therefore, the outlet of the watershed was raised to 1470m AMSL, and the drains at 1469m AMSL.

**Figure 16** depicts plan view of the drain configuration on the domain. The model cells are 5m by 5m, and colored with the elevation DEM. Red lines represent the drain placement. (a) shows the drain array 1, and (b) the drain array 2.

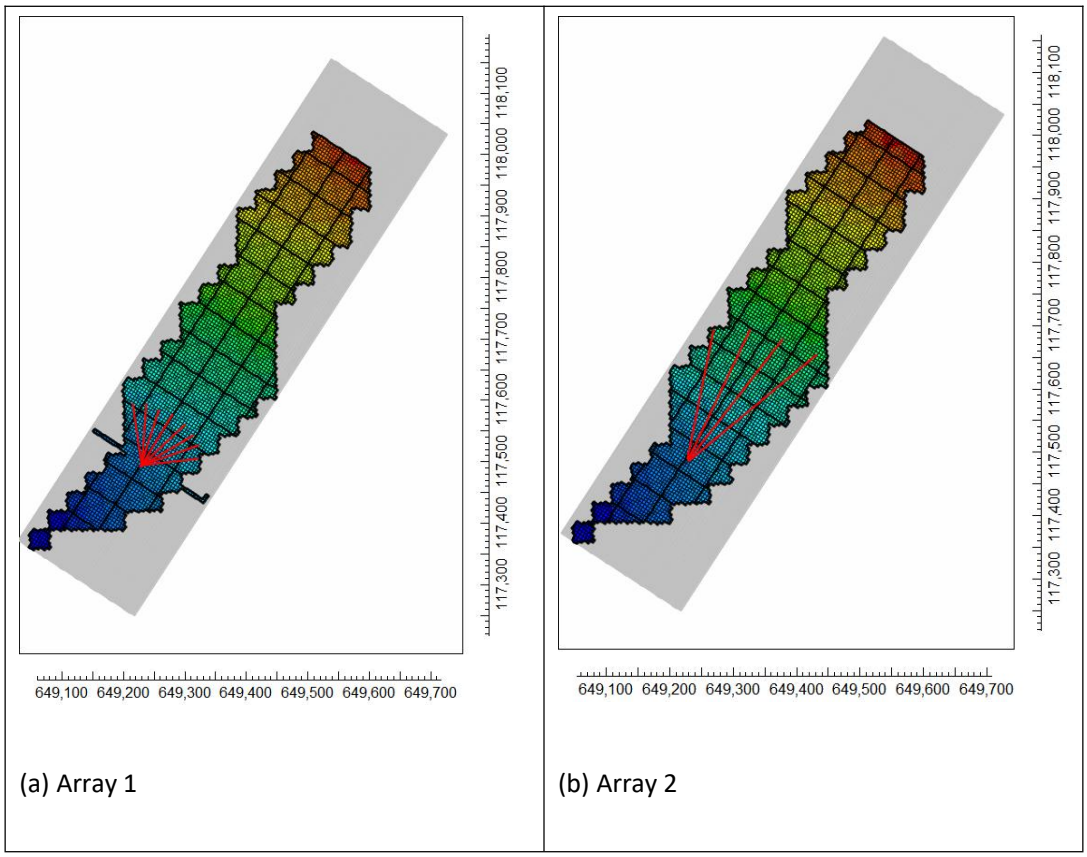



***Figure 16. Plan view of drain configuration.***

### 3.4.2 GEOTECHNICAL ANALYSIS OF THE SLOPE

A prior slope stability analysis was performed in GeoStudio, assuming that the piezometric line was located at the groundsurface (total saturation), with strength parameters of both unconsolidated undrained conditions and consolidated and drained conditions. In the UU conditions, the material had a bulk unit weight of 18.97 KN/m$^3$, cohesion of 37.03 Kpa, and an angle of friction of 14.07°. In CD conditions, the material had a saturated unit weight of 21.75 KN/m$^3$ obtained from the calculation below, a cohesion of 4 Kpa, and an angle of friction of 34.2°.

The saturated unit weight was obtained from the porosity (n= 0.284 as calculated for soil storage under section 3.3). First, the void ratio was calculated as:

$$\mathrm{e} = \frac{\mathrm{n}}{1-\mathrm{n}} = \frac{0.284}{1-0.284} = 0.3966$$

**Equation 18** shows the obtention of the saturated unit weight for the slope analysis in consolidated and drained conditions. The saturated unit weight can be calculated when knowing the specific gravity, the unit weight, and the void ration. Thus,

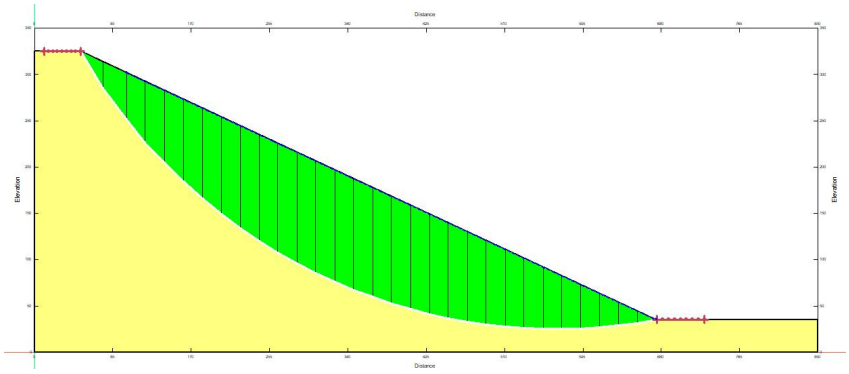
$$\boldsymbol{\gamma_{sat}} = \frac{\boldsymbol{G_s + e}}{\boldsymbol{1 + e}} * \boldsymbol{\gamma_w}$$

***Equation 18. Saturated unit weight***

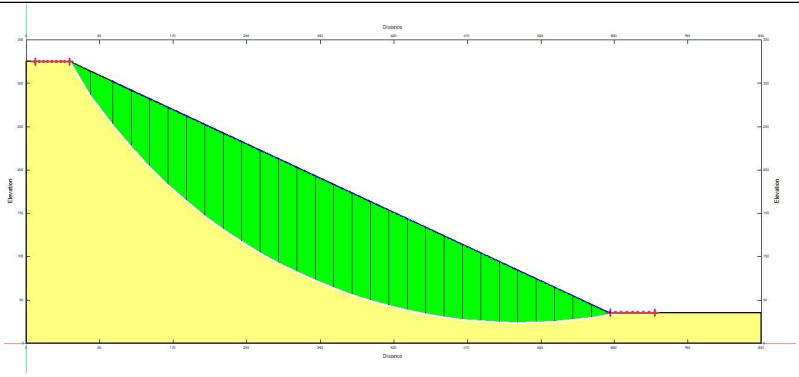
Where $G_s$ was the specific gravity taken as 2.7, and $\gamma_w$ was the unit weight of water equal to 9.81 KN/m$^3$. Therefore,

$$\gamma_{sat} = \frac{2.7 + 0.3966}{1 + 3966} * 9.81 = 21.75\text{KN/m}^3$$

**Figure 17** depicts the slip surfaces for both scenarios when assuming that the slope was fully saturated (piezometric line at ground surface). (a) slip surfaces in UU conditions where the factor of safety was 0.351, (b) slip surfaces in CD conditions where the factor of safety a was 0.897.



(a) Slip surfaces under Uconsolidated Undrained conditions



(b) Slip surfaces under Consolidated Drained conditions

***Figure 17. Slope analysis with piezometric line assumed to be at the groundsurface.***

The slope stability analysis showed that the slope was more prone to failure under unconsolidated and undrained conditions than under consolidated and drained.The following analyses in steady state and transient conditions are discussed in results and discussion.

### 3.4.3 DESIGN OF A DRAIN SECTION

The design of the drains encompasses the determination of the drain dimensions (slot size, drain length and diameter), and spacing, elevation, and the angle of drilling. The drain length and diameter, along with the elevation and angle of drilling, where estimated during the groundwater modelling in MODEL MUSE.

#### 1. SLOT SIZE

As seen in the design considerations in section 2.5 , slot size are perforations of width ranging from 0.25 to 1.3mm that allow water from the slope enter the horizontal drain pipe (Cook, D.I., Santi, P.M. and Higgins, J.D. 2008). They are arranged in two longitudinal rows that are spaced 120° apart around the circumference of the pipe. Considering circular slots, the filter requirement were given by:

$$\boldsymbol{Slot\ diameter < D_{85}soil}$$

From the particle size distribution performed in objective one, $\boldsymbol{D_{85}soil}$ is the sieve size at which 85 percent of the material passed.

**Figure 18** shows the particle size distribution of the soil, which is observed to be fine-drained. About 87.2% of the total mass passed the 75μm sieve as. Therefore the slot size was taken to be the lower limit of the slot range (0.25mm), with care on the geotextile material to prevent clogging.

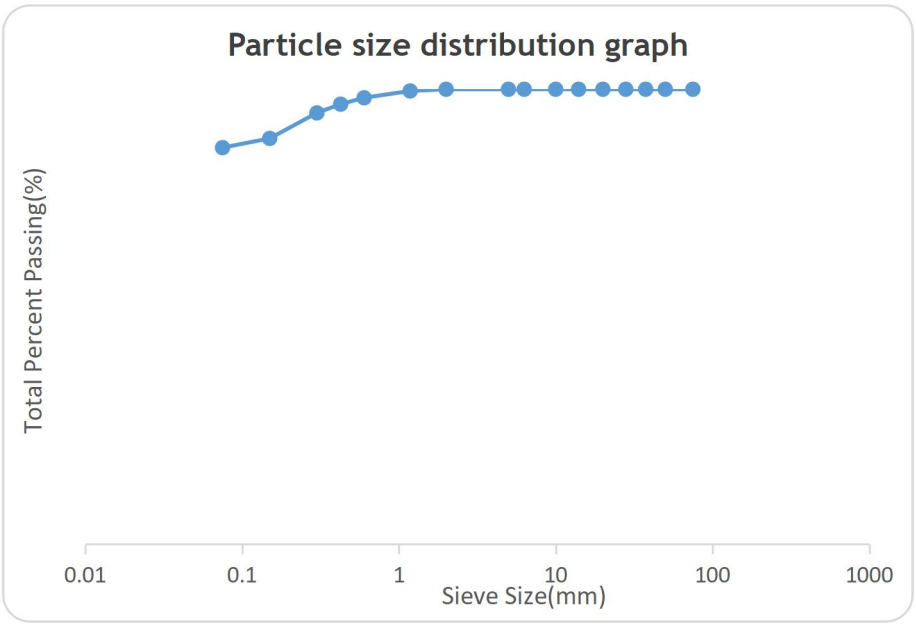



***Figure 18. Particle size distribution of the soil sample.***

## 2. DRAIN SPACING

The drain spacing was determined from analytical methods, discusses by R. Carrol, T. Badger. 2013. They outline the following steps in order to solve the drain spacing $L_d$:

1. Assume the drain depth with respect to peak water level $H_m^0$;

2. Calculate the ratio m= $\frac{H_m^0}{D}$ , where D is the maximum water table elevation above the impermeable surface;

3. Calculate the y-axis $\frac{h_m}{H_m^0}$ such that $h_m$ is the maximum height of water table for which stability of slope is maintained;

4. Find intersection of the calculated $\frac{h_m}{H_m^0}$ and curve choice m, and trance back to the x-axis to obtain the value of $\frac{K*D*t}{S_y L_d^2}$;

**5.** Solve for drain spacing $L_d$ for given value of x-axis $\frac{K*D*t}{S_y L_d^2}$.

**Initial assumptions**

i. The time required to sufficiently lower the water table during a large storm was 0.75 days;
ii. The design storm would force the water table to flood the system such that water rises above the land surface;
iii. During the storm, water raised at a height of 0.5m above the surface;
iv. Drains were located at elevation 1440m AMSL;
v. The impervious surface is at 1436m AMSL.

**Calculations**

The hydraulic conductivity and the specific yield were 0.0133 m/day and 0.01 respectively

1. D was the maximum water table elevation above the impermeable surface. Considering a point at elevation 1445m AMSL. As water raised at a height of 0.5 meters above the surface, D was obtained as [(1445 - 1436) + 0.5], hence 9.5m;
2. $H_m^0$: the drains were located at elevation 1440m AMSL, meaning [9.5-(1440- 1436)], hence 5.5m below the peak water level;
3. m= $\frac{H_m^0}{D}$ was therefore obtained as 0.57;

4. The maximum water height for which stability of slope is maintained ($h_m$) was considered to be the same as the elevation of the drains (1440m AMSL), hence 1440- 1436 = 4 meters.
5. The value on the y-axis $\frac{h_m}{H_m^0}$ was therefore obtained as 0.727.
6. The slope had an angle of 15.5°, equivalent to 28.26%. Therefore, graph b was used. From the graph, $\frac{K*D*t}{S_y L_d^2}$ in the x-axis was obtained as 0.084;
7. Finally, $L_d$ was solved as $\sqrt{\frac{K*D*t}{0.084*S_y}} = \sqrt{\frac{0.0133*9.5*0.75}{0.084*0.01}} = \mathbf{10.61}\boldsymbol{m}$.

**Figure 19** shows the dimensionless curves of maximum water table height with respect to time for slopes of slopes. (a) 10%, (b) 30%, (c) 50%, and (d) 70%. Source: Carrol, T. Badger. 2013. Design Guidelines for Horizontal Drains used for Slope Stabilization.

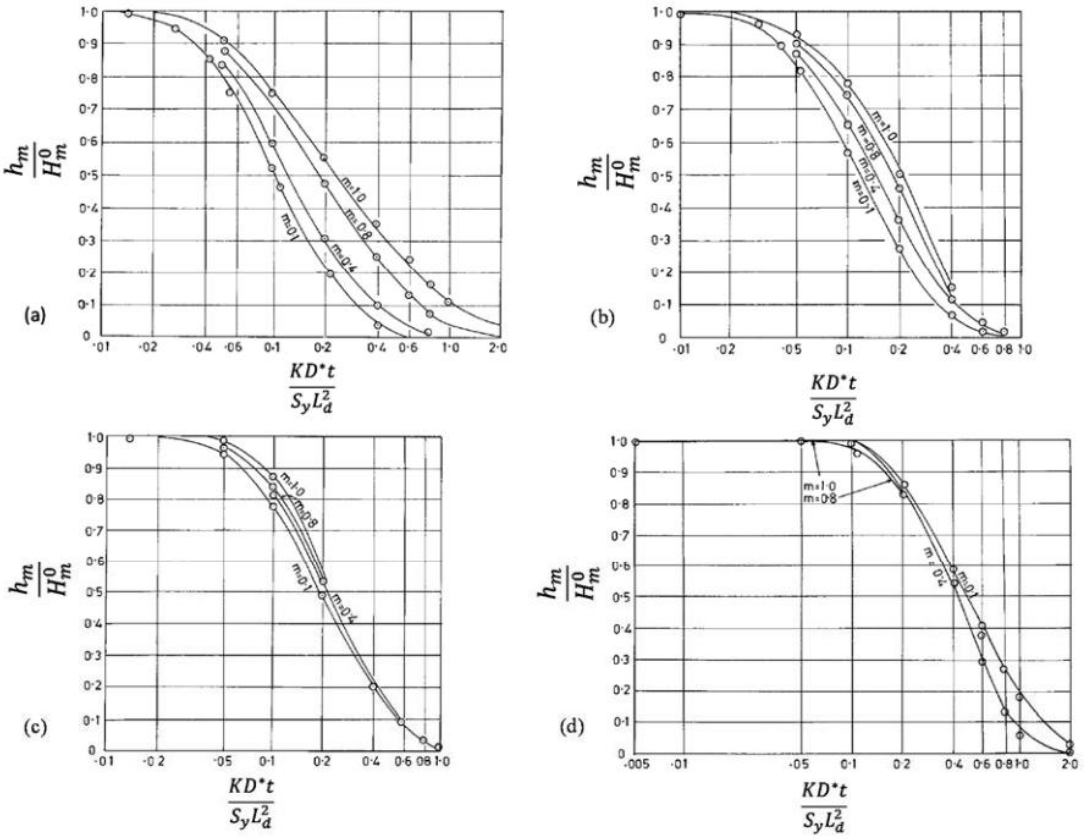



*Figure 19. Dimensionless curves of maximum water table height with respect to time for slopes of slopes.*

# CHAPTER FOUR: RESULTS AND DISCUSSION

## 4.1 SITE CHARACTERIZATION

### *4.1.1 SITE GEOMETRY*

#### 1. ELEVATION

**Figure 20** depicts the elevation map of the area of interest. Altitudes were observed to range between 1400 and 1722 meters AMSL.

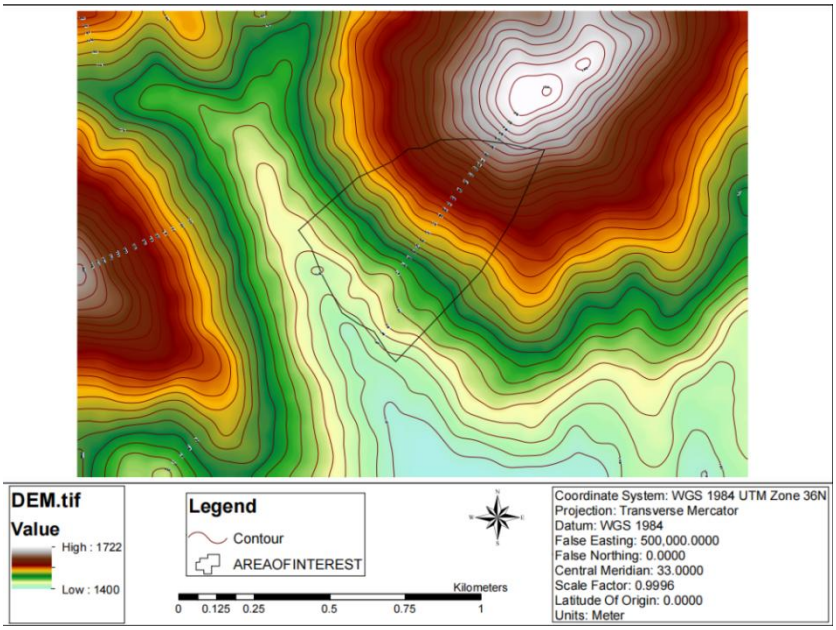



*Figure 20. Elevation map*

#### 2. ANGLE

In general, the slopes of BUDUDA range between 14° and 41° ( Knapen et. al, 2006).

**Figure 21** depicts the angle map. The slopes in the area had a maximum angle value of 28.26%, or 15.78°.

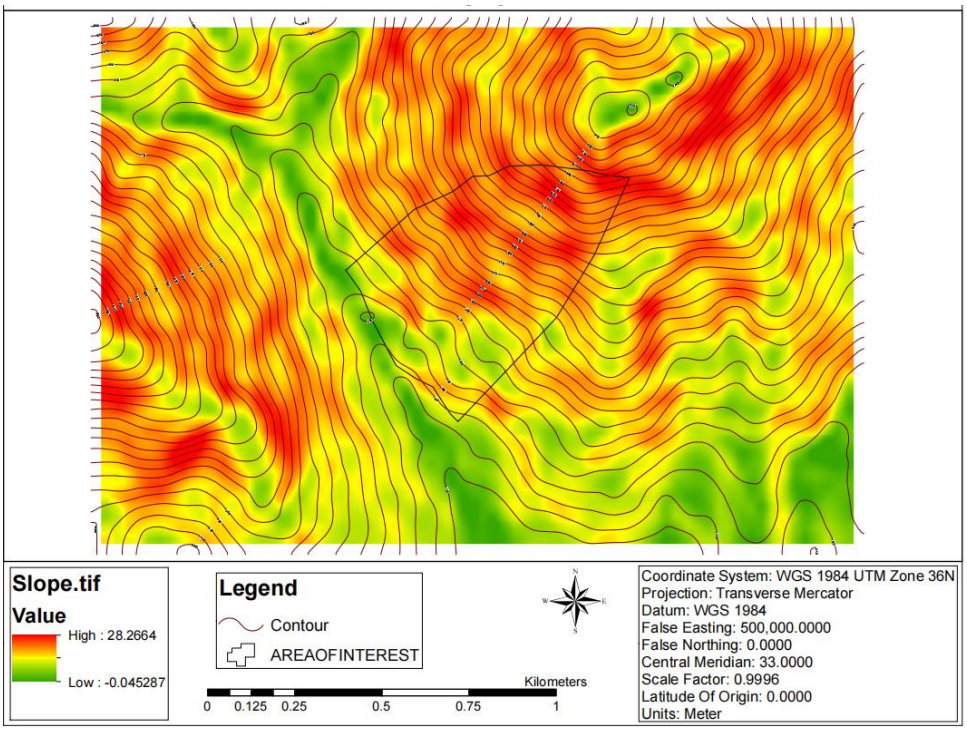



*Figure 21. Angle map*

Sikdar, P K Chakraborty, et al (2004) classify the types of slope according to the slope angle. The slopes were therefore classified as moderate to moderately steep.

**Table 10** shows the slope classification based on the slope angle (°).

*Table 10. Slope classification*

| *Class* | *Symbol* | *Description* |
|---|---|---|
| 0 - 5° | A | Very gentle |
| 5°- 10° | B | Gentle |
| 10°-15° | C | Moderate |
| 15°-25° | D | Moderately steep |

| | | |
|---|---|---|
| 25°-35° | E | Steep |
| >35° | F | Very steep |

### *4.1.2 SOIL PROPERTIES*

#### 1. ATTERBERG LIMITS

#### a. Atterberg limits values

Atterberg limits depict the behaviour of soils in relation to the water content.

**Equation 19** shows the obtention of the shrinkage limit, which is dependant on the Liquid Limit and the Plastic Index.

$$\boldsymbol{SL = 46.4 * (\frac{LL + 45.5}{PI + 46.4}) - 43.5}$$

***Equation 19. Shrinkage limit***

Where

**LL**: liquid limit

**PI**: plastic index

Table.11 summarizes the values obtained for the different Atterberg limits for the sample, where the shrinkage limit was obtained from equation 19.

***Table 11. Atterberg limits values***

| PI | PL | LL | SL |
|---|---|---|---|
| 19.09 | 28.98 | 48.07 | 22.79 |

**b. Atterberg limits graph**

**Equation 20** shows the obtention of the initial volume of soil, considering the dimensions of the mold for linear shrinkage test, L= 140.2mm and R= 12.5mm.

$$\boldsymbol{V_{initial} = \frac{1}{2} \pi * R^2 * L}$$

***Equation 20. Initial volume of soil for linear shrinkage***

$\boldsymbol{V_{initial}} = (\frac{1}{8} * \pi * 12.5^2 * 140.2)$= **34410.257mm³**

i. The volume of soil at shrinkage limit (22.79%) was obtained from

$$V_{SL} = 0.5\pi(12.5)^2(140.2)[1 - 0.228] = \mathbf{26564.72\ mm^3}$$

Considering the linear relationship between the water content and the volume of soil, the volume at plastic limit and liquid limit was obtained as follows:

ii. The volume at plastic limit (soil + water)

$$\mathrm{V_{PL}} = \frac{[100\% + (28.98 - 22.79)\%] \text{ x } 26564.72}{100\%} = \mathbf{28185.17mm^3}$$

iii. The volume at liquid limit (soil + water)

$$\mathrm{V_{LL}} = \frac{[100\% + (48.07 - 22.79)\%] \text{ x } 26564.72}{100\%} = \mathbf{33285.60mm^3}$$

**Figure 22** depicts the Atterberg Limits graph which volumes at the different limits were obtained from the calculation above.

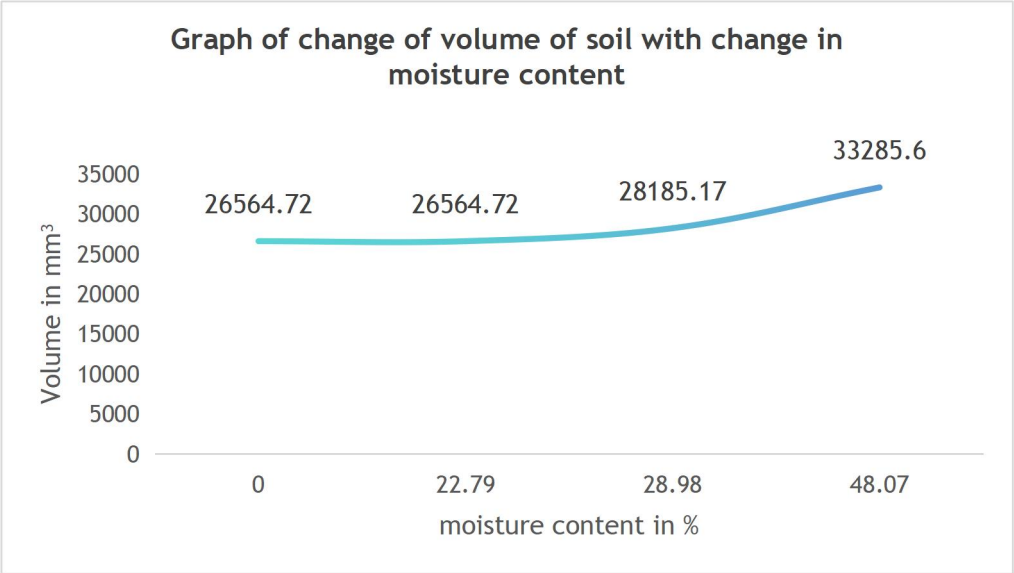



*Figure 22. Atterberg limit graph*

## 2. SOIL CLASSIFICATION

The soil classification followed the Unified Soil Classification Standard (USCS), which classifies the soil according to a prefix and a suffix. For this, the total mass sieved, along with the mass retained at the 75μm and the Atterberg limits should be known.

**Table 12** shows the results of the key parameters for the USCS classification.

*Table 12. Key parameters for soil classification*

| Total mass sieved | Mass retained at 75μm sieve | PI | LL |
|---|---|---|---|
| 143.11 | 15.11 | 19.09 | 48.07 |

### a. *PREFIX*

The prefix is relative to the texture of the soil sample, which can be coarse grained, fine grained, or organic soils. This is determined by the amount of

particles retained at the 75μm sieve. In this case, less than 50% was retained on the sieve of interest for the three samples, hence the soil is considered to be fine grained.

Fine grained soils can either be classified as inorganic clay, or silt\organic clay. In this case, the average plastic index (PI) was as high as 19.09, which was above the A line and greater than 7. The soil was considered as inorganic clay, hence the prefix C.

**b. *SUFFIX***

For fine grained soils, the suffix is relative to the plasticity, which can be considered as low if the liquid limit is less than 50%, or high if it is greater than 50%. In this case, the average liquid limit was as high as 48.07, which was relatively high, hence the extensive use of the suffix H.

**c. OVERALL CLASSIFICATION**

The soil was classified as CH, which is consistent with the study by Poesen and Deckers, 2009, who classified the soil in the same region as CH, with the prevalence of Nistisols in the western zone of the district. Nistisols are characterized by a high clay content, significant shrink-swell capacity, and a poor drainage.

## 3. UNIT WEIGHT

1. The bulk unit weight was obtained from the bulk density test performed in the sample preparation of the falling head permeability test, with an average value of 1.934 $gcm^{-3}$.

**Equation 21** shows the obtention of the bulk unit weight from the bulk density ($\boldsymbol{\rho}$) and the gravity ($\boldsymbol{g}$).

$$\boldsymbol{\gamma = \rho * \frac{g}{100}}$$

***Equation 21. Bulk unit weight***

Where

ρ ($kgm^{-3}$) =1.934 $gcm^{-3}$*1000

g= 9.81 $ms^{-2}$

$$\gamma = 1.934 * 1000 * \frac{9.81}{1000} = \mathbf{18.97 kNm^{-3}}$$

The unit weight of 18.97$kNm^{-3}$ is within the range of clay soil which is between 16 and 22$kNm^{-3}$.

2. The specific gravity on the other hand, was obtained from the specific gravity test. The first and third samples had identical specific gravity values, which were within the typical range for clay and similar cohesive soils (2.60-2.75). The value of 2.61 was consistent with standard values for cohesive soils like clay, indicating that these two samples are likely dense and mineralogically stable, as there was a relatively low organic matter content (Mulatu Tamiru, Worku Firomsa Kabeta, et al. 2024).

## 4. COEFFICIENT OF PERMEABILITY

The average coefficient of permeability (K) was found to be 1.545 *$10^{-7}$ m\s, while the average infiltration rate was as high as 27.3cm\hour, which is considered to be in the category of very rapid according to Poesen and Deckers, 2009. The falling head permeability test was repeated three times on the three samples, enabling to determine a relationship between the soil saturation, the infiltration rate, and the time.

The infiltration rate was observed to decrease as with the cumulative experimentation. This suggested a tenancy of accumulation of water in the soil profile as the soil reaches saturation as explained by Makabayi, Musinguzi and Otukei, 2021b.

**FIG 23** depicts the graph of cumulative infiltration, which is observed to gradually decrease.

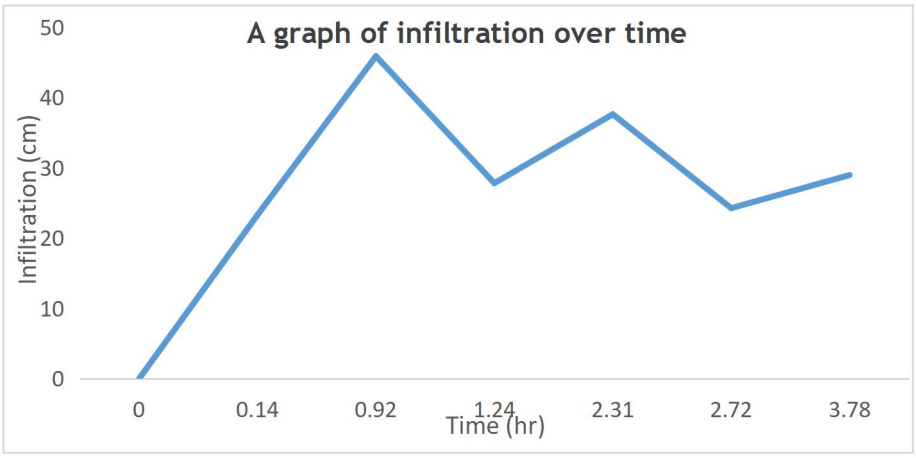



*Figure 23. Infiltration rate graph*

## 5. COHESION AND ANGLE OF FRICTION

### *a. Unconsolidated undrained conditions*

The soil samples underwent barreling which is a kind of distortion where the specimen became wider in the middle and narrower at the ends resembling the shape of a barrel.

The average cohesion value was within the range for cohesive soils such as clay (10 Kpa-100 Kpa) according to BS 1377 Part 7. The friction angle on the other hand, was low, also characteristic for clay, where the internal friction angle tends to be smaller (10° to 20°)compared to granular materials such as sands.

Considering the fact that the test was undrained, these values of effective stress reflect the initial effective stress (taking pore pressure into account).

### b. Consolidated and drained conditions

Table 16 depicts the findings of the direct shear box test. The low value of cohesion (4 Kpa) indicates that the soil had a lower inherent resistance to shear forces when pore water pressures were not a factor. The high angle of friction on the other hand, showed that the soil had a greater resistance to shear forces when pore water pressures where dissipated (ABG. No date).

## 4.2 STUDY OF THE HYDROLOGY

### 4.2.1 WATERSHED DELINEATION

The Watershed  of river TSUTSU was delineated using QGIS, then further sub divided into three main sub catchment.

**Figure 24** illustrates the watershed delineation map for river TSUTSU. It comprised 3 main sub catchment, where the fourth was the extent of the slope of interest.

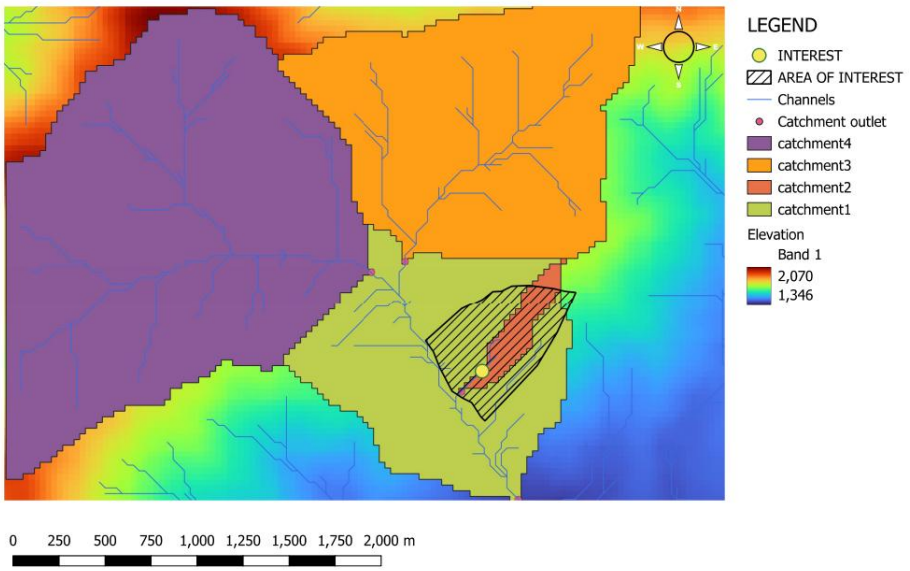



*Figure 24. Watershed delineation map*

**Table 14** summarizes the characteristics of the 3 main sub catchments.

*Table 13. Characteristics of sub catchments*

| Sub catchment | Surface area (Km2) | Longest river path (Km) | Slope $(\frac{m}{m})$ |
|---|---|---|---|
| 1 | 1.5 | 1611 | 0.033 |
| 2 | 1.9 | 3410.236 | 0.1 |

| | | | |
|---|---|---|---|
| 3 | 3.3 | 3999.615 | 0.093 |

### 4.2.2 RAINFALL

#### *1. MONTLY RAINFALL PATERN*

The sum of monthly rainfall was computed to determine the rainfall trend throughout the year. October was found to be the month with the highest rainfall value whereas January was the month with the lowest value.

The amount of rainfall has a considerable influence on the moisture content and pore water pressure in soils. It has been observed that landslides are more likely to occur if high amounts of intense precipitation are preceded by a period of light yet incessant precipitation. In fact, saturation of soils needs a much longer period. This explains why there are more landslides recorded in the last quarter of the year than in the middle, where the high rainfall is first absorbed by dry soils, and towards September, the soil becomes saturated resulting in higher chances of slope failure (Kitutu et al, 2010).

**Figure 25** shows the graph for the average monthly rainfall, which October having the highest value (125364.24 mm), followed by August (125168.64 mm)and April (124452.38 mm).

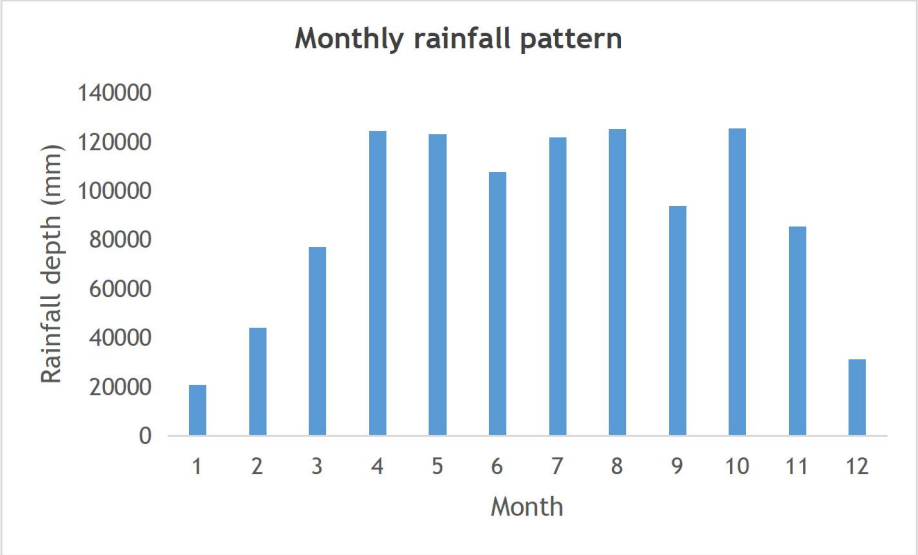



***Figure 25. Monthly rainfall pattern***

## 2. YEARLY RAINFALL INTENSITY

a. The yearly rainfall intensity

The highest magnitudes were observed in 2010 and 2011 with values as high as 132.992mm/year and 142.01mm/year respectively.

Scientists have observed a relation between the increase in rainfall pattern in Eastern Africa, and the El Niño phenomenon, which refers to the oscillation of the ocean-atmosphere system in the tropical Pacific having important consequences worldwide. For example, 27 landslides were recorded in 1997, corresponding to a year of strong El Niño (Kitutu et al, 2010).

In the year 2010-2011, a significant El Niño episode was observed in the tropical Pacific Ocean, with effects extending into adjacent ocean basins. For this time period, the atmospheric indicators showed that the episode

was one of the strongest in the previous century, while oceanic indicators were at moderate to strong levels. This conditions continued through the first quarter of 2011 (World Meteorological Organization, 2011). This explains the high yearly intensity observed, where 2010 corresponds to the year of occurence of the Nametsi landslide, the deadliest on record in the district (Nantumbwe, Bob R. Nakileza et al. 2017).

**Figure 26** illustrates the graph for yearly rainfall intensity, which was observed to be related to global meteorological phenomena such as the El Niño.

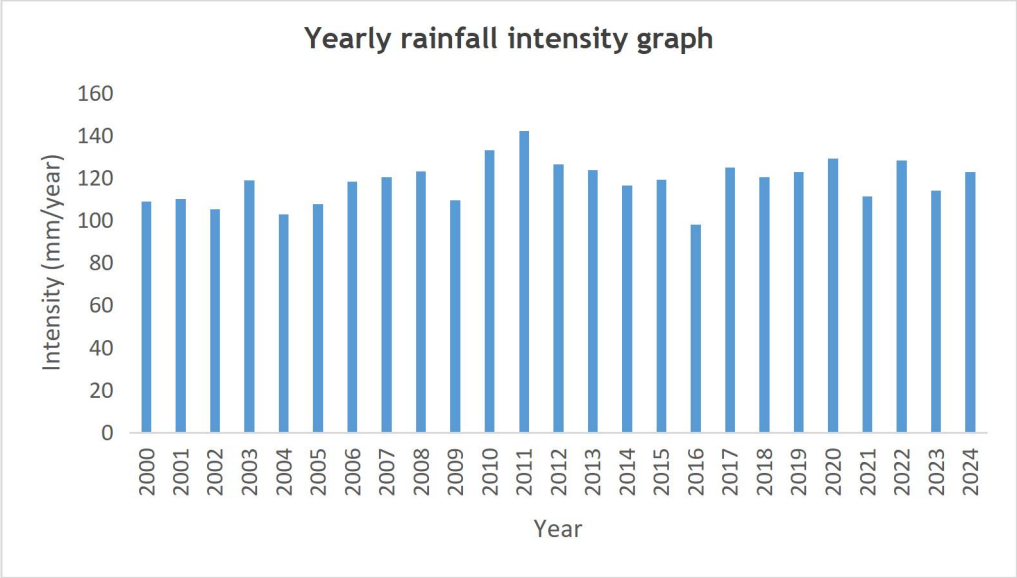



***Figure 26. Yearly rainfall intensity***

b. The maximum yearly daily rainfall intensity

The maximum daily rainfall intensity was observed in 2007, with a value of 1330.96mm.

**Figure 27** illustrates the graph for maximum yearly daily rainfall intensity.

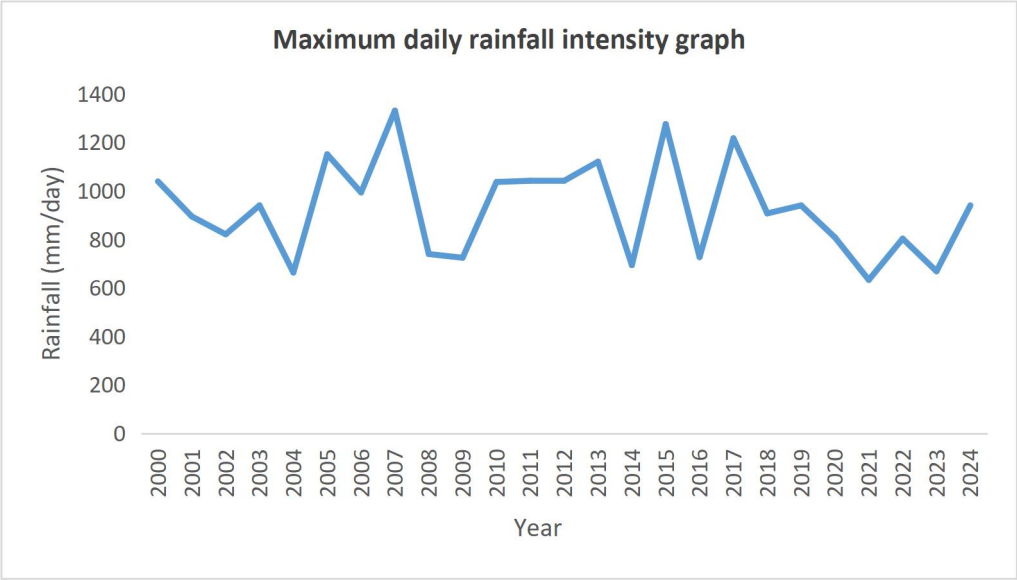



***Figure 27. Maximum daily rainfall intensity chart***

c. The average daily rainfall intensity on rainy days

This analysis only considered the rainy days count for every year. It was observed that 2011 held the highest value with 239.971mm/day, for the same reasons stated above.

**Figure 28** shows the graph for average yearly daily rainfall intensity on rainy days.

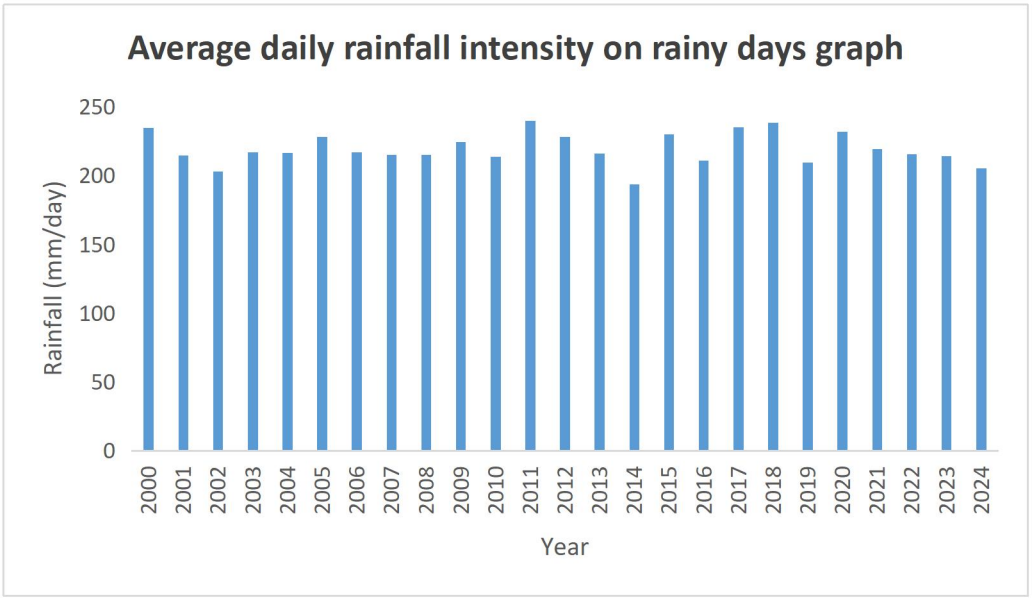


*Figure 28. Average daily rainfall intensity on rainy days*

## 3. RAINFALL RETURN PERIOD

The return time period is an average recurrence interval that gives an insight on the occurrence of a particular rainfall magnitude. However, the 25-years rainfall dateset obtained was relatively relatively short for long-term rainfall analyses since usually, 100-years or 1000-years rainfall datasets are used for rainfall return time estimations (M. Amoakowaash, L. Kofiste, A. Omari-sasu et al. 2021).

**Figure 29** Shows the graph of the return period against the maximum yearly rainfall values.

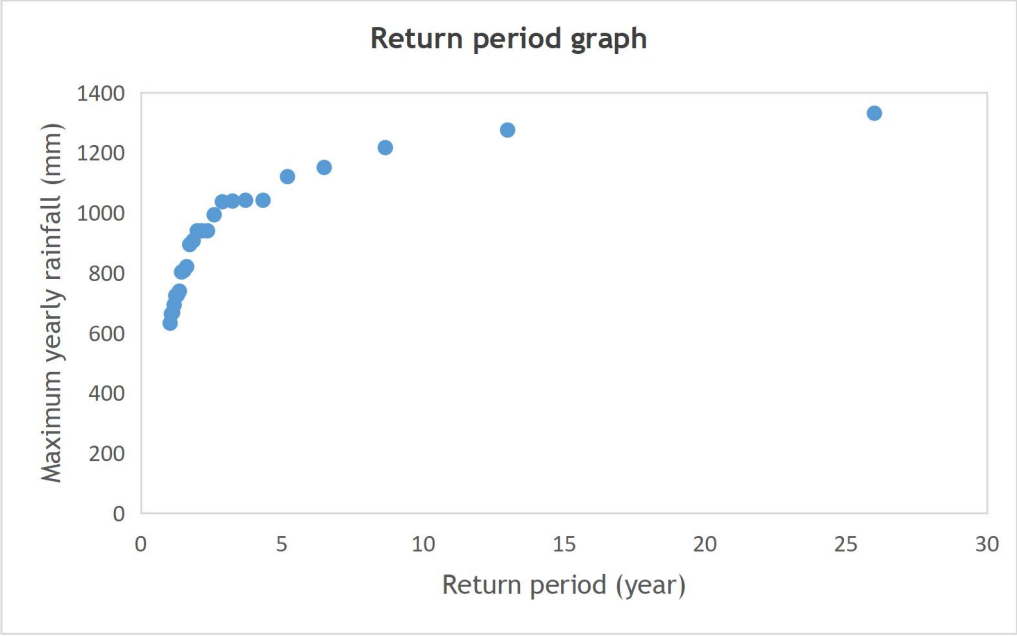



*Figure 29. Return period graph*

### *a. High rainfall events*

The highest recorded rainfall event was 1330.96mm in 2007 and ranked as 1.

This event has a calculated return period of 26 years. The exceedance probability for this event is approximately 0.038 or 3.8%, meaning that the change of this rainfall being exceeded in any given year is 3.8%.

b. Lower rainfall events

Lower rainfall events have shorter return periods and higher exceedance probability. For example, the rainfall of 632.46mm in 2014 (rank 22) has a return period of approximately 1.18 years and an exceedance probability of about 0.85 or 85%, implying that the rainfall of this magnitude is relatively common.

### 4.2.3 MODEL RESULTS

#### 1. WATER LOSSES

In a watershed system, it is not all the rainfall received over the area that is considered as the recharge (R. Carrol, T. Badger. 2013). In fact, as previously seen in FIG 11, the precipitation that fall on the land is either intercepted by the vegetation, lost as a surface run-off, infiltrates into the ground, or is taken back into the atmosphere as evapo-transpiration. Therefore, the portion that infiltrates the ground is very essential, as it is the one that recharges the groundwater. Following the stated reason, the purpose of modelling was to determine the amount of rainfall being lost in the watershed through infiltration. Infiltration made the largest portion, with a value of 67.47%. This had a relation with the characteristics of the

soil, were the infiltration rate was found to be as high as 27.03 cm/hour, as well as the absence of imperious surfaces. The run-off was equally high, provided the moderate slope of 15.5°. The evapo-transpiration portion on the other hand, was the smallest portion of the loss. This could be due to the fact that the model run for only 24 hours, where the rainy weather did not provide adequate conditions for the sun to shine for long enough to cause considerable evapo-transpiration.

**Table 15** summarizes the result of the water loss breakdown. Infiltration constituted the largest portion, with a value of 67.47%.

***Table 14. Water losses in the watershed.***

| Loss | Milimeters | Percentage |
|---|---|---|
| Infiltration | 492.9 | 67.47 |
| Surface | 191.25 | 26.18 |
| Capony | 42.8 | 5.86 |
| Evapo-Transpiration | 3.57 | 0.49 |

## 2. *INFILTRATION*

The infiltration rate was observed to gradually increase, attaining its peak value within six hours, before gradually decreasing and stabilizing after saturation of the soil. This behaviour is similar to the one observed during the falling head permeability test, where the infiltration was observed to rapidly attain a peak value before decreasing with time. This strongly

suggested a tendency of water storage in the soil profile, as highlighted by (Makabayi, Musinguzi and Otukei, 2021a).

**Figure 30** shows the infiltration rate graph plotted by HEC-HMS.

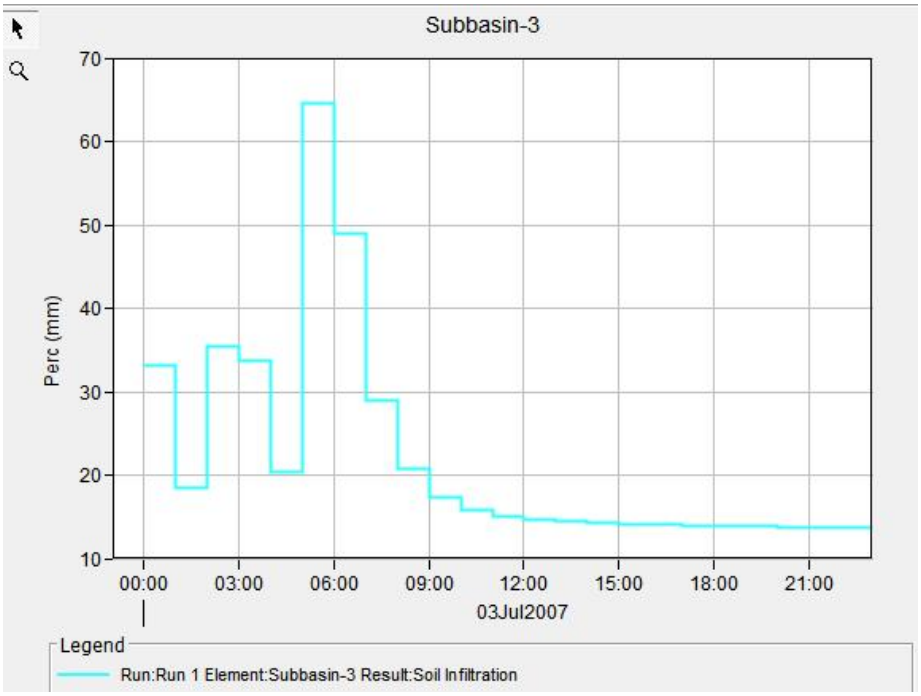



*Figure 30. Infiltration rate graph for sub basin 3*

## 4.3 DESIGN OF THE HORIZONTAL SUB DRAINAGE SYSTEM

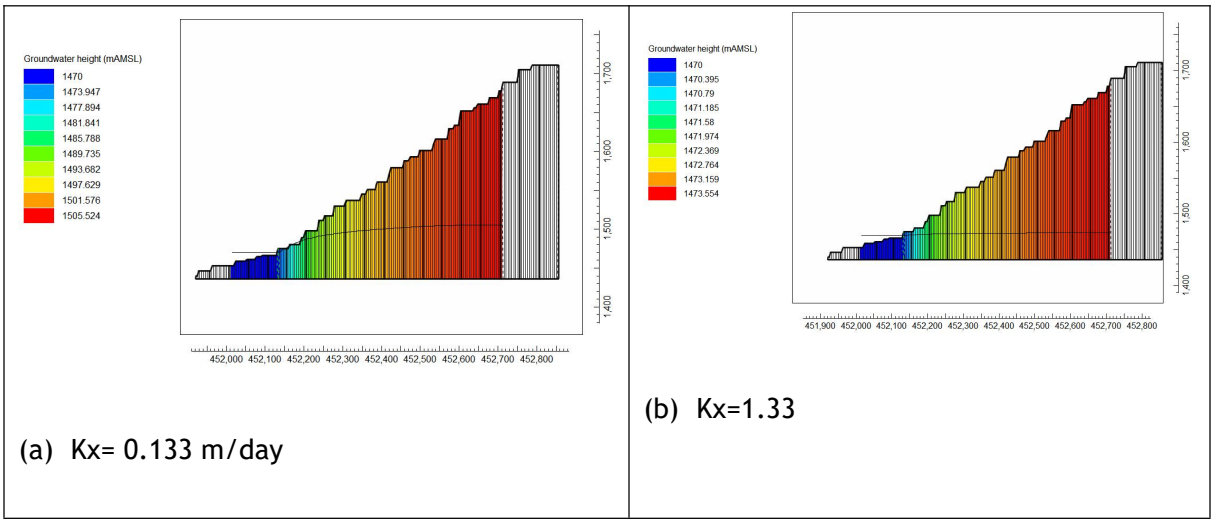
### 4.3.1 INFLUENCE OF SUB DRAINAGE SYSTEM ON THE SLOPE STABILITY

#### *a. Influence of coefficient of permeability on the groundwater flow*

To determine the influence of coefficient of permeability on the groundwater flow, a steady state analysis was run with increased values of Kx. When the Kx was increased to 0.133 m/d and 1.33 m/d respectively, the groundwater table was observed to stabilize at lower depths than when Kx was 0.0133 m/d, where the system was flooded. This is because the low

permeability did not allow water to flow quickly through the soil profile. Rather, water accumulated, causing flooding, even at lower recharge value of 0.002 m/d.

**Figure 31** depicts the profile of the slope with the water table level after a steady state run with recharge equal to 0.002 m/day. (a) shows the piezometric line (black horizontal line) when Kx was equal to 0.133 m/day, and (b) shows the piezometric line (black horizontal line) when Kx was equal to 1.33 m/day. However, the profile with Kx equal is not shown since the system was entirely flooded.




(a) Kx= 0.133 m/day

(b) Kx=1.33

***Figure 31. Influence of Kx on the groundwater flow.***

### *b. Influence of drain configuration on the groundwater flow*

i. Steady state condiditons

A steady state condition was run prior to the transient situation with the 25years 24-hours rainfall event, where the recharge was taken to be 0.002 m/d. Considering Kx= 0.0133 m/day, and isotropy in the layer (K was the same in all 3 dimensions). As mentioned in section 3.4.1 (3), the outlet of

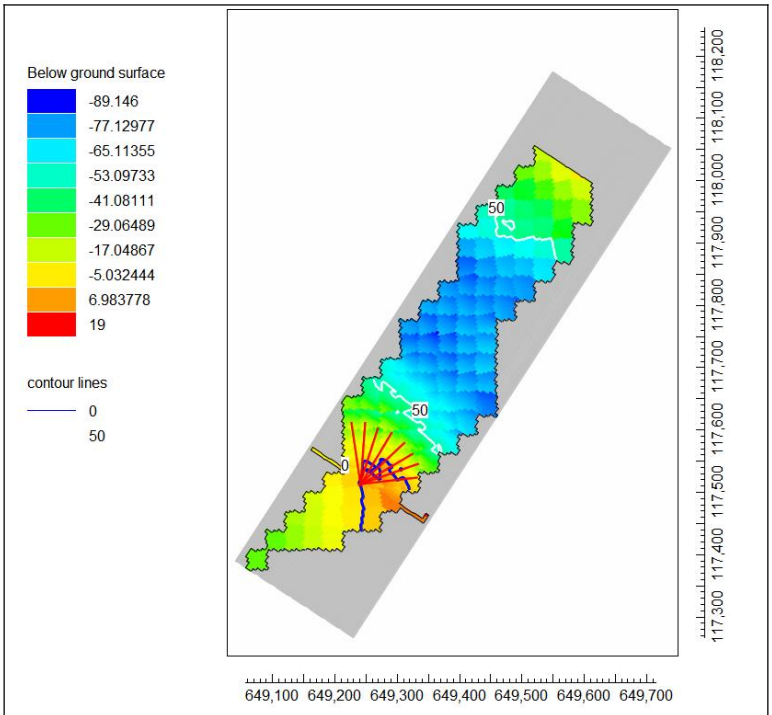
the watershed along with the drain elevation were raised to a higher elevation (from 1440m to 1469m) for design purposes, considering the irregular shape of the watershed that prevented an adequate positioning of drains downstream. Therefore, results below the elevation of the drain were ignored, and the drains assumed to be at the lowest elevation.

To interpret the results, a dataset was created, where the value of each cell was equal to the difference between the top elevation of the cell, and the groundwater head. This helped determine whether the sub drainage system was efficiently preventing flooding by maintaining the groundwater level below the ground surface.

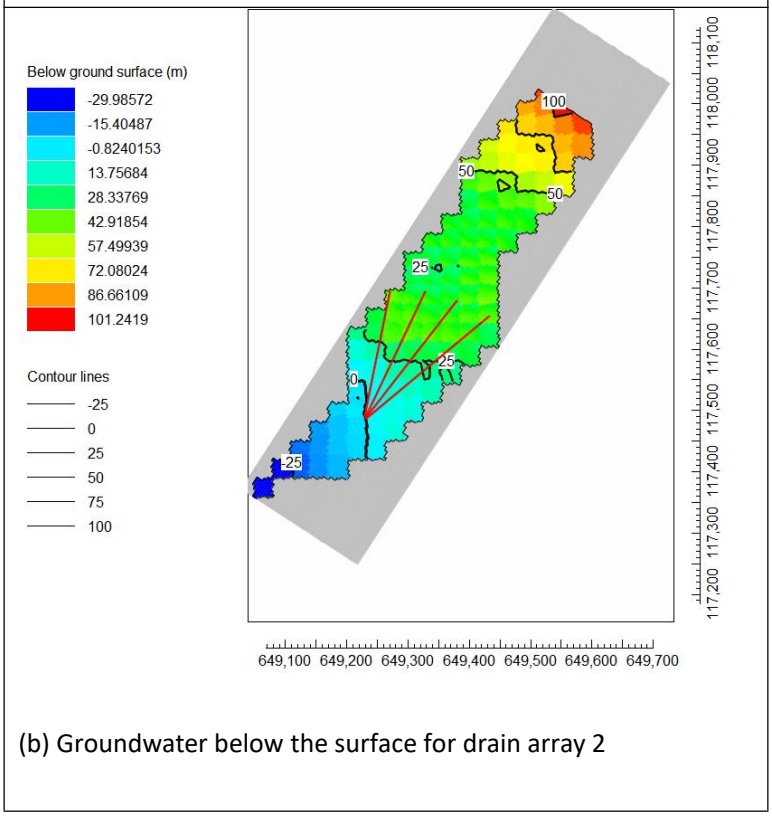
Drain array 1 was observed not to decrease the flooding when there was no drain, however not sufficiently enough for water to remain below the groundsurface. Drain array 2 on the other hand, was able to decrease the flooding, and to maintain the groundwater level below the surface throughout the whole extent of the model domain.

**Figure 32** shows the plan view of the model domain. the grid cells are 5m by 5m, and coloured in accordance with the dataset specification, for instance the difference between the cell top elevation and the groundwater head. Positive values indicate that the groundwater was below the ground surface (ground surface elevation > gw head), while negative values indicate that the groundwater was above the ground surface (ground surface elevation < gw head, thus flooding). (a) is the result for drain array 1, and

(b) the result for drain array 2.



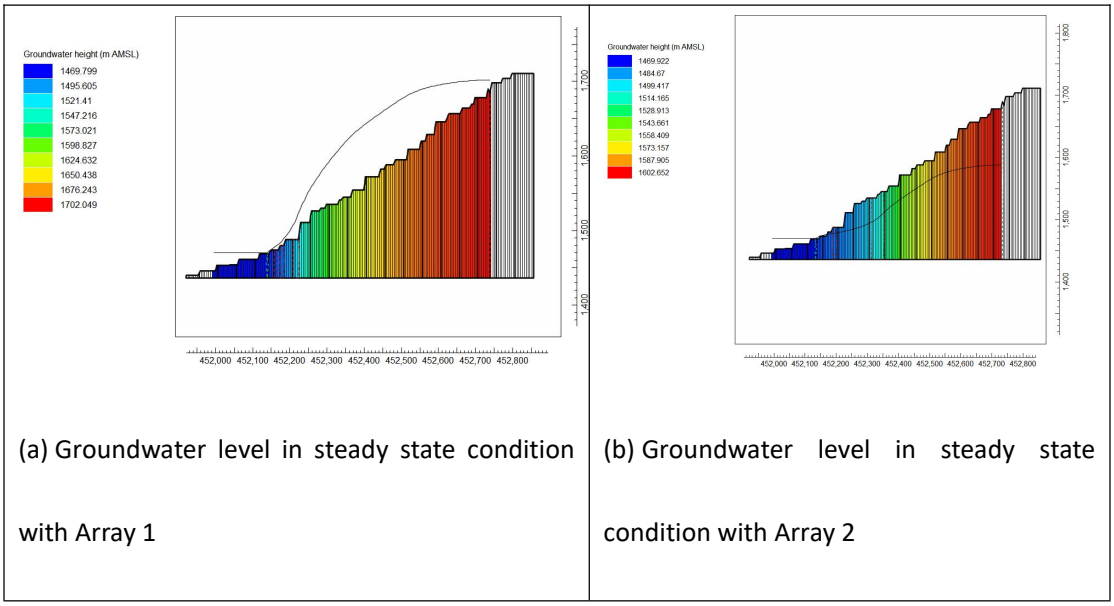

(a) Groundwater below the ground surface with drain array 1




(b) Groundwater below the surface for drain array 2

***Figure 32. Plan view for steady state conditions.***

**Figure 33** shows the slope profile after the steady state simulation. (a) shows the piezometric line (horizontal black line) with drain array 1, which was found not effective at maintaining the groundwater below the ground surface, and (b) shows the piezometric line (horizontal black line) with drain array 2, which efficiently maintained the groundwater level below the ground surface.




(a) Groundwater level in steady state condition with Array 1

(b) Groundwater level in steady state condition with Array 2

***Figure 33. Piezometric line for steady state conditions.***

***Kx=0.0133, VKA=1, sy=0.001, recharge= 0.002m/d. (a) with drain array 1, and (b) with drain array (2).***

ii. Transcient conditions

The transient condition was simulated with the 25years 24-hours rainfall event. The 24-hours event was divided into 24 stress periods of 0.0417 day each. The model time had a total of 25 stress periods, where the first stress period corresponded to the steady state simulation of duration 1day. The hydrological conditions are still the same, for instance, Kx= 0.0133 m:day,

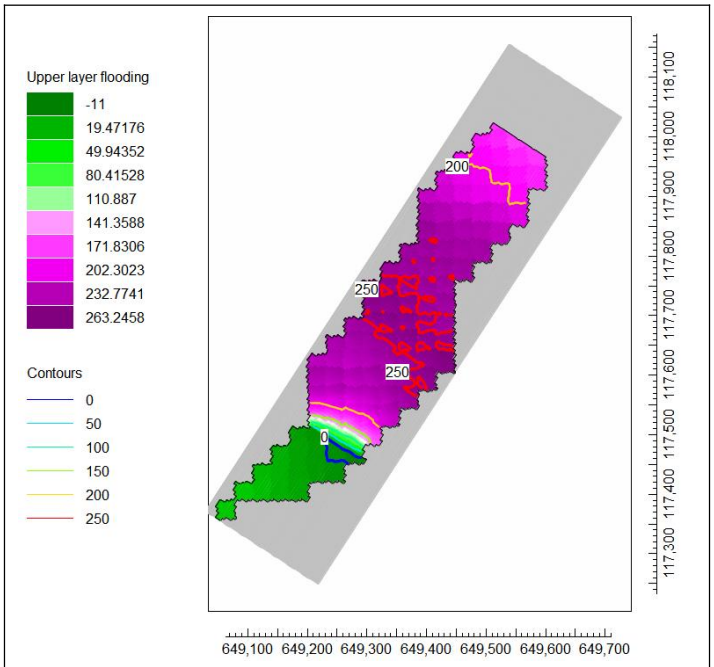
and VKA= 1. The following results are for stress period 23, which had a maximum recharge of 0.059 m/day.

To visualize the results, a dataset was created to observe the flooding of the domain. This is because flooding was expected by increasing the water influx in the system. Therefore, the goal was to check if the drain was efficient at decreasing the risk of water rising beyond the ground surface.

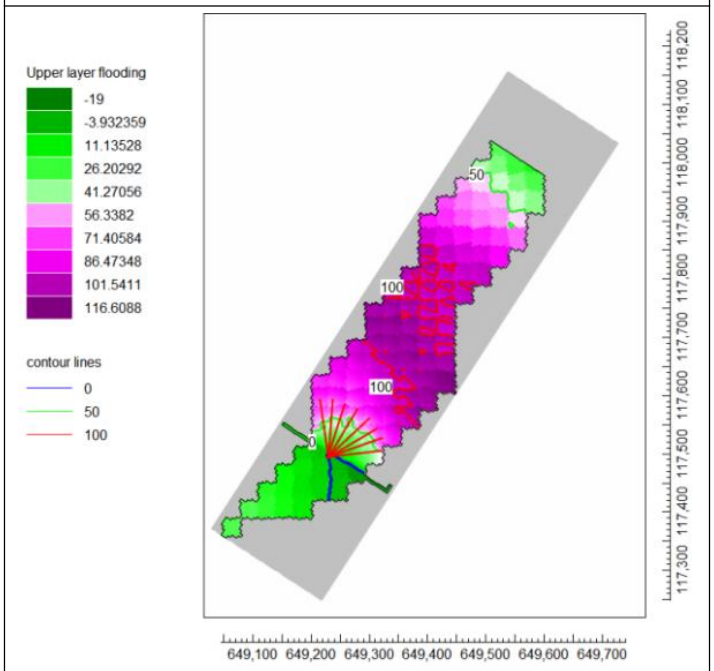
With drain array 1, the entire system remained flooded, implying that is was not efficient at decreasing the risk of flooding. Drain array 2 on the other hand, successfully mitigated the flooding risk upstream, however, it was not able to remove water above surface at the watershed outlet.

**Figure 34** depicts the plan view of the model domain after the transient simulation. The grid cell size is 5m by 5m, and the cells are coloured with respect to the dataset specifications, for instance, the difference between the groundwater head, and the cell top elevation. This implies that positive values indicated flooding (gw head > ground surface elevation), while negative values indicated that the groundwater was below the ground surface (gw head < ground surface elevation). (a) shows the domain without drains incorporated. The system was expected to be severely flooded from the slope tip to the outlet. (b) shows the domain with array 1 incorporated. It was observed to decrease the severity of the flooding, however, not enough to bring groundwater level below the ground surface. (c) show the domain with drain array 2 incorporated. It was observed to efficiently

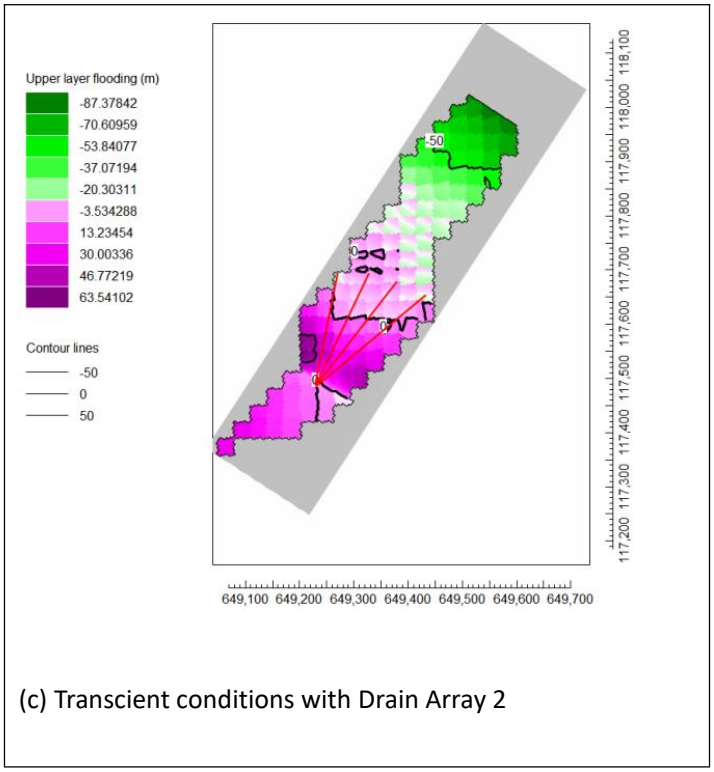
mitigate flooding upstream, however, was not able to remove the water at the watershed outlet.




(a) Transcient conditions without drains




(b) Transcient conditions with Array 1




(c) Transcient conditions with Drain Array 2

***Figure 34. Upper layer flooding (m AMSL) in stress period 23 of the 25 year 24-hour precipitation event.***

### *c. Improvements to drain array 1*

From the above discussion, it was seen that drain array 2 was more efficient than drain array 1. However in practical sense, it would be hard to install horizontal drains 200 meters long. Therefore, an improvement was brought to the first configuration to check if it would improve the efficiency of the system. An additional array of four drains of about 90 meters, drilled at an angle of 10° from one another, and at an elevation of 1537m AMSL was therefore incorporated.

**Figure 35** shows the plan view of the drain configuration on the domain. The model cells are 5m by 5m, and colored with the elevation DEM. Red lines represent the drain placement. Drain array 1 is located at 1469m AMSL,

and the additional array is located at 1537m AMSL.

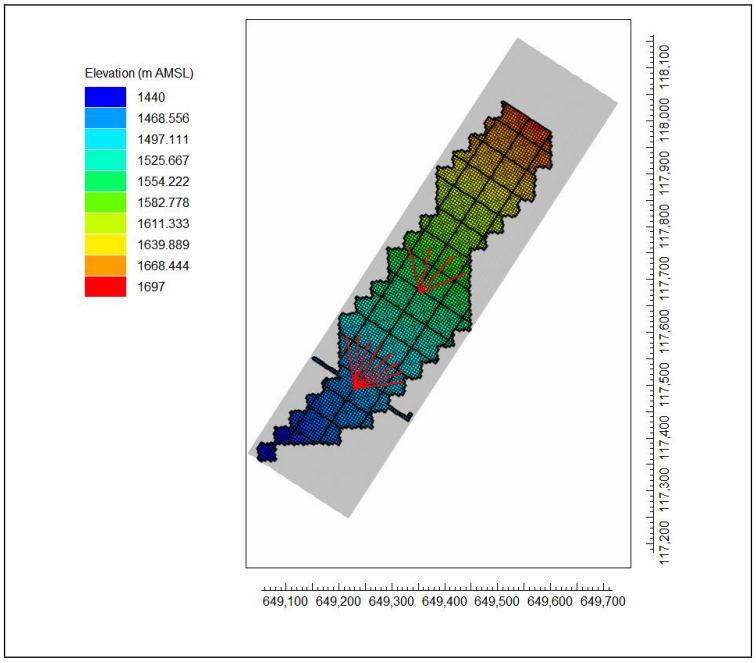


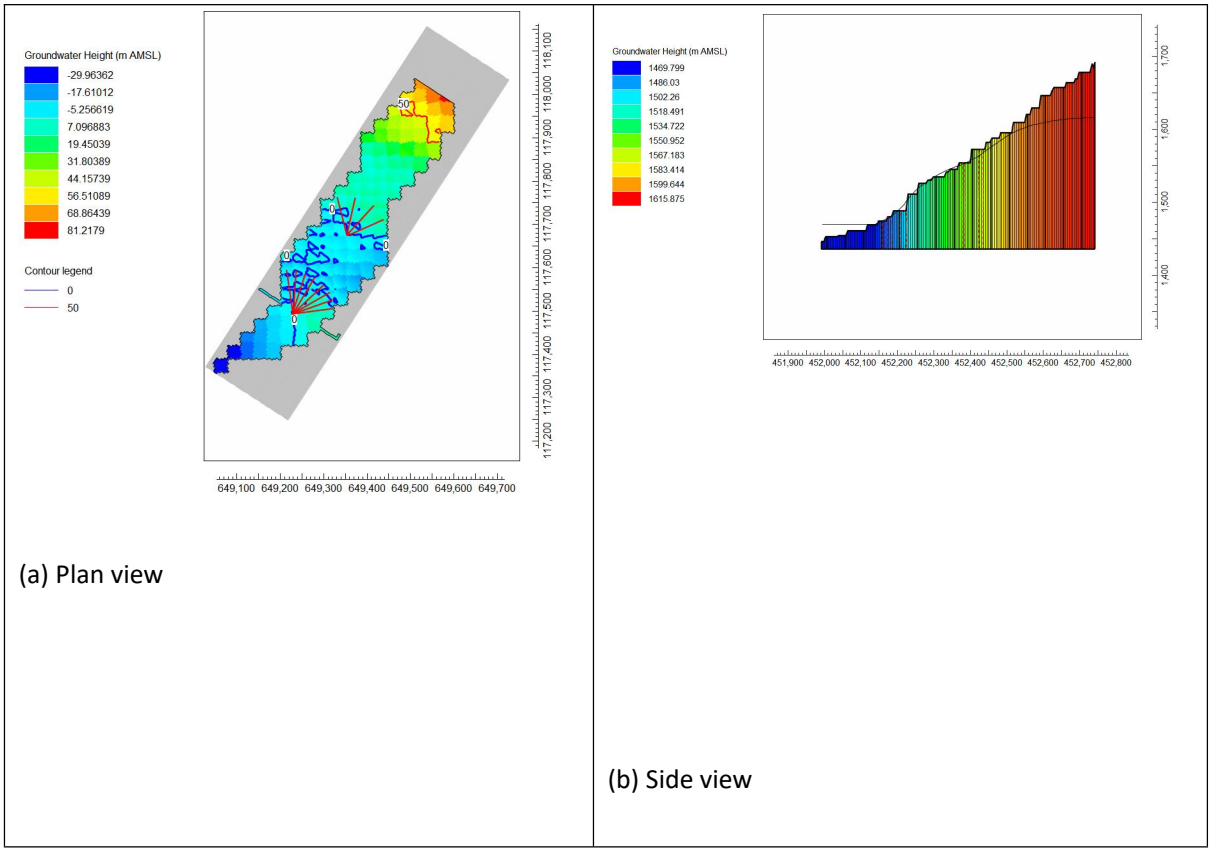

***Figure 35. Improved drain configuration***

i. Steady state conditions

Considering the same simulation conditions as used before, for instance Kx= 0.0133 m/day, VKA= 1, and recharge= 0.002 m/day, the new configuration was observed to have significantly decreased the risk of flooding. However, water was still above the ground surface between location of the two drain arrays.

**Figure 36**: (a) plan view of the model domain. the grid cells are 5m by 5m, and coloured in accordance with the dataset specification, for instance the difference between the cell top elevation and the groundwater head. Positive values indicate that the groundwater was below the ground surface (ground surface elevation > gw head), while negative values indicate that the groundwater was above the ground surface (ground surface elevation <

gw head, thus flooding). Flooded was only observed to occur between the location of the two drain arrays. (b) shows the piezometric line (horizontal black line), which was observed to be lower than before with only drain array 1.




(a) Plan view

(b) Side view

***Figure 36. Steady state simulation for improved drain configuration***

ii. Transient conditions

The transient simulation showed an improvement in the ability of decreasing the flood risk. No flooding was observed at the slope tip, while flooding occurred at the slope toe, and between the location of the two arrays.

**Figure 37** shows the plan view of the model domain after the transient simulation. The grid cell size is 5m by 5m, and the cells are coloured with respect to the dataset specifications, for instance, the difference between

the groundwater head, and the cell top elevation. This implies that positive values indicated flooding (gw head > ground surface elevation), while negative values indicated that the groundwater was below the ground surface (gw head < ground surface elevation).

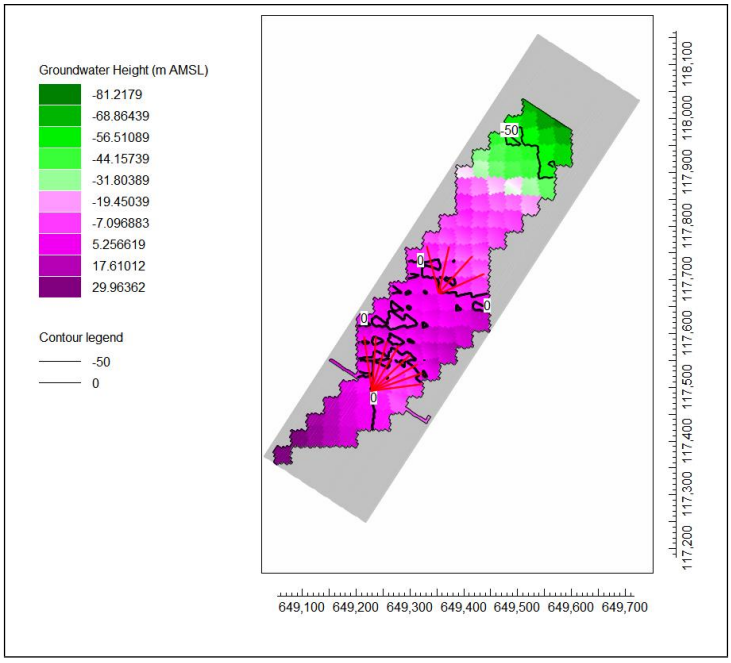



***Figure 37. Transcient similation for improved drained configuration***

From the above discussion, it was observed that long continuous drains positionned at a single lower location were more efficient than shorter drains positionned at different locations. Shorter drains had a smaller area of influence, and hence could not decrease the risk of flooding at elevations beyond their influence.

Of all the scenarios, drain array 2 was the one that provided satisfactory groundwater levels, and therefore, those were the piezometric lines considered in the geotechnical analysis of the slope.

### 4.3.2 GEOTECHNICAL ANALYSIS OF THE SLOPE

**1. Initial conditions**

Initially, the soil was assumed to be fully saturated, with the piezometric line being at the groundsurface. Under Unconsolidated and undrained conditions, the slope was unstable with a factor of safety of 0.351, while in consolidated and drained conditions however, the factor of safety was 0.897. Cahyaningsih, Catur Asteriani. 2019 provide insights of landslide susceptibility based on the value of the factor of safety. They are summarized in table 16. When the slope is assumed fully saturated, its factor of safety is below 1.07, indicating a very unstable slope, which high risk of landslide occurrence.

***Table 15. Factor of safety ranges***

| *Factor of safety value* | *Landslide intensity* |
|---|---|
| FOS less than 1.07 | Landslide occurred regular/ frequent (unstable slope) |
| 1.07< FOS< 1.25 | Landslide case (critical slope) |
| FOS over 1.25 | Rare landslide (relatively stable slope) |

**2. Analysis**

From the reasons stated before, the geotechnical analysis only accounted for the piezometric lines provided by drain array 2.

i. In steady state conditions

The drainage system increased the factor of safety for both conditions,

unconsolidated undrained being 0.570 (increase of 38.42%), and consolidated and drained 1.401 (35% increase). This is because groundwater significantly dropped below the groundsurface from the previously position which was assumed to be at the ground surface. The pore water pressure acting on the slope thus reduced, increasing the factor of safety.

ii. In transient condition

The factor of safety decreased again provided the expected flooding. It was 0.524 (decrease of 8.07%) for unconsolidated and drained conditions, while 1.207 (decrease of 13.85%) for consolidated and drained. An increase in water influx was previously observed to increase the risk of flood occurrence. This was linked to the low permeability, where water took more time to travel through the soil profile. Groundwater levels therefore raised, flooding the slope toe where the drains were not able to mitigate the risk. This lead to an increase in pore water pressure, therefore a decrease in the factor of safety.

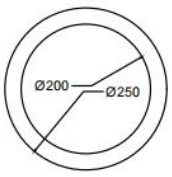
### 4.3.3 DESIGN OF THE SUB DRAINAGE SYSTEM

The sub drainage system consists of four drainage pipes arranged in a fan configuration. The drains, which are 200 meters long with an internal diameter of 100mm, are drilled with an angle of 12° from each other. They are perforated with circular slots of diameter 0.25mm, arranged in four longitudinal rows. Taking a section x-x along the slope, the drains are at an

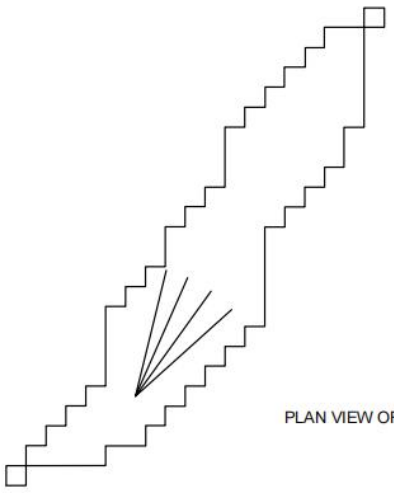
elevation of 1465m AMSL, and they are drilled at an angle of 10° to the horizontal plane.

The drain spacing was calculated to be 10.61 meters. However, this was just an analytical estimation which is prone to changes based on expertise and site conditions as explained by Cook, Santi and Higgins (2008).

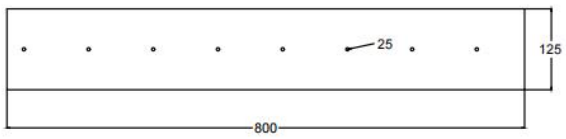
## 4.3.4 DESIGN DRAWING



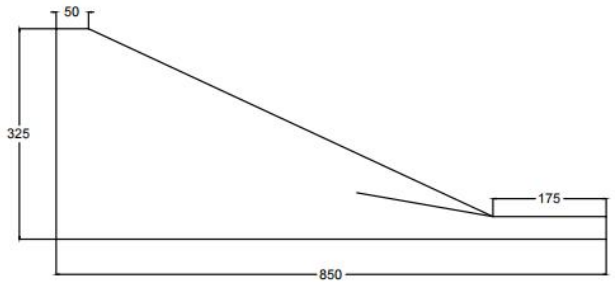

DRAIN CROSS SECTION



PLAN VIEW OF SLOPE




SIDE VIEW OF DRAIN




CROSS SECTION OF THE SLOPE

| | | | | | |
|---|---|---|---|---|---|
| This drawing is our property. It cannot be reproduced or communicated without our written agreement | | | | | |
| DRAWN BY MAMFA | DATE April 10th, 2025 | DRAWING TITLE: DESIGN OF A DRAIN SECTION AND DRAIN CONFIGURATION | | | |
| CHECKED BY MAMFA | DATE April 10th, 2025 | SIZE: A3 | DRAWING NUMBER | | REV |
| DESIGNED BY | DATE | SCALE: 1/2500 | | | SHEET: 1/1 |

# CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

## 5.1 CONCLUSIONS

This study involved the design and determination of the suitability of a horizontal sub drainage system in the context of landslide hazard mitigation, using a combination of analytical and numerical methods for groundwater and geotechnical modelling. Key findings and conclusions can be outlined as follows:

1. The site characterization showed that the area was naturally prone to the occurrence of landslide events when diving into its geological properties.

a. The site geometry of the area depicted high elevations (1400 - 1722m AMSL), and moderately steep slopes of maximum 28.26°.

b. The soil property findings were the following:

i. The soil was majorly composed of fine particles (clay) with a moderately high plasticity;

ii. The infiltration rate was very high, with a value of 0.273m/hours, yet it depicted a low permeability of 3.7368 * $10^{-4}$m/hour. This situation showed a tendency of water storage in the soil profile as discussed by scholars (Makabayi, B., Musinguzi, M. and Otukei, J.R. 2021a);

iii. On the other hand, the strength parameters, for instance the cohesion and angle of friction were strongly influenced by the drainage conditions. In fact, they were 37.03 Kpa and 14.07° in unconsolidated and

undrained conditions, while in consolidated and drained conditions they were 4kpa and 34.2 Kpa respectively.

2. The hydrological survey showed that:

i. Rainfall had a great impact on the stability of the slope as the landslides were rainfall-induced. Various statistical analyses were computed, and it was observed that some extreme weather conditions inducing landslides were driven by world-scale hydrological processes such as the El Niño;

ii. The distribution of water losses in the watershed were greatly influenced by the land-use and inherent soil properties. For instance, the absence of impervious surfaces, and the high infiltration rate of the soil, along with the moderately steep slopes cause a large portion of the rainfall falling on the land (67.47%) to infiltrate the ground.

3. Design of the horizontal sub drainage system

i. The groundwater modelling showed that the seepage was greatly influenced by the coefficient of permeability. Water accumulated in the soil profile considering its low coefficient of permeability. This increased the chances of the groundsurface flood with increased rainfall intensity;

ii. Drainage was observed to have a significant impact on the seepage of the slope. Drain array 1 consisted of 8 drains of length 100m. It was found not effective in lowering the groundwater table in both steady

state and transient conditions. Drain array 2 on the other hand, consisted of 4 drains of length 200m. It was found effective in lowering groundwater table in steady state conditions, and fairly good at lowering the ground water up slope in transient conditions;

iii. Long and continuous drains were more efficient at regulating the groundwater levels than shorter drains installed at different locations. This is because shorter drains could not influence the seepage beyond their area of influence;

iv. The slope was found to be more stable when it was drained. Preventing the drainage (unconsolidated and undrained conditions) lead to an increase of pore water pressure within the slope, and hence its equilibrium.

## 5.2 RECOMMENDATIONS

1. Advanced studies should be conducted to assess the suitability of sub drains in field. This will entail installing the drains in the slope, as well as piezometers in order to monitor the groundwater over a prolonged period of time.
2. Further research should be conducted on the design of horizontal sub drainage systems, incorporating more complex geologic configurations such as multiple layers and discontinuities.
3. Also, research should be directed to the domain of hydrology in remote

areas prone to natural fatalities of this type, where scholars has shown that it is the leading cause of death and damage to property (UNDRR DesInventar Sendai, 2020). This would allow to an active collection of key data that are necessary for the design of solutions .

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# APPENDICES

## APPENDIX A: Secondary data of BUDUDA Rainfall (2000_2025)

| Year | Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2000 | January | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6.1 | 1.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | February | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| | March | 0 | 0 | 0 | 0 | 13.4 | 2.9 | 17.5 | 5.8 | 1.5 | 1.5 | 3.7 | 7.3 | 0 | 0 | 0 | 14.8 | 8.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.5 |
| | April | 9.2 | 0 | 0 | 10.3 | 2.3 | 0 | 8 | 10.2 | 6.8 | 13.7 | 0 | 0 | 0 | 0 | 22.8 | 9 | 3.6 | 0 | 0 | 3.6 | 0 | 16.1 | 6.9 | 2.3 | 9.2 | 4.5 | 20.9 | 6 | 13.4 | 19.4 | |
| | May | 15.9 | 7.4 | 8.5 | 7.4 | 9.5 | 0 | 12.8 | 8.5 | 13.9 | 5.3 | 14.2 | 1.1 | 2.2 | 1.6 | 2.2 | 9.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 17.3 | 0 | 0 | 9.8 | 9.8 | 17.7 | 13.8 |
| | June | 0 | 0 | 0 | 4.1 | 12.4 | 0 | 0 | 9.2 | 12.9 | 0 | 3.3 | 6.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 22.2 | 3.3 | 0 | 0 | 13.1 | 16.4 | 5.8 | 9.6 | 11.5 | 9.6 | 7.7 | |
| | July | 0 | 0 | 10.5 | 5.3 | 0 | 0 | 0 | 0 | 27.3 | 31.8 | 16.5 | 14.1 | 0 | 0 | 2.4 | 8.1 | 6.1 | 0 | 0 | 14.2 | 13.9 | 17 | 1.5 | 0 | 12.3 | 0 | 0 | 0 | 0 | 0 | 0 |
| | August | 9.1 | 9.1 | 0 | 0 | 0 | 1.9 | 3.7 | 9.3 | 15 | 22.4 | 3.4 | 25.5 | 20.4 | 17 | 1.7 | 15.5 | 8.6 | 13.7 | 1.7 | 8.6 | 4.8 | 9.6 | 0 | 0 | 0 | 7 | 7 | 7 | 0 | 0 | 0 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | September | 6.9 | 1.7 | 0 | 6.9 | 0 | 0 | 0 | 8.3 | 0 | 6.6 | 0 | 0 | 0 | 0 | 9.9 | 5.2 | 1 | 3.1 | 0 | 6.2 | 13 | 7 | 0 | 1 | 0 | 1.5 | 0 | 3 | 0 | 7.4 | |
| | October | 4.7 | 10.6 | 3.5 | 11.7 | 0 | 8.4 | 13.2 | 20.3 | 8.4 | 6 | 13.5 | 0 | 5.1 | 5.1 | 8.4 | 1.2 | 6.2 | 18.6 | 11.1 | 40.9 | 0 | 0 | 0 | 0 | 7.3 | 0 | 0 | 0 | 0 | 0 | 20.5 |
| | November | 10.5 | 9.2 | 7.9 | 5.3 | 1.3 | 6 | 12 | 6 | 5 | 0 | 3.6 | 0 | 0 | 4.8 | 3.6 | 23.1 | 12 | 9.4 | 7.7 | 10.3 | 20.7 | 4.5 | 5.4 | 2.7 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | December | 0 | 7.8 | 15.5 | 2.9 | 0 | 3.6 | 0 | 0 | 0 | 2.7 | 0 | 4.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.4 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 |
| 2001 | January | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6.2 | 4.5 | 2.2 | 0 | 3.4 | 0 | 0 | 0 | 0 | 4.2 | 4.9 | 2.6 | 7.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | February | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10.9 | 0 | 8.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10.7 | 2.1 | 0 | 0 | 0 | 0 | 0 | | | |
| | March | 0 | 0 | 0 | 0 | 24.2 | 18.7 | 2.9 | 0 | 8.6 | 0 | 0 | 0 | 12.7 | 0 | 7.3 | 0 | 3.3 | 9.9 | 15.8 | 5.3 | 3.7 | 0 | 3.7 | 0 | 9.2 | 13.4 | 0 | 3.7 | 3.7 | 9.8 | 2.4 |
| | April | 0 | 11.7 | 0 | 2.3 | 7 | 5.9 | 1.5 | 4.4 | 5.9 | 0 | 0 | 0 | 7.1 | 0 | 9.5 | 0 | 0 | 0 | 5.5 | 5.5 | 9.4 | 0 | 1.2 | 13 | 7.1 | 6.8 | 10.2 | 17 | 1.7 | 0 | |
| | May | 1.1 | 14.9 | 9.6 | 7.4 | 13.8 | 9.5 | 0 | 12.6 | 12.6 | 10.5 | 2.4 | 7.1 | 0 | 7.1 | 0 | 0 | 0 | 0 | 9.6 | 0 | 0 | 12.9 | 4.3 | 0 | 4.3 | 2.3 | 0 | 11.3 | 6.8 | 11.3 | 0 |
| | June | 0 | 2.4 | 7.3 | 0 | 26.9 | 12.3 | 1.5 | 12.3 | 10.8 | 4.6 | 1.7 | 5 | 0 | 0 | 15.1 | 0 | 0 | 11.1 | 7.4 | 0 | 0 | 0 | 8 | 4 | 12 | 35.2 | 7 | 15.8 | 17.6 | 0 | |
| | July | 0 | 0 | 15.8 | 0 | 0 | 20.8 | 0 | 0 | 0 | 0 | 0 | 14.4 | 0 | 4.8 | 12 | 0 | 12.5 | 17.8 | 10.7 | 5.3 | 6.3 | 4.7 | 7.9 | 4.7 | 15.8 | 0 | 0 | 0 | 0 | 0 | 0 |
| | August | 0 | 4.5 | 9.1 | 0 | 4.5 | 0 | 0 | 0 | 0 | 14.7 | 0 | 6.7 | 6.7 | 8.9 | 2.2 | 6 | 8 | 6 | 8 | 0 | 0 | 5.3 | 0 | 10.5 | 8.8 | 13.5 | 8.4 | 10.1 | 20.2 | 5.1 | 0 |

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| | September | 2.6 | 0 | 9.1 | 19.5 | 3.9 | 1.6 | 14.4 | 0 | 0 | 0 | 0 | 6.7 | 0 | 0 | 0 | 2.8 | 0 | 4.6 | 5.5 | 11.1 | 11.5 | 10.6 | 8 | 0 | 11.5 | 4.8 | 0 | 1.2 | 13.1 | 0 | |
| | October | 0 | 1.7 | 0 | 0 | 10.4 | 1.3 | 6.4 | 11.5 | 6.4 | 11.5 | 0 | 11 | 0 | 0 | 6.6 | 0 | 0 | 0 | 0 | 17.6 | 0 | 9.5 | 4.8 | 7.1 | 8.3 | 16.4 | 4.1 | 16.4 | 17.8 | 12.3 | 9.6 |
| | November | 9.7 | 0 | 13.8 | 4.2 | 0 | 3.1 | 1 | 2 | 19.3 | 1 | 0.9 | 11.1 | 7.7 | 12.8 | 11.6 | 10.7 | 0 | 9.8 | 9.8 | 12.4 | 5.1 | 6.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | December | 0 | 0 | 1.3 | 0 | 10.3 | 0 | 4.8 | 0 | 0 | 0 | 0 | 0 | 3.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.3 | 0 | 1.1 | 1.1 | 0 | 0 |
| 2002 | January | 4.7 | 10.3 | 0.9 | 8.4 | 19.7 | 3.6 | 0 | 0 | 0 | 0 | 1.4 | 5.6 | 0 | 1.4 | 0 | 1.2 | 0 | 0 | 1.2 | 3.5 | 0 | 5.6 | 6.3 | 0 | 0 | 4.8 | 0 | 0 | 0 | 0 | 0 |
| | February | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8.9 | 0 | 0 | 0 | 2.9 | 0 | 5.8 | 11.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 14.1 | | | |
| | March | 3.7 | 7.5 | 24.2 | 0 | 24.2 | 14.9 | 12.8 | 0 | 4.3 | 0 | 0 | 0 | 0 | 16.6 | 0 | 0 | 8.2 | 7.5 | 3 | 4.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | April | 0 | 11.9 | 0 | 0 | 15.9 | 4.9 | 0 | 0 | 0 | 9.9 | 5.8 | 26.2 | 8.7 | 10.2 | 2.9 | 0 | 1.4 | 8.2 | 10.9 | 8.2 | 7.3 | 5.5 | 0 | 0 | 0 | 0 | 3 | 6 | 0 | 6 | |
| | May | 0 | 11.3 | 20.5 | 17.5 | 15.4 | 18.9 | 20 | 1.1 | 3.2 | 2.1 | 0 | 0 | 7.2 | 1.4 | 2.9 | 0 | 3.4 | 5.1 | 8.4 | 11.8 | 26.4 | 9.3 | 14 | 7.8 | 12.4 | 0 | 0 | 0 | 0 | 0 | 0 |
| | June | 8.3 | 8.3 | 0 | 0 | 0 | 0 | 3.5 | 5.3 | 5.3 | 10.6 | 6.6 | 3.3 | 4.9 | 8.2 | 0 | 12.3 | 0 | 14.8 | 9.8 | 0 | 4.4 | 13.1 | 4.4 | 0 | 0 | 11.5 | 0 | 6.9 | 4.6 | 2.3 | |
| | July | 0 | 17.8 | 0 | 0 | 0 | 0 | 0 | 32.3 | 0 | 0 | 3 | 14.8 | 0 | 3 | 0 | 0 | 16.9 | 6.3 | 0 | 2.1 | 0 | 2.4 | 11.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 21.4 |
| | August | 0 | 0 | 0 | 20.1 | 0 | 12.5 | 5 | 0 | 0 | 5 | 13.2 | 0 | 0 | 0 | 5.3 | 0 | 0 | 0 | 9.2 | 0 | 8.8 | 3.5 | 12.3 | 0 | 0 | 0 | 2.8 | 0 | 0 | 13.8 | 0 |

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| | September | 8.2 | 2.1 | 2.1 | 0 | 0 | 0 | 0 | 0 | 0 | 9.8 | 9.1 | 7.8 | 6.5 | 1.3 | 3.9 | 2.9 | 5.8 | 0 | 0 | 0 | 0 | 0 | 2.2 | 4.5 | 7.9 | 3.4 | 0 | 2.3 | 6.8 | 10.1 | |
| | October | 22.7 | 4.5 | 1.1 | 4.5 | 3.4 | 8 | 2.7 | 8 | 5.3 | 6.6 | 8.4 | 0 | 4.2 | 2.1 | 4.2 | 1.3 | 0 | 9.3 | 18.6 | 14.6 | 9.8 | 4.3 | 0 | 22.8 | 17.3 | 10.5 | 0 | 6 | 0 | 0 | 22.6 |
| | November | 0 | 1.5 | 0 | 16.3 | 4.4 | 12.1 | 2.2 | 0 | 0 | 5.5 | 0 | 0 | 2.4 | 8.8 | 1.2 | 4.4 | 8.7 | 1.1 | 2.2 | 0 | 0 | 3.7 | 5.6 | 13 | 5.6 | 6.4 | 0 | 0 | 0 | 0 | |
| | December | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6.2 | 2.1 | 0 | 0 | 8.4 | 3.1 | 6.9 | 0 | 1.6 | 5.6 | 0 | 0.8 | 3.6 | 7.1 | 6 | 10.1 | 0 | 1.2 |
| 2003 | January | 0 | 2.9 | 8.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.7 | 5.4 | 7.4 | 3.5 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | February | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5.4 | 5.4 | 0 | 0 | 0 | 0 | 13.1 | 0 | 12.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.5 | 0 | 1.9 | | | |
| | March | 13.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 16.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.5 | 5.5 | 6.3 | 0 | 0 | 0 | 17.6 | 9.4 | 2.3 | 10.5 |
| | April | 0 | 0 | 0 | 0 | 0 | 6.6 | 4.4 | 0 | 0 | 0 | 0 | 5.9 | 23.8 | 0 | 17.8 | 0 | 17.6 | 5.4 | 6.8 | 0 | 7.9 | 14.7 | 6.8 | 3.4 | 4.5 | 0 | 8.8 | 0 | 0 | 22.9 | |
| | May | 0 | 3.2 | 11.7 | 14.9 | 16 | 6.6 | 0 | 14.3 | 2.2 | 9.9 | 3.9 | 16.6 | 0 | 9.8 | 5.9 | 7.3 | 2.4 | 0 | 4.9 | 0 | 0 | 11.6 | 5.8 | 9.6 | 0 | 8.2 | 20.5 | 0 | 2 | 12.3 | 0 |
| | June | 6 | 0 | 9 | 0 | 9 | 5.2 | 0 | 5.2 | 5.2 | 10.4 | 4.3 | 2.9 | 1.4 | 20.9 | 8.6 | 14.5 | 7.3 | 12.1 | 0 | 4.8 | 13.1 | 0 | 6.6 | 6.6 | 6.6 | 13.4 | 11.5 | 11.5 | 1.9 | 5.8 | |
| | July | 7.3 | 16.9 | 2.4 | 12.1 | 19.4 | 2.3 | 29 | 8.1 | 13.9 | 0 | 8.1 | 16.1 | 0 | 0 | 0 | 0 | 8.1 | 2 | 12.1 | 6.1 | 8.9 | 1.8 | 12.5 | 1.8 | 0 | 0 | 0 | 0 | 6.5 | 13 | 0 |
| | August | 0 | 0 | 0 | 14.3 | 0 | 4.7 | 9.3 | 0 | 0 | 11.7 | 2.3 | 11.5 | 4.6 | 2.3 | 2.3 | 22.7 | 3.2 | 9.7 | 4.9 | 29.2 | 2.9 | 8.8 | 8.8 | 2.9 | 26.4 | 11.5 | 22.9 | 0 | 8.8 | 0 | 1.8 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | September | 3.2 | 3.2 | 0 | 8.1 | 3.2 | 5.1 | 9 | 3.8 | 3.8 | 7.7 | 1.6 | 0 | 8.1 | 3.2 | 3.2 | 5.6 | 8.4 | 9.3 | 0 | 0 | 8.1 | 0.9 | 7.2 | 19.7 | 1.8 | 0 | 5.5 | 0 | 4.1 | 4.1 | |
| | October | 2.8 | 4.4 | 14.5 | 18.9 | 1.1 | 2.5 | 1.2 | 16 | 16 | 8.6 | 0 | 26.2 | 6.4 | 7.9 | 0 | 1.3 | 37 | 4 | 1.3 | 1.3 | 3 | 0 | 12.1 | 0 | 0 | 0 | 14.4 | 0 | 11.2 | 0 | 4.8 |
| | November | 5 | 18.7 | 18.7 | 1.2 | 2.5 | 0 | 0 | 0 | 21 | 8 | 0 | 0 | 0 | 1.8 | 5.5 | 6.7 | 0 | 0 | 1.7 | 0 | 0 | 4 | 0 | 5.3 | 1.3 | 0 | 0 | 5.7 | 24.1 | 8 | |
| | December | 4.1 | 0 | 0 | 4.1 | 12.3 | 0.6 | 3.1 | 5 | 5.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2004 | Januay | 0 | 5.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11.8 | 0 | 1.2 | 7.9 | 0 | 7.9 | 1.3 | 0 | 0 | 0 | 0 | 15.2 | 2.5 | 0 | 0 | 0 | 5.1 | 5.8 | 1.5 |
| | February | 9.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8.9 | 0 | 0 | 15.2 | 15.2 | 0 | 0 | 9.6 | 21.6 | 12 | 0 | 0 | 6.9 | 10.4 | 10.4 | | |
| | March | 0 | 19.5 | 0 | 0 | 0 | 0 | 0 | 8.4 | 0 | 0 | 0 | 0 | 13.2 | 5.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.5 | 16 | 0 | 0 | 9.8 | 3.7 |
| | April | 0 | 0 | 5.3 | 17.7 | 15.1 | 8.6 | 0 | 5.4 | 23.2 | 16.2 | 0 | 0 | 8.1 | 8.1 | 4.1 | 0 | 8.3 | 10.7 | 26.1 | 10.7 | 4.9 | 0 | 0 | 13.5 | 8.6 | 2.1 | 0 | 0 | 0 | 19.2 | |
| | May | 0 | 9.4 | 7 | 5.9 | 4.7 | 3.2 | 9.5 | 9.5 | 12.7 | 8.5 | 11.7 | 7.8 | 0 | 12.7 | 3.9 | 0 | 8.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 21.9 | 0 | 0 |
| | June | 0 | 0 | 18.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.8 | 0 | 0 | 0 | 10.6 | 8.5 | 14.9 | 10.6 | 25.5 | 9.8 | 6.6 | 0 | 16.4 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | July | 0 | 0 | 0 | 0 | 11.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10.2 | 0 | 0 | 2.2 | 6.7 | 0 | 0 | 13.4 | 3.5 | 10.5 | 12.2 | 0 | 0 | 16.6 | 22.9 | 0 | 16.6 | 0 | 9.4 |
| | August | 14.5 | 10.9 | 12.1 | 0 | 14.5 | 0 | 2.8 | 0 | 0 | 16.6 | 19 | 1.9 | 9.5 | 5.7 | 1.9 | 0 | 15.4 | 15.4 | 0 | 0 | 0 | 12.8 | 0 | 1.8 | 7.3 | 0 | 10.2 | 0 | 3.4 | 0 | 0 |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | September | 6.2 | 4.1 | 2.1 | 0 | 0 | 0 | 12.9 | 0 | 0 | 0 | 0 | 8.7 | 2.2 | 0 | 0 | 4 | 1 | 0 | 12.1 | 0 | 5.8 | 7.7 | 1 | 6.7 | 3.8 | 1.1 | 8.5 | 4.2 | 5.3 | 10.6 | |
| | October | 19.5 | 5.7 | 4.6 | 4.6 | 0 | 6.1 | 0 | 3 | 7.6 | 3 | 2.5 | 12.5 | 0 | 0 | 0 | 7.7 | 0 | 1.9 | 3.8 | 1.9 | 0 | 0 | 0 | 13.2 | 0 | 1.5 | 6 | 6 | 10.5 | 13.5 | 3 |
| | November | 1.5 | 7.4 | 0 | 10.4 | 3 | 0 | 0 | 0 | 8.1 | 4.1 | 10.1 | 0 | 4 | 4 | 0 | 0 | 0 | 2.2 | 6.5 | 7.6 | 0 | 10.6 | 7.9 | 8.8 | 11.5 | 0 | 0 | 0 | 0 | 0 | |
| | December | 3.7 | 0 | 8.7 | 0 | 0 | 1.9 | 1 | 0 | 2.9 | 0 | 0 | 0 | 0 | 0 | 10.7 | 9.4 | 2.3 | 5.5 | 0 | 0 | 4.5 | 1.5 | 3 | 0 | 0 | 0 | 0 | 0 | 4.1 | 0 | 2 |
| 2005 | January | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5.2 | 3.7 | 1.8 | 6.2 | 9.2 | 0 | 5.5 |
| | February | 11.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14.7 | 13.6 | 14.7 | | | |
| | March | 14.9 | 5 | 0 | 7.4 | 0 | 0 | 13.9 | 0 | 0 | 0 | 0 | 4.8 | 0 | 9.6 | 0 | 18.9 | 13 | 11.8 | 9.4 | 9.4 | 11.5 | 2.6 | 0 | 2.6 | 24.2 | 0 | 7.8 | 2.6 | 0 | 0 | 0 |
| | April | 0 | 0 | 0 | 12.3 | 7.4 | 10.7 | 5.4 | 0 | 4 | 1.3 | 15.7 | 0 | 14.1 | 7.9 | 0 | 0 | 0 | 0 | 0 | 7.8 | 1.3 | 5.1 | 11.6 | 5.1 | 0 | 12.4 | 17 | 1.5 | 12.4 | 9.3 | |
| | May | 9.4 | 10.4 | 11.5 | 14.6 | 10.4 | 24.7 | 9.3 | 12.4 | 2.1 | 5.1 | 3.1 | 10.3 | 5.2 | 7.2 | 1 | 10.3 | 0 | 6.9 | 3.4 | 6.9 | 31.7 | 11.7 | 0 | 0 | 1.7 | 18.6 | 2.1 | 10.3 | 0 | 10.3 | 0 |
| | June | 8.3 | 8.3 | 0 | 0 | 0 | 0 | 0 | 3.5 | 7 | 0 | 0 | 0 | 0 | 8.6 | 0 | 0 | 9.9 | 0 | 0 | 4.9 | 29.6 | 11.9 | 0 | 0 | 0 | 0 | 6.9 | 9.2 | 6.9 | 2.3 | |
| | July | 5.3 | 0 | 0 | 0 | 10.5 | 17.7 | 5.9 | 2.9 | 0 | 0 | 0 | 0 | 0 | 0 | 15.5 | 0 | 0 | 0 | 0 | 8.8 | 14.3 | 4.8 | 3.2 | 9.5 | 6.4 | 9.8 | 45.3 | 15.7 | 23.6 | 0 | 9.8 |
| | August | 0 | 0 | 14.3 | 0 | 0 | 0 | 0 | 0 | 0 | 16.3 | 10 | 0 | 6 | 10 | 6 | 13.8 | 13.8 | 8.6 | 10.4 | 0 | 8.1 | 0 | 13 | 0 | 9.7 | 16.4 | 0 | 10.3 | 0 | 0 | 0 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | September | 0 | 6.9 | 0 | 3.5 | 5.2 | 12.7 | 8.9 | 3.8 | 0 | 5.7 | 0 | 7.9 | 5.3 | 1.3 | 13.1 | 9.5 | 13.8 | 4.3 | 9 | 0 | 1.5 | 1.5 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 5.7 | |
| | October | 5.6 | 0 | 5.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10.6 | 1.5 | 9.1 | 25.8 | 4.6 | 12.7 | 0 | 11.3 | 2.8 | 5.6 | 14.4 | 0 | 12.2 | 14.4 | 3.3 | 6.7 | 6.7 | 0 | 0 | 5 | 8.4 |
| | November | 4.4 | 8.9 | 3 | 0 | 5.9 | 0 | 9.9 | 1.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.3 | |
| | December | 1 | 1 | 1 | 15.4 | 2.1 | 2.8 | 1.4 | 0 | 0 | 0 | 5.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2006 | January | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.8 | 4.9 | 0 | 0 | 0.8 | 6.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | February | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10.3 | 11.6 | 12.9 | 0 | 0 | 17.3 | 2.9 | 0 | 0 | 0 | 4.3 | 0 | 8.6 | 10.7 | 1.2 | 13 | | | |
| | March | 0 | 0 | 0 | 0 | 0 | 1.6 | 6.5 | 12.9 | 1.6 | 0 | 0 | 15.9 | 1.8 | 0 | 3.5 | 0 | 8.4 | 17.6 | 0 | 1.4 | 1.3 | 18.4 | 2.5 | 15.3 | 3.8 | 11.5 | 0 | 0 | 0 | 1.9 | 0 |
| | April | 20.3 | 0 | 17.9 | 16.2 | 0 | 0 | 1.2 | 7.4 | 11.7 | 7.4 | 6.5 | 0 | 6.5 | 0 | 0 | 9.9 | 11.1 | 4.9 | 14.8 | 3.7 | 14.5 | 18.6 | 14.5 | 7.2 | 15.5 | 20.4 | 0 | 3.7 | 0 | 3.7 | |
| | May | 1.1 | 5.6 | 14.1 | 5.6 | 5.6 | 0 | 7.4 | 9.5 | 10.6 | 14.8 | 17.8 | 2.8 | 1.9 | 12.2 | 15 | 23.4 | 21.2 | 1.5 | 8.8 | 0 | 0 | 0 | 4.2 | 2.1 | 16.6 | 0 | 12.6 | 19.9 | 28.9 | 19.9 | 7.2 |
| | June | 9.8 | 0 | 0 | 4.9 | 0 | 0 | 12.7 | 2.1 | 2.1 | 0 | 1.6 | 9.3 | 0 | 9.3 | 7.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 28.6 | 6.4 | 0 | 11.7 | 7.8 | 0 | 17.6 | 3.9 | |
| | July | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20.1 | 0 | 1.7 | 9.7 | 0 | 5.8 | 0 | 0 | 0 | 0 | 8.9 | 0 | 13.4 | 0 | 0 | 18.2 | 0.9 | 7.8 | 3.6 | 16.8 | 0 | 6 | 0 | 8.4 |
| | August | 1.1 | 9.2 | 19.5 | 16.1 | 20.7 | 39.1 | 28.6 | 0 | 20 | 0 | 11.8 | 0 | 0 | 0 | 0 | 0 | 10 | 5.7 | 0 | 0 | 4 | 0 | 0 | 0 | 4 | 5.9 | 9.8 | 0 | 6.9 | 7.8 | 0 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | September | 0 | 2.3 | 9 | 0 | 0 | 0 | 4.2 | 3.3 | 7.5 | 0 | 0.8 | 4 | 9.7 | 0 | 1.6 | 5.2 | 3.8 | 2.3 | 7.5 | 3.3 | 3.8 | 2.7 | 2.7 | 2.7 | 4.3 | 4.3 | 0 | 3.2 | 8.5 | 12.8 | |
| | October | 5.7 | 8 | 3.4 | 7.4 | 10.9 | 0 | 0 | 6 | 9 | 5.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.4 | 10 | 6.5 | 5.9 | 9.8 | 16.8 | 22.4 | 4.9 | 7.7 | 0 |
| | November | 11.6 | 0 | 1 | 1 | 0 | 7.1 | 0 | 0 | 0 | 0 | 6.1 | 1.8 | 0 | 2.4 | 1.2 | 6.1 | 20.6 | 12.3 | 0 | 8.8 | 16.2 | 18.8 | 6.8 | 2.6 | 10.2 | 0.7 | 2.2 | 10.3 | 2.9 | 0 | |
| | December | 0 | 0 | 0 | 0 | 0 | 6.7 | 6.4 | 0 | 0 | 0 | 0 | 0 | 10.3 | 0.4 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 4.2 | 1.9 | 2.3 | 0.4 | 0 | 4.1 | 0.2 | 7.5 | 3.3 | 1 |
| 2007 | January | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.2 | 0.4 | 0 | 3.1 | 1.4 | 0 | 6.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7.8 | 8.4 | 0 |
| | February | 0.7 | 11 | 20.6 | 19.9 | 12.5 | 5.8 | 4.4 | 5.1 | 3.6 | 3.6 | 1 | 3.1 | 9.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8.3 | 0 | 10.8 | 7.4 | | | |
| | March | 9.3 | 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 2.9 | 5.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | April | 0 | 0 | 0 | 0 | 0 | 8.7 | 0 | 0 | 8.1 | 18.5 | 10.7 | 2.8 | 19.2 | 17.1 | 12.1 | 0 | 4.4 | 1.9 | 6.3 | 25.4 | 1.4 | 1.4 | 2.2 | 0 | 12.9 | 5.6 | 0 | 0 | 0 | 9.9 | |
| | May | 4.9 | 1.8 | 1.8 | 6.1 | 8 | 2.8 | 0 | 0 | 7.7 | 4.9 | 3.1 | 3.1 | 2.6 | 10.4 | 6.7 | 11.3 | 6.4 | 14.5 | 1.6 | 0 | 0 | 0 | 2 | 16.4 | 5.1 | 18.6 | 0 | 2.8 | 14.9 | 16.7 | 17.7 |
| | June | 19.6 | 13.9 | 3.5 | 5.2 | 2.3 | 9.4 | 2.2 | 11.5 | 38.2 | 2.2 | 11.5 | 10.2 | 16.9 | 14.9 | 4.1 | 0 | 6.8 | 21.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.6 | 0 | 0 | |
| | July | 0 | 9.5 | 52.4 | 1.2 | 0 | 0 | 0 | 10.2 | 0 | 0 | 0 | 4.6 | 4.6 | 7.6 | 3.1 | 1 | 6.9 | 2.9 | 6.9 | 13.7 | 0 | 6.9 | 0 | 8.1 | 0 | 15.6 | 12.7 | 14.6 | 37 | 33.1 | 5.8 |
| | August | 6.9 | 6.9 | 1.4 | 15.2 | 4.2 | 2.2 | 3.3 | 13 | 11.9 | 0 | 0.9 | 24.1 | 23.2 | 6 | 7.7 | 10.6 | 0.9 | 9.7 | 17.7 | 2.7 | 5.1 | 1.7 | 10.1 | 3.4 | 6.8 | 0 | 5.2 | 6 | 9.5 | 6 | 24.1 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | September | 8.8 | 6.8 | 4.7 | 4.7 | 4.1 | 12.6 | 9.7 | 8 | 16.6 | 13.7 | 14.3 | 7.2 | 4.2 | 7.2 | 13.1 | 2.4 | 4.9 | 0 | 2 | 9.8 | 4.3 | 1.9 | 7.2 | 5.8 | 5.3 | 0.6 | 0 | 11.3 | 2.5 | 1.9 | |
| | October | 1.2 | 12.1 | 11 | 0 | 8.7 | 0 | 6.5 | 5.1 | 7.6 | 3.3 | 6.4 | 0 | 0 | 19.1 | 0 | 4.5 | 0 | 0 | 7.9 | 0 | 6.4 | 13.4 | 1.7 | 3.5 | 8.7 | 0 | 5.9 | 0 | 0 | 5.9 | 0 |
| | November | 0 | 0 | 15.5 | 5.4 | 9.5 | 0 | 4.1 | 0 | 0 | 7.6 | 6.8 | 7.8 | 0 | 2.1 | 0 | 6.8 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 4.6 | 0 | 0 | 0 | 0 | 6.3 | 1.6 | |
| | December | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5.8 | 10.9 | 0.3 | 0 | 12.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2008 | January | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.6 | 3.1 | 1.7 | 3 | 0 | 0.7 | 2.3 | 9 |
| | February | 9.8 | 0 | 0 | 0 | 0 | 5.5 | 18.6 | 0 | 0 | 2.1 | 9.4 | 4.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6.9 | 0 | 0 | 0 | | |
| | March | 1.4 | 0 | 0 | 0 | 22 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 11.3 | 3.5 | 3.4 | 0 | 0 | 19.8 | 6.8 | 0 | 15 | 0 | 1.6 | 4.7 | 14.1 | 0 | 0 | 5.1 | 3.2 | 5.1 |
| | April | 10.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14.3 | 24.9 | 0 | 14.7 | 2.2 | 9.5 | 0 | 0 | 9.6 | 26.4 | 16.2 | 6.5 | 3.2 | 1.9 | 9.1 | 1.9 | 0 | 0 | 0 | 0 | 11 | |
| | May | 11.2 | 0 | 1.3 | 5.9 | 0 | 0 | 0.7 | 0 | 13.2 | 0 | 0.5 | 15.3 | 7.4 | 2 | 8.9 | 0 | 0 | 3.5 | 0 | 22.7 | 8.5 | 10.1 | 12.4 | 28.7 | 12.4 | 2.1 | 8.4 | 9.4 | 9.4 | 7.3 | 3.1 |
| | June | 1.1 | 5.4 | 14 | 21.5 | 19.4 | 9.4 | 8.5 | 0 | 8.5 | 0.9 | 0 | 0 | 0 | 13.2 | 3.8 | 13.5 | 10.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11.9 | |
| | July | 0 | 0 | 29.1 | 9.3 | 2.6 | 7.1 | 16.6 | 1.2 | 13 | 10.7 | 2.2 | 8.6 | 21.6 | 11.9 | 0 | 8.4 | 0 | 9.3 | 15.9 | 3.7 | 11.7 | 15.8 | 18.8 | 2.3 | 4.5 | 1.3 | 0 | 0 | 17.7 | 5.1 | 6.3 |
| | August | 6.3 | 21.5 | 7.6 | 6.3 | 2.5 | 1.9 | 7.7 | 15.5 | 12.6 | 6.8 | 9.1 | 2.7 | 20 | 12.7 | 0.9 | 0 | 7.9 | 15.8 | 11.4 | 8.8 | 7.6 | 14.4 | 0 | 9.1 | 10.6 | 10 | 2.5 | 6.7 | 25.1 | 4.2 | 11.7 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | September | 1.6 | 9.4 | 3.9 | 0 | 3.9 | 2.2 | 0 | 1.1 | 4.3 | 3.2 | 5.3 | 4.7 | 4.7 | 0.7 | 10.7 | 0 | 3.4 | 6.3 | 1.9 | 7.8 | 4 | 9 | 4.5 | 12.5 | 7.6 | 6.4 | 1.9 | 0.6 | 0 | 7 | |
| | October | 7.7 | 0 | 16.5 | 20.4 | 0 | 0 | 4 | 9.3 | 13.3 | 4 | 6.6 | 14.1 | 2.8 | 0 | 0 | 3.5 | 4.3 | 10.4 | 0 | 0 | 1.1 | 0 | 7.9 | 25.3 | 6.7 | 21.7 | 1.4 | 0 | 20.3 | 9.8 | 8.4 |
| | November | 10.5 | 8.7 | 18.7 | 16.3 | 6 | 8.4 | 14.9 | 4.5 | 0 | 2.2 | 5.7 | 0 | 0 | 6 | 0 | 4.9 | 0.5 | 3.2 | 8.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.6 | 2.6 | 0 | |
| | December | 0 | 5.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.2 | 4.8 | 0 | 0 | 0 | 0 | 6.2 | 1.4 | 3.4 | 0 | 0 | 0 | 0 |
| 2009 | January | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.7 | 1.4 | 0 | 0 | 4.5 | 1.4 | 0 | 8.5 | 0.7 | 0 | 0 | 2.9 |
| | February | 8.5 | 13.2 | 0 | 4.7 | 0 | 7.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14.2 | 0 | 0 | 0 | 0.8 | 17.6 | 0 | 0 | 0 | 0 | 0 | | | |
| | March | 0 | 0 | 0 | 0 | 12.6 | 0 | 0 | 0 | 0 | 0 | 0 | 6.6 | 4.1 | 13.2 | 0 | 0 | 14.6 | 3.4 | 0 | 0 | 0 | 10.2 | 0 | 0 | 0 | 0 | 0 | 0 | 6.1 | 21.1 | 28.3 |
| | April | 22.1 | 16.4 | 11.5 | 0 | 2.5 | 2.3 | 7.6 | 0 | 0 | 6.8 | 0 | 15.9 | 6.1 | 6.1 | 15.2 | 3.8 | 2.3 | 4.6 | 0 | 10.7 | 1.3 | 10.8 | 5.1 | 0 | 7 | 0 | 5.5 | 16.6 | 0 | 25.2 | |
| | May | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 1.7 | 2.3 | 22 | 22.1 | 0 | 15.2 | 16.6 | 7.4 | 21.5 | 7.2 | 0 | 21.5 | 14.3 | 12.7 | 14.6 | 0 | 0 | 4.5 | 15.9 | 14 | 20.6 | 6.5 | 3.7 | 7.5 |
| | June | 0 | 5.5 | 0 | 0 | 8.3 | 4.4 | 4.4 | 2.9 | 0 | 0 | 0 | 0 | 0 | 11.5 | 11.5 | 0 | 15.9 | 6.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.8 | 0 | 28.5 | 8.5 | 5.7 | |
| | July | 3.4 | 10.3 | 0 | 0 | 0 | 0 | 0 | 0 | 13.1 | 0 | 0 | 0 | 0 | 1.6 | 17.4 | 16.3 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 8.1 | 7.2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | August | 0 | 0 | 0 | 14.7 | 7.3 | 0 | 0 | 11.6 | 0 | 0 | 0 | 0 | 16.6 | 5.5 | 20.3 | 9.1 | 8.2 | 6.4 | 7.3 | 6.4 | 8.1 | 10.1 | 0 | 0 | 0 | 0 | 1.3 | 6.6 | 0 | 9.3 | 0 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | September | 0 | 21 | 5.4 | 0 | 2.7 | 4.8 | 0 | 2.4 | 0.8 | 8 | 0 | 0 | 9.6 | 14.4 | 0 | 1.7 | 0.4 | 14.4 | 10.5 | 5.7 | 0 | 2.1 | 7.4 | 7.9 | 0 | 4.6 | 8.2 | 1 | 15.9 | 5.6 | |
| | October | 4 | 6.3 | 8 | 8 | 8 | 13.4 | 2.7 | 7.4 | 2 | 4 | 13.7 | 6.9 | 0 | 0 | 9.4 | 6.6 | 21.6 | 19 | 0 | 0 | 0 | 0 | 0 | 11.7 | 0 | 0.8 | 8.4 | 7.6 | 19 | 1.5 | 0 |
| | November | 0 | 0 | 0 | 0 | 11.4 | 4.8 | 5.5 | 0 | 0 | 1.4 | 0 | 2.6 | 7.8 | 0 | 0 | 14.4 | 0 | 0 | 1.1 | 0 | 0 | 0 | 0 | 0 | 0 | 2.8 | 0 | 9.1 | 6.3 | 0 | |
| | December | 0 | 2.3 | 4.5 | 0 | 0 | 0 | 0 | 0 | 3.6 | 13.1 | 18.4 | 9 | 0 | 0 | 1.7 | 4.5 | 4.5 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 5.1 | 8.5 | 8.6 | 10.3 | 11.7 | 7.4 | 0 | 7.4 |
| 2010 | January | 15 | 2 | 6.5 | 5 | 1 | 2.2 | 0 | 0 | 1.1 | 2.7 | 7.2 | 0 | 0 | 0 | 0 | 0 | 1.6 | 2.4 | 0 | 0.8 | 4.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | February | 0 | 0 | 0 | 6.7 | 13.3 | 9.7 | 15.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0.9 | 16.1 | 26.8 | 0 | 1.9 | 0 | 16.9 | 8.9 | 13.3 | 9.4 | 6.4 | 40.8 | 0 | 15 | 9 | | | |
| | March | 1 | 11.6 | 29.1 | 6.8 | 1.9 | 5.1 | 2.6 | 11.1 | 0 | 1.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14.3 | 0 | 5.6 | 13 | 20.4 | 1.9 | 8 | 12.9 | 5.3 | 0 | 2.9 | 16.4 | 2.9 |
| | April | 6.2 | 7.8 | 0 | 1.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14.7 | 22.4 | 13.3 | 19.6 | 0 | 14.9 | 3.5 | 4.3 | 2.8 | 4.8 | 10.2 | 12.6 | 1.2 | 0 | 9.4 | 0 | 1.3 | 2.7 | 2.7 | |
| | May | 3.2 | 0 | 0 | 1.6 | 8 | 9 | 18.5 | 9.5 | 6.3 | 0.5 | 12.5 | 4.8 | 6.2 | 8.7 | 8.7 | 14 | 5.8 | 0 | 7.4 | 4.1 | 0 | 9.9 | 6.3 | 10.8 | 5.4 | 14 | 0 | 1.2 | 7 | 7 | 0 |
| | June | 0 | 0 | 18.9 | 15.1 | 0 | 4.4 | 11.5 | 0 | 2.6 | 6.2 | 4.2 | 9.8 | 2.8 | 25.1 | 3.8 | 22.7 | 21.1 | 17.9 | 11.6 | 0 | 1.6 | 17.2 | 17.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | July | 2.5 | 12.5 | 32.5 | 2.5 | 0 | 0 | 0 | 11.2 | 0 | 0 | 5.7 | 10.3 | 0 | 8 | 11.5 | 3.2 | 0 | 0 | 0 | 6.4 | 2.5 | 10.7 | 3.3 | 0 | 16.4 | 5.1 | 5.1 | 18.3 | 0 | 19.3 | 30.5 |
| | August | 19.3 | 3 | 7.4 | 0 | 0 | 0 | 0 | 2.5 | 0 | 9.9 | 19.3 | 0 | 4.1 | 0 | 7.1 | 5.7 | 10 | 0 | 0 | 0 | 3.2 | 0 | 3.2 | 5.6 | 20.8 | 7.1 | 0 | 5.3 | 23 | 1.8 | 7.1 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | September | 4.9 | 0 | 7.4 | 4.9 | 0 | 10.8 | 1.3 | 0 | 4.7 | 7.4 | 12.7 | 7.3 | 8.5 | 3.6 | 9.7 | 5.8 | 5.3 | 5.8 | 2.4 | 0 | 10.6 | 2.4 | 6.3 | 5.3 | 0 | 0 | 8.5 | 4.3 | 0 | 0 | |
| | October | 0 | 0 | 0 | 0 | 16 | 7.2 | 9.1 | 2 | 11.1 | 3.3 | 0.8 | 10.6 | 11.8 | 7.6 | 21.2 | 0 | 5.1 | 13.4 | 22.3 | 17.2 | 4 | 8.6 | 13.7 | 5.7 | 5.1 | 9 | 13.1 | 3.3 | 0.8 | 2.5 | 0 |
| | November | 12.1 | 10.2 | 3.2 | 6.4 | 8.3 | 3 | 0 | 10.7 | 0 | 1.8 | 3 | 2 | 6.5 | 7.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.2 | 7.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | December | 10 | 0 | 0 | 0 | 0 | 5.4 | 2.6 | 5.4 | 6 | 4.9 | 7.5 | 3.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.3 | 0 | 0 | 7.4 | 7.7 | 8 | 4.6 | 4.9 | 1.8 | 2.2 | 0 |
| 2011 | January | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.7 | 3.1 | 4.5 | 0 | 0 | 0 | 0 | 0 | 8.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | February | 6.3 | 3.2 | 4.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | |
| | March | 0 | 0 | 0 | 0 | 0 | 0 | 14.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8.1 | 7.7 | 0 | 1.9 | 0 | 0 | 8.6 | 7.9 | 7.2 | 2.9 | 0 | 0 | 10.7 | 6.6 | 2.4 | 10.7 | 6 |
| | April | 9.5 | 0 | 0 | 0 | 0 | 0 | 13.8 | 6.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7.3 | 0 | 0 | 0 | 2.9 | 5.8 | 0.6 | 11.1 | 12.2 | 11.4 | 13.8 | 0 | 9.8 | 6.5 | |
| | May | 20.5 | 0 | 3.2 | 0 | 18.3 | 15.1 | 22.2 | 9.1 | 7.1 | 13.1 | 0 | 0 | 12.8 | 0 | 0 | 15.9 | 0 | 9.9 | 4.6 | 13.7 | 0 | 0 | 0 | 11.1 | 19.4 | 6.9 | 10.3 | 2.3 | 0 | 1.1 | 10.3 |
| | June | 16.6 | 12.2 | 11.1 | 13.3 | 0 | 2.2 | 3.7 | 9.6 | 11.1 | 26.6 | 9.3 | 14.6 | 23.3 | 16.6 | 4 | 11.3 | 6.3 | 0 | 2.5 | 15 | 0 | 0 | 10.6 | 16.6 | 12.1 | 16.7 | 32.5 | 11.4 | 8.8 | 7 | |
| | July | 28.5 | 41 | 9.1 | 5.7 | 0 | 9.7 | 5.5 | 0 | 5.5 | 9.7 | 0 | 0 | 14.3 | 6.5 | 5.2 | 7.5 | 0 | 0 | 4.3 | 12.8 | 10.7 | 11.5 | 1.5 | 9.2 | 14.5 | 0 | 25 | 10 | 30 | 8.5 | 15 |
| | August | 2.8 | 7.1 | 1.4 | 0 | 21.9 | 11.8 | 16.7 | 11.3 | 1.5 | 0 | 10.5 | 2.6 | 22.8 | 15.8 | 2.6 | 9.9 | 11.7 | 10.8 | 0 | 7.2 | 6.5 | 8.9 | 0.8 | 7.3 | 8.1 | 0.8 | 13.4 | 17.6 | 3.3 | 7.5 | 17.6 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | September | 14.1 | 4.4 | 3.1 | 6.9 | 13.2 | 9.8 | 13.8 | 14.9 | 12.1 | 6 | 9 | 6.6 | 1.2 | 15 | 12 | 4.2 | 11.9 | 0 | 7 | 0 | 0 | 0 | 4.7 | 14 | 9.8 | 0 | 8 | 11 | 14 | 10 | |
| | October | 13.3 | 1.2 | 2.3 | 4.6 | 11 | 5.6 | 16.6 | 4 | 0 | 4 | 6.8 | 6.8 | 21.2 | 15.1 | 3 | 0 | 2 | 22.5 | 10.2 | 2.7 | 0 | 4.1 | 11.5 | 3.4 | 0 | 4.3 | 10.1 | 3.6 | 10.8 | 10.1 | 12.2 |
| | November | 3.7 | 9.9 | 9.3 | 4.3 | 20.5 | 6.7 | 8.6 | 13.8 | 10.9 | 0 | 0 | 4.8 | 0 | 0 | 0 | 1.1 | 0 | 4.5 | 1.1 | 0 | 0.5 | 0 | 2.3 | 15.9 | 8 | 5.5 | 10.5 | 10.5 | 9.4 | 13.8 | |
| | December | 0 | 7.3 | 8.3 | 2.9 | 1 | 0 | 0 | 3.2 | 0 | 0 | 0 | 0 | 2.5 | 1.6 | 0 | 3.7 | 2.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2012 | January | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 6.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | February | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7.6 | 0.8 | 2.5 | 1.7 | | |
| | March | 1.9 | 0 | 11.5 | 0 | 3.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.9 | 27.2 |
| | April | 8.3 | 12.4 | 14.9 | 0 | 14.1 | 5.1 | 11.4 | 1.7 | 15.9 | 4.6 | 3.5 | 12.5 | 2.1 | 13.9 | 41 | 19 | 0 | 13.5 | 8.6 | 4.9 | 15.5 | 5.6 | 0 | 3.1 | 1.2 | 20.6 | 11.5 | 0 | 2.5 | 4.9 | |
| | May | 13.8 | 1.6 | 8.5 | 8.5 | 16.4 | 7.4 | 11.6 | 7.9 | 7.9 | 7.9 | 0 | 4 | 14.5 | 1 | 12 | 10.1 | 9.2 | 0.8 | 4.2 | 5 | 1.7 | 8.3 | 24.9 | 0 | 11.6 | 0 | 9.7 | 0 | 0 | 0 | 0 |
| | June | 0 | 10.9 | 9.7 | 17 | 0 | 2.2 | 5.8 | 15.9 | 25.9 | 14.4 | 5.5 | 9.1 | 0 | 0 | 3.6 | 0 | 0 | 19.4 | 0 | 12.9 | 15.3 | 9.8 | 25.1 | 0 | 0 | 5 | 5 | 13 | 9 | 5 | |
| | July | 13.3 | 10.7 | 9.3 | 0 | 6.7 | 0 | 9.8 | 0 | 17.2 | 15.3 | 6.3 | 0 | 0 | 0 | 0 | 12.6 | 5.2 | 16.6 | 14 | 0.9 | 14.9 | 0 | 18.2 | 15 | 4.8 | 0.8 | 0 | 13.4 | 7.2 | 15.5 | 15.5 | 18.5 |
| | August | 19.5 | 12.2 | 0 | 17 | 2.4 | 0 | 1.1 | 9.9 | 18.6 | 0 | 3.9 | 21.2 | 3.9 | 6.8 | 0 | 0 | 1 | 3.9 | 14.4 | 11.6 | 0 | 6.9 | 8.5 | 4.6 | 18.5 | 0 | 15.8 | 8.8 | 7.5 | 8.8 | 4.4 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | September | 8.9 | 19.1 | 3.2 | 0 | 7.6 | 0 | 6.6 | 10.8 | 10.2 | 12.6 | 5.2 | 9.2 | 12.7 | 23.1 | 8.7 | 2.1 | 4.8 | 1.1 | 6.9 | 0 | 2 | 6 | 3 | 9.4 | 1 | 11.6 | 3.2 | 6.8 | 4.7 | 4.7 | |
| | October | 3.2 | 6.4 | 0 | 0 | 0 | 0 | 2.3 | 0 | 0 | 16.9 | 0 | 24.9 | 0 | 9.6 | 4 | 0 | 0 | 0 | 0 | 0 | 11.2 | 0 | 0 | 0 | 0 | 9.5 | 18.3 | 0.7 | 0 | 15.4 | 1.5 |
| | November | 7 | 5.1 | 12 | 14.5 | 3.8 | 2 | 11.3 | 6.4 | 12.7 | 0 | 0 | 0 | 6.2 | 2.5 | 2.5 | 9.4 | 4.7 | 0 | 4.7 | 0 | 0 | 7.7 | 1.7 | 1.7 | 3.9 | 0 | 7.8 | 14.3 | 0 | 0 | |
| | December | 0 | 0 | 0 | 0 | 13.3 | 4.5 | 4.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.3 | 0 | 0 | 0 | 0 | 0 | 0 | 2.9 | 2.3 | 0 | 0.3 | 0.7 | 7.7 | 0 | 5.4 | 0 |
| 2013 | January | 0 | 2.8 | 4.2 | 0 | 0 | 0 | 0 | 6.6 | 0 | 3.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.4 | 0.4 | 7 | 0.4 |
| | February | 18.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.3 | 6.6 | 0 | 0 | 0 | 0 | 0 | 0 | 8.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | |
| | March | 0 | 0 | 0 | 0 | 0 | 0 | 9.8 | 11.1 | 12.5 | 10.5 | 2.3 | 6.2 | 10.1 | 9.3 | 0 | 0 | 1.5 | 7.4 | 14.8 | 0 | 15.8 | 0.6 | 9.5 | 16.4 | 0.6 | 19.4 | 15.6 | 14.5 | 1.6 | 8.1 | 13.5 |
| | April | 0 | 13.5 | 11.7 | 10.8 | 0 | 19 | 10.6 | 7.4 | 16.4 | 11.1 | 12 | 6.4 | 10.4 | 2.4 | 4 | 0.7 | 0 | 1.4 | 2.1 | 22.9 | 0 | 9.1 | 2.8 | 0 | 7 | 10.4 | 14.4 | 0 | 11.2 | 8 | |
| | May | 9.5 | 6.1 | 3.9 | 0.6 | 13.9 | 14.3 | 10.1 | 8.5 | 7.9 | 1.6 | 5.7 | 7 | 0 | 1.3 | 0 | 0 | 0 | 4.8 | 4.8 | 0 | 0 | 0 | 0 | 0 | 18.7 | 13.2 | 9.6 | 4.8 | 0 | 0 | 0 |
| | June | 9.7 | 0 | 0 | 0 | 3.2 | 0 | 0 | 0 | 13.2 | 11.5 | 2.9 | 7.9 | 15.1 | 8.6 | 4.3 | 19.4 | 35.5 | 1.1 | 6.5 | 2.2 | 0 | 0 | 0 | 0 | 0 | 0 | 5.6 | 0 | 5.6 | 0 | |
| | July | 0 | 1.5 | 16.7 | 9.1 | 1.5 | 0 | 0 | 0 | 0 | 0 | 10.1 | 0 | 0 | 17.6 | 0 | 0 | 1.7 | 21.8 | 16.5 | 13.1 | 0 | 6.7 | 5.7 | 8.6 | 0 | 0 | 1 | 25.4 | 44.1 | 0 | 8.1 |
| | August | 16.1 | 0 | 0 | 0 | 14.6 | 6.5 | 14.8 | 9.3 | 10.2 | 13.9 | 12.9 | 0 | 0 | 9.9 | 9.9 | 12.6 | 12.6 | 0.9 | 5.4 | 7.2 | 12.8 | 5.6 | 5.6 | 8.8 | 0 | 0 | 0 | 0 | 0 | 4.8 | 9.6 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | September | 11 | 4.5 | 7.8 | 7.8 | 4.5 | 1.3 | 3.3 | 9.4 | 4.7 | 6 | 3.9 | 16.2 | 0.6 | 6.5 | 1.9 | 3.6 | 9.9 | 4.5 | 4.1 | 4.5 | 0.9 | 0.9 | 6.8 | 14 | 13.5 | 11.2 | 12.2 | 5.8 | 0 | 0 | |
| | October | 0 | 10.5 | 8.8 | 4.1 | 7.6 | 3 | 16.3 | 4.8 | 22.4 | 4.8 | 22.7 | 7.6 | 11.3 | 2.3 | 9.1 | 6.3 | 9.4 | 0 | 0 | 7.1 | 1.8 | 10.2 | 0 | 5.4 | 12 | 9.4 | 13 | 0 | 23.1 | 4.3 | 0 |
| | November | 0 | 0 | 0 | 0 | 0 | 3.4 | 1.7 | 0 | 5.6 | 7.8 | 3.5 | 2.6 | 5.6 | 10.4 | 18.6 | 0 | 0 | 8.7 | 7.6 | 0 | 0 | 8.9 | 7.5 | 9.9 | 0 | 4.1 | 0 | 0 | 0 | 6.2 | |
| | December | 0 | 0 | 0 | 0 | 0 | 5.5 | 0 | 0 | 2.3 | 0 | 7.5 | 0 | 1.8 | 1.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.7 | 6.1 | 6.8 |
| 2014 | January | 12.2 | 3.1 | 0 | 0 | 0 | 0 | 3.9 | 2.1 | 2.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.9 | 0.8 | 5.4 | 0 | 3.6 | 3.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | February | 0 | 0 | 0 | 0 | 16.8 | 9.5 | 0 | 0 | 1.4 | 0 | 0 | 7.9 | 0 | 0 | 0 | 0 | 0 | 0 | 14.2 | 16.3 | 2.9 | 6.4 | 0 | 13.2 | 0.7 | 0 | 0 | 0 | | | |
| | March | 0 | 0 | 0 | 0 | 0 | 0 | 8.4 | 0 | 0 | 0 | 6.4 | 1.4 | 17.2 | 6.4 | 5 | 13.3 | 0 | 0 | 0 | 0 | 0 | 0.6 | 27.3 | 13.3 | 0.6 | 0 | 0 | 3.4 | 2.3 | 5.7 | 0 |
| | April | 2.8 | 0.9 | 6.5 | 15.7 | 7.4 | 14.4 | 2.3 | 0 | 0 | 0 | 0 | 10.6 | 10.2 | 3.4 | 5.1 | 0 | 0 | 0 | 0 | 8.3 | 6.9 | 6.2 | 4.8 | 1.4 | 0 | 6 | 0 | 8 | 0 | 10 | |
| | May | 9.4 | 0.6 | 4.4 | 2.8 | 18.3 | 17 | 10.8 | 9.2 | 9.5 | 8.2 | 14.6 | 6.8 | 5.8 | 1.9 | 8 | 0 | 8.4 | 5 | 15.9 | 0 | 7.8 | 9.5 | 14.7 | 6.1 | 0 | 7.5 | 7.5 | 11.7 | 0 | 6.4 | 4.3 |
| | June | 2.5 | 12.3 | 8.6 | 11.1 | 1.2 | 0 | 0 | 0 | 3.1 | 14.5 | 4.5 | 5.6 | 3.3 | 0 | 0 | 0 | 0 | 3.8 | 10.1 | 20.2 | 16.7 | 6.3 | 0 | 0 | 0 | 0 | 0 | 2.6 | 18 | 0 | |
| | July | 0 | 14.8 | 0 | 0 | 0 | 0 | 17.3 | 0 | 0 | 3.5 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 12.5 | 20.8 | 5.4 | 11.2 | 7.7 | 0 | 9.2 | 19.6 | 10.4 | 1.2 | 0 | 0 |
| | August | 1.6 | 0 | 0 | 19.4 | 4.9 | 9.5 | 23.8 | 0 | 5.7 | 9 | 2.4 | 4.8 | 8.4 | 0 | 6 | 1.9 | 13.2 | 4.7 | 7.5 | 5.7 | 13.9 | 2.5 | 0 | 4.1 | 9.8 | 4.1 | 12.3 | 4.9 | 20.5 | 9.8 | 17.2 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | September | 8 | 19.1 | 0.9 | 8.6 | 11.7 | 9.3 | 0 | 2.5 | 2.5 | 0 | 5.9 | 0 | 0 | 11.1 | 2.2 | 0 | 4.7 | 0 | 7.5 | 10.3 | 4.1 | 5 | 10.9 | 6.8 | 6.8 | 1.8 | 0 | 6.7 | 4.3 | 4.9 | |
| | October | 0 | 4.2 | 0 | 7.8 | 4.9 | 5.2 | 5.8 | 9 | 13.5 | 1.3 | 0.8 | 4 | 5.5 | 7.9 | 23 | 6.5 | 2.6 | 0 | 13.8 | 24.9 | 13.9 | 0 | 4.2 | 4.8 | 5.4 | 3.7 | 1.8 | 0 | 0.9 | 0 | 14.7 |
| | November | 0 | 17.8 | 2.2 | 2.2 | 0 | 5.6 | 9.3 | 0 | 7.1 | 5.6 | 8.8 | 0.5 | 1.1 | 4.8 | 0 | 12.4 | 2.4 | 1.4 | 1.9 | 8.8 | 3.1 | 4 | 10.6 | 11.9 | 9.7 | 5.5 | 0 | 3.1 | 6.8 | 11.7 | |
| | December | 11.4 | 6.5 | 5.5 | 0 | 0 | 0 | 0 | 1.2 | 3.1 | 3.5 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 8.1 | 0.8 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2015 | January | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | February | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15.8 | 0 | 4.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.9 | 2.4 | 0 | | | |
| | March | 0 | 0 | 0 | 5.7 | 8.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8.7 | 14 | 11.3 | 9.2 | 0 | 10.9 | 8 | 6.9 | 9.2 |
| | April | 1.5 | 15.8 | 50.2 | 9.1 | 13.6 | 10.7 | 1.3 | 13.8 | 0 | 0 | 0 | 0.8 | 0 | 0 | 31 | 6.9 | 4.6 | 4.6 | 1.5 | 3.8 | 20.5 | 5.9 | 18 | 3.8 | 1.6 | 18.6 | 1.6 | 0 | 2.8 | 19 | |
| | May | 13.3 | 5.8 | 7.2 | 3.3 | 5 | 23.9 | 0 | 7.7 | 1.6 | 8 | 9.3 | 2.2 | 0 | 0 | 0 | 13.8 | 0 | 8.4 | 13.8 | 6.1 | 10.4 | 0 | 0 | 0 | 0 | 1.1 | 5.7 | 1.1 | 8.6 | 11.5 | 2.3 |
| | June | 11.1 | 0 | 19.6 | 21.7 | 14.8 | 3 | 0 | 11.9 | 3 | 1 | 0 | 8.3 | 6.3 | 7.9 | 3.9 | 23.2 | 21.1 | 13.2 | 8.4 | 7.4 | 6.6 | 0 | 0 | 0 | 25.6 | 12.9 | 3.4 | 0 | 6.2 | 4.5 | |
| | July | 15.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16.9 | 8.9 | 4 | 5.8 | 2.9 | 5.8 | 6.2 | 11.6 | 19.3 | 4.6 | 12.5 | 0 | 5.7 | 0 |
| | August | 18.2 | 23.7 | 0 | 0 | 9.7 | 5.5 | 4.1 | 0 | 7.5 | 2.7 | 0 | 0 | 9.9 | 0 | 0 | 7.7 | 13.4 | 4.6 | 0 | 0 | 10.8 | 13.2 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 22.4 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | September | 7.6 | 15.8 | 0 | 3.4 | 0.7 | 13.2 | 0 | 8.8 | 1.4 | 0.7 | 0 | 0 | 11.5 | 13.5 | 0 | 0 | 0 | 10.5 | 3.7 | 3.5 | 2.7 | 4.6 | 2.2 | 0 | 7 | 5.9 | 3.9 | 0 | 0 | 5.2 | |
| | October | 12.2 | 2.3 | 0 | 0 | 0 | 0 | 0 | 0 | 4.6 | 14.6 | 27 | 0 | 22.1 | 7.5 | 0 | 17.3 | 6.4 | 10.6 | 9.9 | 11.2 | 10.4 | 9.6 | 4.9 | 4.1 | 4.9 | 5.4 | 10.4 | 21.7 | 33.8 | 13.7 | 13 |
| | November | 5.9 | 1.2 | 9.1 | 27.5 | 2.2 | 0 | 5.5 | 6.6 | 3.2 | 7.1 | 11 | 5.5 | 0 | 0 | 5.3 | 14.8 | 0 | 14.8 | 4.5 | 1.4 | 8.3 | 1.7 | 0 | 0 | 0 | 17 | 4.6 | 2.8 | 1.9 | 0 | |
| | December | 8.3 | 5.9 | 0 | 9 | 7.3 | 0 | 6 | 0 | 0 | 0 | 0 | 7.2 | 1 | 0 | 0 | 0 | 1.2 | 4.8 | 1.2 | 0 | 0 | 0 | 0 | 0 | 0 | 1.6 | 7.3 | 0 | 0 | 0 | 0 |
| 2016 | January | 0 | 0 | 0 | 6.6 | 0 | 0 | 0.7 | 1.6 | 1.2 | 9.1 | 2.7 | 3.8 | 5.4 | 3 | 5.4 | 0 | 8.5 | 0 | 6.6 | 3.9 | 2.6 | 1.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | February | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7.1 | 0 | 0 | | |
| | March | 0 | 16.8 | 0 | 0 | 0 | 0 | 3.2 | 20 | 9.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10.7 | 5.1 | 0 | 0 | 0 | 8.6 | 7.1 | 5.9 | 0 | 0 | 0 | 0 | 0.6 | 12.7 | 17.7 |
| | April | 28.6 | 0 | 16.4 | 23.1 | 0 | 6.4 | 18.4 | 5 | 3.1 | 10.3 | 13.2 | 7.5 | 14.3 | 0 | 9.4 | 15.4 | 7.4 | 2.7 | 3.7 | 1.7 | 5 | 3.6 | 4.2 | 12.8 | 15.8 | 20.2 | 7.3 | 2.8 | 2.8 | 9.3 | |
| | May | 0 | 5 | 17.5 | 13.8 | 11.9 | 7.6 | 0 | 0 | 0.7 | 7.3 | 11.7 | 12.7 | 5.5 | 5 | 7.7 | 0 | 7.7 | 6 | 0 | 13.7 | 3 | 9 | 0 | 0 | 2.2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | June | 8.9 | 0 | 0 | 3.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5.6 | 6.3 | 0 | 4.4 | 0 | 15 | 0 | 4.8 | 0 | 23.8 | 0 | 26.5 | 11.1 | 0 | 0 | 0 | 0 | |
| | July | 13.3 | 0 | 0 | 0 | 0 | 0 | 3.5 | 0 | 3.5 | 13.2 | 11.5 | 0 | 0 | 0 | 0 | 0 | 9.2 | 4.3 | 6.3 | 13 | 6.8 | 1 | 5.4 | 0 | 6.8 | 12.5 | 6 | 11.3 | 0 | 6 | 0 |
| | August | 0 | 20.4 | 3.6 | 19.8 | 10.2 | 16.4 | 23.7 | 0 | 2.9 | 1.9 | 7 | 4 | 15.4 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 3.5 | 5.9 | 9.4 | 0 | 0 | 0 | 11.4 | 0 | 0 | 0 | 0 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | September | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12.6 | 0 | 0 | 0 | 5.1 | 8.3 | 7.2 | 0 | 5.9 | 4.7 | 6.4 | 1.7 | 1.8 | 2.5 | 0.8 | 7.3 | 8 | 9.9 | 10.2 | 12.4 | 1.3 | 4.3 | |
| | October | 4.3 | 16.7 | 12.4 | 9.7 | 9.2 | 0 | 8 | 0 | 0 | 0 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.1 | 3.3 | 5.9 | 7.2 | 5.2 | 0 | 15.2 | 10.6 | 12.1 | 0 | 0 | 0 |
| | November | 3.8 | 7 | 16.5 | 12.7 | 1.3 | 6.9 | 5.2 | 3.4 | 0 | 1.7 | 0 | 0 | 0 | 0 | 0 | 10.3 | 4.4 | 1.5 | 7.3 | 0 | 0 | 0 | 4.7 | 13.6 | 8.4 | 0 | 7.3 | 9.1 | 11.6 | 0 | |
| | December | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2017 | January | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 109.22 | 0 | 0 |
| | February | 312.42 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 99.06 | 322.58 | 223.52 | 373.38 | 327.66 | 132.08 | 0 | 279.4 | 66.04 | 0 | 215.9 | 0 | | | |
| | March | 0 | 0 | 431.8 | 144.78 | 0 | 182.88 | 0 | 0 | 294.64 | 0 | 0 | 0 | 0 | 0 | 508 | 596.9 | 53.34 | 35.56 | 17.78 | 35.56 | 187.96 | 40.64 | 0 | 0 | 271.78 | 106.68 | 299.72 | 157.48 | 0 | 0 | 0 |
| | April | 0 | 0 | 0 | 0 | 640.08 | 213.36 | 363.22 | 15.24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 515.62 | 439.42 | 198.12 | 30.48 | 198.12 | 91.44 | 30.48 | 368.3 | 0 | 215.9 | 0 | 474.98 | 673.1 | 0 | 119.38 | |
| | May | 124.46 | 383.54 | 398.78 | 149.86 | 0 | 365.76 | 243.84 | 190.5 | 0 | 215.9 | 0 | 0 | 170.18 | 152.4 | 0 | 101.6 | 226.06 | 182.88 | 182.88 | 162.56 | 332.74 | 0 | 0 | 0 | 0 | 243.84 | 0 | 0 | 121.92 | 213.36 | 121.92 |
| | June | 66.0 | 302. | 0 | 0 | 401. | 101. | 127 | 0 | 251. | 0 | 0 | 0 | 0 | 0 | 264. | 0 | 0 | 187. | 281. | 0 | 274. | 353. | 314. | 0 | 0 | 256. | 0 | 256. | 332. | 76.2 | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 4 | 26 | | | 32 | 6 | | | 46 | | | | | | 16 | | | 96 | 94 | | 32 | 06 | 96 | | | 54 | | 54 | 74 | | |
| | July | 43.18 | 642.62 | 210.82 | 1216.66 | 782.32 | 314.96 | 66.04 | 429.26 | 83.82 | 0 | 0 | 271.78 | 0 | 980.44 | 309.88 | 314.96 | 292.1 | 68.58 | 393.7 | 147.32 | 58.42 | 510.54 | 99.06 | 294.64 | 157.48 | 142.24 | 99.06 | 480.06 | 210.82 | 154.94 | 83.82 |
| | August | 0 | 208.28 | 0 | 0 | 167.64 | 27.94 | 68.58 | 431.8 | 147.32 | 147.32 | 180.34 | 114.3 | 139.7 | 243.84 | 114.3 | 0 | 180.34 | 215.9 | 0 | 0 | 88.9 | 0 | 243.84 | 187.96 | 111.76 | 335.28 | 124.46 | 292.1 | 220.98 | 0 | 721.36 |
| | September | 345.44 | 160.02 | 149.86 | 0 | 0 | 419.1 | 160.02 | 0 | 228.6 | 220.98 | 175.26 | 66.04 | 340.36 | 124.46 | 0 | 91.44 | 236.22 | 35.56 | 109.22 | 180.34 | 208.28 | 132.08 | 106.68 | 248.92 | 17.78 | 0 | 111.76 | 0 | 347.98 | 388.62 | |
| | October | 213.36 | 231.14 | 0 | 0 | 0 | 35.56 | 0 | 0 | 71.12 | 246.38 | 459.74 | 137.16 | 157.48 | 391.16 | 68.58 | 17.78 | 441.96 | 594.36 | 0 | 0 | 165.1 | 119.38 | 76.2 | 15.24 | 391.16 | 195.58 | 332.74 | 0 | 78.74 | 254 | 38.1 |
| | November | 0 | 167.64 | 855.98 | 518.16 | 30.48 | 76.2 | 261.62 | 50.8 | 411.48 | 0 | 0 | 137.16 | 0 | 0 | 0 | 0 | 167.64 | 22.86 | 0 | 0 | 0 | 0 | 0 | 246.38 | 101.6 | 0 | 0 | 0 | 0 | 312.42 | |
| | December | 0 | 0 | 0 | 0 | 203.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 93.98 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2018 | January | 0 | 157.48 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 101.6 | 0 | 0 | 0 | 0 | 0 |
| | February | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 248.92 | 373.38 | 299.72 | 0 | 180.34 | 0 | 0 | 0 | 33.02 | 198.12 | | | |
| | March | 398.78 | 0 | 0 | 167.64 | 66.04 | 0 | 0 | 0 | 0 | 309.88 | 320.04 | 71.12 | 160.02 | 17.78 | 444.5 | 83.82 | 83.82 | 474.98 | 101.6 | 83.82 | 0 | 0 | 50.8 | 25.4 | 304.8 | 0 | 0 | 0 | 162.56 | 53.34 | 0 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | April | 231.14 | 231.14 | 441.96 | 358.14 | 0 | 193.04 | 741.68 | 165.1 | 0 | 246.38 | 447.04 | 71.12 | 482.6 | 0 | 695.96 | 185.42 | 0 | 111.76 | 149.86 | 149.86 | 162.56 | 205.74 | 132.08 | 325.12 | 0 | 241.3 | 381 | 200.66 | 381 | 0 | |
| | May | 200.66 | 15.24 | 243.84 | 129.54 | 215.9 | 515.62 | 215.9 | 271.78 | 0 | 27.94 | 55.88 | 40.64 | 0 | 347.98 | 83.82 | 165.1 | 292.1 | 281.94 | 538.48 | 309.88 | 731.52 | 40.64 | 0 | 0 | 439.42 | 0 | 238.76 | 612.14 | 53.34 | 25.4 | 78.74 |
| | June | 137.16 | 220.98 | 332.74 | 248.92 | 525.78 | 0 | 467.36 | 45.72 | 0 | 45.72 | 93.98 | 0 | 0 | 0 | 353.06 | 464.82 | 33.02 | 266.7 | 33.02 | 0 | 0 | 269.24 | 0 | 403.86 | 906.78 | 411.48 | 482.6 | 205.74 | 137.16 | 342.9 | |
| | July | 871.22 | 528.32 | 0 | 0 | 0 | 104.14 | 0 | 104.14 | 276.86 | 312.42 | 0 | 335.28 | 0 | 0 | 302.26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 279.4 | 238.76 | 0 |
| | August | 0 | 0 | 0 | 0 | 0 | 0 | 340.36 | 0 | 114.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 185.42 | 449.58 | 665.48 | 144.78 | 558.8 | 269.24 | 0 | 500.38 | 347.98 | 0 | 109.22 | 238.76 | 129.54 |
| | September | 0 | 185.42 | 302.26 | 116.84 | 200.66 | 0 | 0 | 0 | 236.22 | 0 | 78.74 | 642.62 | 203.2 | 0 | 15.24 | 45.72 | 73.66 | 0 | 134.62 | 45.72 | 0 | 0 | 129.54 | 0 | 0 | 116.84 | 91.44 | 0 | 477.52 | 271.78 | |
| | October | 167.64 | 287.02 | 0 | 50.8 | 0 | 0 | 53.34 | 53.34 | 190.5 | 383.54 | 96.52 | 355.6 | 172.72 | 452.12 | 269.24 | 259.08 | 370.84 | 386.08 | 530.86 | 0 | 0 | 0 | 0 | 0 | 0 | 218.44 | 91.44 | 398.78 | 345.44 | 144.78 | 144.78 |
| | November | 236.22 | 383.54 | 104.14 | 0 | 0 | 40.64 | 0 | 25.4 | 223.52 | 335.28 | 152.4 | 0 | 101.6 | 0 | 0 | 15.24 | 0 | 45.72 | 284.48 | 0 | 119.38 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | December | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 132.08 | 111.76 | 261.62 | 228.6 | 38.1 | 0 | 0 | 205.74 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 45.72 | 0 | 15.24 | 73.66 | 0 |
| 20 | January | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 205. | 0 | 0 | 10.1 | 0 | 0 | 0 | 60.9 | 76.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| 19 | y | | | | | | | | | | | | | | | | 74 | | | 6 | | | | 6 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Februa ry | 0 | 0 | 0 | 0 | 0 | 0 | 210. 82 | 0 | 0 | 0 | 0 | 462. 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 269. 24 | 0 | 0 | 93.9 8 | 142. 24 | 0 | 0 | 0 | 0 | | | |
| | March | 0 | 60.9 6 | 88.9 | 449.5 8 | 149. 86 | 91.4 4 | 215. 9 | 30.4 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 279. 4 | 129. 54 | 0 | 0 | 93.9 8 | 0 |
| | April | 0 | 27.9 4 | 0 | 568.9 6 | 0 | 0 | 0 | 0 | 259. 08 | 139. 7 | 0 | 0 | 33.0 2 | 0 | 358. 14 | 0 | 358. 14 | 0 | 0 | 0 | 627. 38 | 454. 66 | 81.2 8 | 307. 34 | 81.2 8 | 375. 92 | 355. 6 | 63.5 | 208. 28 | 0 | |
| | May | 0 | 60.9 6 | 297. 18 | 259.0 8 | 15.2 4 | 0 | 276. 86 | 248. 92 | 134. 62 | 99.0 6 | 500. 38 | 213. 36 | 99.0 6 | 73.6 6 | 0 | 142. 24 | 0 | 383. 54 | 142. 24 | 241. 3 | 269. 24 | 248. 92 | 269. 24 | 248. 92 | 269. 24 | | 320. 04 | 0 | 63.5 | 0 | 190. 5 |
| | June | 27.9 4 | 553. 72 | 193. 04 | 665.4 8 | 0 | 269. 24 | 25.4 | 0 | 218. 44 | 0 | 0 | 0 | 0 | 0 | 0 | 297. 18 | 149. 86 | 0 | 0 | 0 | 0 | 160. 02 | 53.3 4 | 106. 68 | 266. 7 | 175. 26 | 99.0 6 | 200. 66 | 350. 52 | 175. 26 | |
| | July | 0 | 167. 64 | 167. 64 | 294.6 4 | 0 | 0 | 149. 86 | 0 | 688. 34 | 419. 1 | 302. 26 | 91.4 4 | 271. 78 | 0 | 149. 86 | 0 | 452. 12 | 0 | 0 | 0 | 373. 38 | 22.8 6 | 185. 42 | 0 | 0 | 403. 86 | 939. 8 | 0 | 0 | 134. 62 | 27.9 4 |
| | August | 497. 84 | 0 | 106. 68 | 0 | 248. 92 | 129. 54 | 271. 78 | 467. 36 | 50.8 | 0 | 22.8 6 | 154. 94 | 287. 02 | 548. 64 | 0 | 0 | 0 | 332. 74 | 76.2 | 91.4 4 | 22.8 6 | 137. 16 | 0 | 231. 14 | 182. 88 | 195. 58 | 314. 96 | 22.8 6 | 238. 76 | 388. 62 | 195. 58 |
| | Septe mber | 0 | 241. 3 | 73.6 6 | 55.88 | 203. 2 | 165. 1 | 213. 36 | 0 | 165. 1 | 180. 34 | 220. 98 | 99.0 6 | 48.2 6 | 187. 96 | 187. 96 | 0 | 15.2 4 | 236. 22 | 58.4 2 | 0 | 0 | 106. 68 | 73.6 6 | 0 | 99.0 6 | 205. 74 | 81.2 8 | 172. 72 | 81.2 8 | 246. 38 | |
| | Octobe r | 142. 24 | 292. 1 | 0 | 284.4 8 | 312. 42 | 198. 12 | 226. 06 | 106. 68 | 271. 78 | 650. 24 | 444. 5 | 556. 26 | 370. 84 | 241. 3 | 129. 54 | 165. 1 | 701. 04 | 58.4 2 | 165. 1 | 182. 88 | 172. 72 | 363. 22 | 78.7 4 | 0 | 22.8 6 | 0 | 160. 02 | 60.9 6 | 160. 02 | 198. 12 | 259. 08 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | November | 670.56 | 137.16 | 426.72 | 274.32 | 76.2 | 546.1 | 73.66 | 279.4 | 0 | 60.96 | 381 | 518.16 | 76.2 | 0 | 0 | 99.06 | 20.32 | 0 | 0 | 109.22 | 205.74 | 581.66 | 170.18 | 121.92 | 33.02 | 208.28 | 0 | 0 | 83.82 | 251.46 | |
| | December | 439.42 | 40.64 | 0 | 0 | 0 | 48.26 | 104.14 | 86.36 | 86.36 | 40.64 | 0 | 0 | 99.06 | 0 | 0 | 0 | 254 | 0 | 0 | 0 | 7.62 | 45.72 | 91.44 | 53.34 | 388.62 | 101.6 | 38.1 | 38.1 | 38.1 | 20.32 | 0 |
| 2020 | January | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 111.76 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 190.5 | 83.82 | 406.4 | 314.96 | 96.52 | 76.2 | 0 |
| | February | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 210.82 | 0 | 0 | 88.9 | 0 | 0 | 281.94 | 185.42 | 205.74 | | |
| | March | 657.86 | 0 | 76.2 | 419.1 | 0 | 147.32 | 0 | 383.54 | 17.78 | 218.44 | 271.78 | 0 | 139.7 | 0 | 665.48 | 0 | 0 | 375.92 | 226.06 | 0 | 0 | 0 | 0 | 325.12 | 510.54 | 0 | 177.8 | 111.76 | 88.9 | 0 | 0 |
| | April | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 266.7 | 0 | 408.94 | 551.18 | 657.86 | 106.68 | 632.46 | 190.5 | 157.48 | 78.74 | 0 | 0 | 154.94 | 45.72 | 63.5 | 406.4 | 248.92 | 165.1 | 320.04 | 40.64 | 279.4 | |
| | May | 203.2 | 236.22 | 167.64 | 180.34 | 167.64 | 142.24 | 142.24 | 86.36 | 373.38 | 0 | 38.1 | 0 | 132.08 | 0 | 111.76 | 238.76 | 22.86 | 144.78 | 144.78 | 0 | 279.4 | 228.6 | 127 | 0 | 0 | 0 | 119.38 | 314.96 | 40.64 | 0 | 0 |
| | June | 0 | 0 | 0 | 0 | 652.78 | 0 | 83.82 | 83.82 | 226.06 | 0 | 0 | 0 | 0 | 88.9 | 421.64 | 0 | 0 | 0 | 58.42 | 342.9 | 0 | 0 | 0 | 304.8 | 304.8 | 391.16 | 129.54 | 104.14 | 236.22 | 0 | |
| | July | 0 | 0 | 340.36 | 226.06 | 0 | 190.5 | 558.8 | 543.56 | 271.78 | 652.78 | 312.42 | 0 | 25.4 | 312.42 | 807.72 | 508 | 553.72 | 0 | 0 | 0 | 149.86 | 43.18 | 0 | 0 | 584.2 | 0 | 208.28 | 0 | 177.8 | 254 | 312.42 |
| | August | 0 | 210. | 0 | 0 | 421. | 248. | 408. | 421. | 0 | 0 | 213. | 256. | 213. | 662. | 469. | 515. | 172. | 160. | 203. | 289. | 0 | 223. | 93.9 | 48.2 | 177. | 134. | 88.9 | 236. | 180. | 203. | 269. |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 82 | | | 64 | 92 | 94 | 64 | | | 36 | 54 | 36 | 94 | 9 | 62 | 72 | 02 | 2 | 56 | | 52 | 8 | 6 | 8 | 62 | | 22 | 34 | 2 | 24 |
| | Septe mber | 203. 2 | 172. 72 | 0 | 81.28 | 0 | 353. 06 | 0 | 96.5 2 | 0 | 114. 3 | 0 | 86.3 6 | 0 | 127 | 170. 18 | 0 | 104. 14 | 0 | 91.4 4 | 220. 98 | 106. 68 | 142. 24 | 76.2 | 165. 1 | 271. 78 | 187. 96 | 106. 68 | 266. 7 | 0 | 220. 98 | |
| | Octobe r | 27.9 4 | 254 | 27.9 4 | 137.1 6 | 462. 28 | 0 | 55.8 8 | 0 | 350. 52 | 165. 1 | 0 | 215. 9 | 236. 22 | 647. 7 | 78.7 4 | 0 | 0 | 81.2 8 | 0 | 467. 36 | 38.1 | 137. 16 | 137. 16 | 137. 16 | 289. 56 | 0 | 416. 56 | 294. 64 | 797. 56 | 485. 14 | 0 |
| | Novem ber | 0 | 40.6 4 | 0 | 60.96 | 365. 76 | 340. 36 | 203. 2 | 177. 8 | 0 | 38.1 | 109. 22 | 0 | 25.4 | 139. 7 | 279. 4 | 63.5 | 388. 62 | 38.1 | 25.4 | 63.5 | 0 | 106. 68 | 0 | 269. 24 | 40.6 4 | 292. 1 | 292. 1 | 480. 06 | 243. 84 | 0 | |
| | Decem ber | 0 | 66.0 4 | 381 | 66.04 | 0 | 0 | 0 | 172. 72 | 0 | 0 | 132. 08 | 0 | 0 | 0 | 0 | 0 | 0 | 180. 34 | 0 | 0 | 0 | 78.7 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 134. 62 |
| 20 21 | Januar y | 330. 2 | 15.2 4 | 0 | 0 | 0 | 0 | 0 | 0 | 297. 18 | 30.4 8 | 38.1 | 25.4 | 63.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 104. 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Februa ry | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 495. 3 | 15.2 4 | 330. 2 | 281. 94 | 236. 22 | 203. 2 | 462. 28 | 0 | 462. 28 | 0 | 0 | 0 | 104. 14 | 185. 42 | 124. 46 | 40.6 4 | 0 | 0 | 0 | | | |
| | March | 0 | 0 | 0 | 457.2 | 0 | 0 | 0 | 292. 1 | 58.4 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 190. 5 | 0 | 213. 36 | 0 | 48.2 6 | 342. 9 | 0 | 0 | 0 | 182. 88 | 134. 62 | 0 | 398. 78 | 0 | 33.0 2 |
| | April | 66.0 4 | 220. 98 | 0 | 398.7 8 | 332. 74 | 182. 88 | 0 | 271. 78 | 332. 74 | 0 | 474. 98 | 548. 64 | 147. 32 | 0 | 274. 32 | 424. 18 | 213. 36 | 198. 12 | 30.4 8 | 485. 14 | 388. 62 | 335. 28 | 200. 66 | 373. 38 | 226. 06 | 20.3 2 | 76.2 | 441. 96 | 632. 46 | 345. 44 | |
| | May | 109. 22 | 325. 12 | 187. 96 | 93.98 | 472. 44 | 449. 58 | 487. 68 | 170. 18 | 154. 94 | 182. 88 | 142. 24 | 243. 84 | 175. 26 | 335. 28 | 0 | 127 | 0 | 0 | 284. 48 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 109. 22 | 0 | 403. 86 | 0 | 0 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | June | 0 | 71.12 | 375.92 | 579.12 | 172.72 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 185.42 | 187.96 | 48.26 | 236.22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 223.52 | 0 | 0 | |
| | July | 0 | 370.84 | 91.44 | 91.44 | 0 | 0 | 0 | 0 | 284.48 | 0 | 104.14 | 0 | 0 | 419.1 | 68.58 | 381 | 292.1 | 157.48 | 279.4 | 134.62 | 213.36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 157.48 | 0 | 236.22 |
| | August | 0 | 0 | 0 | 363.22 | 0 | 185.42 | 0 | 421.64 | 157.48 | 106.68 | 0 | 45.72 | 563.88 | 474.98 | 203.2 | 0 | 254 | 0 | 50.8 | 0 | 292.1 | 93.98 | 0 | 0 | 53.34 | 0 | 99.06 | 48.26 | 0 | 220.98 | 441.96 |
| | September | 160.02 | 0 | 142.24 | 142.24 | 195.58 | 15.24 | 198.12 | 243.84 | 396.24 | 182.88 | 111.76 | 160.02 | 96.52 | 271.78 | 223.52 | 160.02 | 309.88 | 12.7 | 160.02 | 45.72 | 170.18 | 215.9 | 147.32 | 297.18 | 101.6 | 241.3 | 119.38 | 119.38 | 119.38 | 172.72 | |
| | October | 0 | 248.92 | 320.04 | 175.26 | 132.08 | 213.36 | 241.3 | 0 | 177.8 | 0 | 464.82 | 485.14 | 96.52 | 213.36 | 20.32 | 157.48 | 297.18 | 17.78 | 436.88 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 |
| | November | 33.02 | 444.5 | 358.14 | 317.5 | 0 | 104.14 | 284.48 | 0 | 0 | 15.24 | 0 | 0 | 40.64 | 109.22 | 274.32 | 0 | 0 | 0 | 248.92 | 309.88 | 342.9 | 124.46 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | December | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 109.22 | 0 | 0 | 0 | 0 | 116.84 | 0 | 241.3 | 307.34 | 187.96 | 38.1 | 0 | 58.42 | 106.68 | 0 | 38.1 |
| 2022 | January | 134.62 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 175.26 | 30.48 | 304.8 | 30.48 | 0 | 7.62 | 43.18 | 104.14 | 0 | 114.3 | 0 | 0 | 0 | 0 | 0 | 0 | 165.1 | 0 |
| | February | 0 | 281.94 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 185.42 | 0 | 198.12 | 73.66 | 0 | 99.06 | 22.86 | 167.64 | 358.14 | 287.02 | 332.74 | 0 | 116.84 | 0 | 284.48 | 350.52 | 231.14 | 0 | 0 | | | |
| | March | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 193. | 76.2 | 0 | 0 | 0 | 33.0 | 256. | 50.8 | 325. | 170. | 127 | 48.2 | 205. | 396. | 0 | 0 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | 04 | | | | | 2 | 54 | | 12 | 18 | | 6 | 74 | 24 | | |
| | April | 0 | 0 | 0 | 0 | 518.16 | 266.7 | 0 | 0 | 0 | 0 | 261.62 | 139.7 | 330.2 | 523.24 | 802.64 | 185.42 | 447.04 | 370.84 | 215.9 | 0 | 190.5 | 231.14 | 259.08 | 340.36 | 259.08 | 246.38 | 370.84 | 266.7 | 185.42 | 0 | |
| | May | 294.64 | 147.32 | 162.56 | 0 | 104.14 | 284.48 | 170.18 | 271.78 | 27.94 | 0 | 0 | 104.14 | 43.18 | 104.14 | 193.04 | 71.12 | 251.46 | 0 | 0 | 0 | 0 | 91.44 | 180.34 | 589.28 | 0 | 137.16 | 756.92 | 574.04 | 574.04 | 228.6 | 0 |
| | June | 444.5 | 0 | 0 | 0 | 185.42 | 0 | 248.92 | 109.22 | 55.88 | 0 | 185.42 | 0 | 0 | 0 | 0 | 469.9 | 0 | 408.94 | 292.1 | 0 | 0 | 40.64 | 444.5 | 403.86 | 0 | 170.18 | 0 | 43.18 | 0 | 170.18 | |
| | July | 553.72 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 238.76 | 0 | 375.92 | 0 | 345.44 | 0 | 264.16 | 53.34 | 294.64 | 68.58 | 271.78 | 0 | 0 | 0 | 0 | 0 | 165.1 | 330.2 | 0 |
| | August | 373.38 | 0 | 0 | 373.38 | 203.2 | 0 | 0 | 0 | 0 | 0 | 0 | 78.74 | 0 | 500.38 | 157.48 | 269.24 | 170.18 | 0 | 99.06 | 243.84 | 233.68 | 254 | 58.42 | 292.1 | 154.94 | 0 | 0 | 411.48 | 515.62 | 596.9 | 391.16 |
| | September | 101.6 | 121.92 | 20.32 | 101.6 | 121.92 | 228.6 | 350.52 | 30.48 | 289.56 | 167.64 | 139.7 | 185.42 | 139.7 | 279.4 | 248.92 | 198.12 | 93.98 | 45.72 | 116.84 | 162.56 | 12.7 | 76.2 | 149.86 | 137.16 | 187.96 | 53.34 | 27.94 | 40.64 | 299.72 | 287.02 | |
| | October | 129.54 | 144.78 | 363.22 | 116.84 | 144.78 | 276.86 | 0 | 535.94 | 0 | 96.52 | 109.22 | 132.08 | 0 | 264.16 | 241.3 | 627.38 | 0 | 312.42 | 147.32 | 198.12 | 383.54 | 0 | 0 | 0 | 0 | 0 | 515.62 | 228.6 | 190.5 | 0 | 76.2 |
| | November | 63.5 | 368.3 | 431.8 | 208.28 | 48.26 | 144.78 | 0 | 360.68 | 353.06 | 210.82 | 134.62 | 556.26 | 154.94 | 246.38 | 256.54 | 289.56 | 162.56 | 35.56 | 0 | 205.74 | 0 | 167.64 | 180.34 | 91.44 | 38.1 | 7.62 | 149.86 | 284.48 | 205.74 | 0 | |
| | December | 0 | 0 | 0 | 172.72 | 0 | 0 | 0 | 43.18 | 127 | 127 | 27.94 | 185.42 | 284.48 | 27.94 | 99.06 | 218.44 | 55.88 | 152.4 | 0 | 104.14 | 68.58 | 0 | 68.58 | 0 | 0 | 119.38 | 10.16 | 147.32 | 0 | 0 | 0 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2023 | January | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 11.1 | 1.4 | 0 | 0 | 0 | 0 |
| | February | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 11.1 | 1.4 | 0 | | | |
| | March | 4.3 | 19.7 | 2 | 14.3 | 0 | 0 | 0 | 0 | 0 | 0.5 | 28.1 | 13 | 3 | 0 | 8.7 | 0 | 4.4 | 1.1 | 18 | 6.2 | 0 | 4 | 3.4 | 0.8 | 3 | 2.5 | 0 | 26 | 2.2 | 49 | 32 |
| | April | 0 | 0.5 | 0.2 | 3.6 | 0.5 | 0 | 0 | 26.6 | 5 | 9.2 | 0 | 0 | 28 | 16.2 | 0 | 13.4 | 9.2 | 44.5 | 0 | 0 | 0 | 9.3 | 0.2 | 7.4 | 16.5 | 0 | 0.1 | 9.4 | 2.8 | 1.5 | |
| | May | 8.5 | 2.6 | 1.7 | 3.2 | 8.5 | 8.2 | 0 | 0.1 | 0.6 | 16.2 | 20.3 | 0 | 0.1 | 20 | 13.5 | 0.1 | 2 | 0.1 | 2.3 | 0 | 5.3 | 0.7 | 1 | 0.9 | 4.5 | 9 | 12.1 | 3.5 | 3 | 22 | 0.7 |
| | June | 1.7 | 13 | 0 | 0 | 0 | 0 | 3.2 | 28.5 | 0 | 6.1 | 6.4 | 13.1 | 4.3 | 3.5 | 12.1 | 0.1 | 3.2 | 46.5 | 1.3 | 0.1 | 11.3 | 0.1 | 19.5 | 7.5 | 6.5 | 0 | 0 | 26 | 12 | 8 | |
| | July | 10 | 3 | 0 | 3.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 2.7 | 0 | 7.8 | 0.7 | 1.4 | 0 | 0 | 0.6 | 1.1 | 0 | 0 | 8 | 13 | 1 | 0 | 0 | 0 | 23 | 0.6 | 0.1 |
| | August | 0 | 11.5 | 5.7 | 1.1 | 0.6 | 2 | 0.6 | 0 | 0.7 | 27.7 | 4.5 | 0.5 | 1.3 | 4.6 | 0 | 0 | 0.8 | 0 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | September | 0 | 8.5 | 0 | 35.7 | 13.5 | 3.7 | 1 | 0 | 40.2 | 67 | 0.1 | 0.7 | 1.1 | 7.5 | 5.7 | 18 | 2.5 | 13.5 | 0.7 | 5 | 1.5 | 13 | 0.6 | 6.4 | 47.3 | 17 | 6.7 | 1.5 | 4.5 | 23.5 | |
| | October | 15.1 | 17.4 | 0.5 | 0 | 5.5 | 4.5 | 2 | 0.5 | 9.7 | 12 | 13.7 | 0.7 | 11.5 | 13.4 | 3.3 | 2.5 | 0 | 7.2 | 0 | 1.4 | 0.5 | 7.6 | 4.1 | 1.1 | 9.4 | 17.4 | tr | 31.3 | 19.1 | 8.3 | 15.8 |
| | November | 75.1 | 2.4 | 7.7 | 6.6 | 4.6 | 0.7 | 7.6 | 0.5 | 4.5 | 0.1 | 25.7 | 8.1 | 0 | 0.5 | 16.1 | 8.6 | 12.1 | 0 | 15.5 | 6.8 | 9.8 | 1.1 | 0 | 45.1 | 0 | 0 | 2.1 | 1.6 | 8.1 | 0.6 | |
| | December | 6.9 | 0 | 0 | 0.1 | 0 | 4.6 | 2.3 | 1.5 | 2.3 | 3 | 0.1 | 4.8 | 0 | 0 | 1.1 | 0.6 | 0 | 0 | 0 | 0.5 | 0.1 | 2.1 | 0 | 0 | 0 | 0 | 2.1 | 0 | 0 | 29.3 | 17.5 |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2024 | January | 8.1 | 1.1 | 2.3 | 2.4 | 0 | 2.6 | 2 | 4.2 | 2.2 | 2.6 | 22.4 | 0.1 | 2.1 | 1 | 0 | 0 | 0.1 | 0 | 0 | 1.5 | tr | 0 | 0 | 0 | 6.6 | 0.5 | tr | 0 | 0 | 0.8 | 0 |
| | February | 4.5 | 0 | 1 | 1 | 2 | 1 | 0 | 0 | 11.4 | 11 | 3.7 | 0 | 1.4 | 28.5 | 4.3 | 0 | 0 | 0 | 0 | 2.1 | 0 | 0 | 0 | 0 | 0 | 8.1 | 23 | 1.1 | 0.1 | | |
| | March | 25 | 0 | 20 | 5.4 | 4.5 | 4 | 15.7 | 4.8 | 0.1 | 17.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.7 | 6.3 | 3 | 16.1 | 18.5 | 38.4 | 2.5 | 22.6 |
| | April | 4.5 | 22.7 | 35.5 | 1.1 | 28.7 | 12.8 | 3.3 | 0.5 | 0 | 0.7 | 0 | 0 | 2.9 | 0 | 2.6 | 8.5 | 3.8 | 14.5 | 2.8 | 34.1 | 6.5 | 6.9 | 6.8 | 7.8 | 4.7 | 0.1 | 32.5 | 33 | 2.5 | 8.8 | |
| | May | 24 | 7.5 | 4.2 | 15.5 | 0.1 | 0 | 0.7 | 0.5 | 44.7 | 20 | 5.7 | 0.1 | 0.9 | 0.1 | 2.5 | 0.1 | 0 | 15.7 | 6.7 | 16.3 | 9.7 | 18.9 | 23 | 0.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | June | 0 | 0 | 1.3 | 3.4 | 0 | 2.4 | 15.3 | 3.5 | 1.4 | 0 | 0 | 2.6 | 0 | 0 | 2.5 | 3.5 | 3.7 | 0 | 4.6 | 2 | 44.6 | 1.5 | 4.4 | 11.4 | 1.1 | 0 | 1.4 | 3 | 2 | 0 | |
| | July | 0 | 1 | 0 | 0 | tr | 2.1 | 5.1 | 0 | 3.4 | tr | 4.2 | 3.2 | 8.4 | 0 | 0.8 | 9.1 | 0 | 1 | 28.3 | 0 | 0 | 20.5 | 0.6 | 0.7 | 0 | 0 | 0.5 | 0 | 4.3 | 0 | 0 |
| | August | 0 | 0 | 30.1 | 0 | 2.4 | 0 | 0 | 7.2 | 30.2 | 6.1 | 7.7 | 12.5 | 1 | 0.7 | tr | 2.7 | 14.1 | 0.7 | 2.8 | 0 | 2.3 | tr | 0 | tr | 3.9 | 6.1 | 0 | 17.8 | 13.4 | 25 | 0 |
| | September | 3.5 | 0 | 11.1 | 22.3 | 0.8 | 3 | 2.4 | 0 | 4.2 | 1.2 | 12.4 | 0.6 | 4.1 | tr | 0 | 19.3 | 26.6 | 2.2 | 4.2 | 0 | 5 | 2.8 | 0.1 | 5.7 | 3.4 | 0 | 9.4 | 2.6 | 2.7 | 2.1 | |
| | October | 20 | 0 | 0 | 0 | 27 | 57 | 16.2 | 2.7 | tr | 10 | 1.2 | 0.6 | 6.5 | 26.4 | 17.4 | tr | tr | 16.3 | 0 | 18.4 | 7.4 | 13.4 | 32.5 | 1 | 15.1 | 11.4 | 0 | 1.3 | 18.4 | tr | 2.1 |
| | November | 2.2 | 9.2 | tr | tr | 3.3 | 11 | 9.2 | 0.1 | 0 | 0 | 6.8 | 0 | 0 | 3.4 | 8.2 | 0 | tr | 0 | tr | 3.9 | 1.4 | 24 | 2.4 | 30.4 | 0 | 21 | 13.7 | 16.2 | 3.7 | 0 | |
| | December | 0.5 | 5.9 | 1.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 | 0.5 | 16.0 | 2.0 | 16.3 | tr | 1.3 | 2.3 | 2.5 | tr | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2025 | January | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.8 | 5.1 | 3.2 | 1.8 | 2.7 | 0 | 0 | 0 | 0 |
| | February | 13 | 0 | 0 | 0 | 0 | no data | no data | no data | no data | no data | no data | no data | no data | no data | no data | no data | no data | no data | no data | no data | no data | no data | no data | no data | no data | no data | no data | no data | no data | no data | no data | no data |

# APPENDIX B: Secondary data of BUDUDA borehole

| Borehole Number | Li/BUD/004 | Li/BUD/003 | MBL/05/440 | Li/BUD/006 | DWD32763 | MBL/05/030 | MBL/05/045 | MBL/05/032 | Li/BUD/001 | Li/BUD/005 | Li/BUD/002 | DWD51922 | DWD41494 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Point | Deep Well | Deep Well | Deep Well | Deep Well | Borehole | Deep Well | Deep Well | Deep Well | Deep Well | Deep Well | Deep Well | Borehole | Borehole |
| Latitude | | | | | 0.362853 | 0.083333333 | | 0.1 | | | | 1.012400314 | 1.183333333 |
| Longitude | | | | | 33.779708 | 32.11666667 | | 32.1 | | | | 34.37051575 | 33.98333333 |
| Altitude(m) | | | | | 0.362853 | 0.083333333 | | 0.1 | | | | 1.012400314 | 1.183333333 |
| UTM Zone | 36S | 36S | 36N | 36S | 36 | 36N | 36N | | 36S | 36S | 36S | 36N | 36N |
| WM Zone | | | | | | | | | | | | | |
| District | BUDUDA | BUDUDA | BUDUDA | BUDUDA | BUDUDA | BUDUDA | BUDUDA | BUDUDA | BUDUDA | BUDUDA | BUDUDA | BUDUDA | BUDUDA |
| County | MANJIYA | MANJIYA | MANJIYA | MANJIYA | MANJIYA | MANJIYA | MANJIYA | MANJIYA | MANJIYA | MANJIYA | MANJIYA | MANJIYA | MANJIYA |
| Subcounty | SHAFAT | BUMAY | BUSKIKA | BUDUDA | TOWN | BAKIGAI | BUKIGAI | BAKIGAI | BUDUDA | BUDUDA TC | BUSKIKA | BUBIITA | BUKIGAI |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SA | OILA | | | COUNCIL | | | | | | | | |
| Parish | BUWALI | BUNADUTU | BUFUTSA | BUDUDA T/C | NASHULA | BUNAMUBI | BULOBI | BUMATANDA | BUSHINYEKWA | BULOLI M/WARD | BUSHUNYA | BUWALI | BUMATANDA |
| Village | BUBISKWA | NAGOBE | NANGOKO | BUDUDA CELL | BUNAEMEBE | BUNAMUBI | NAMAWULULU | BUMUKOYA | WAMARA | BULOLI | BUMATAYA | BUWASHI | BUMUKOYA |
| Source Name | | | | | | | | | | | | | |
| Owner Ship | | | | | Communal | | | | | | | Communal | Communal |
| Owner Contact Number | | | | | | | | | | | | 0 | 1010101010 |
| Water Use | | | | | Communal | | | | | | | Domestic | Domestic |
| Organization | | | | | | | | | | | | DRACO (UGANDA) LIMITED | DRACO (U) LTD |
| Site Investigation Method | | | | | | | | | | | Electrical Resistivity Method | | |
| Date of Investigation | | | | | | | | | | | | 29-01-2018 | 41671 |
| Recommended Depth of Borehole(m) | | | | | | | | | | | | 55 | |
| Date of Completion | 34004 | 34004 | 34004 | 34004 | 34004 | 34004 | 34004 | 34004 | 34004 | 34004 | 34004 | 43314 | 18-01-2014 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drilling Method | | | | | | | | | | | | Direct Air Rotary | Direct Air Rotary |
| Casing Material | | | | | PVC | | | | | | | PVC | 127 |
| Casing Diameter(mm) | | | | | 127 | | | | | | | 127 | |
| Total Casing Length(m) | 0 | 0 | 0 | 0 | 2.75 | 0 | 0 | 0 | 0 | 0 | 0 | 45 | |
| Height of Surface Casing(m) | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Datum Elevation(m a.g.l) | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | | |
| Borehole Seal Type | | | | | | | | | | | | Cement | |
| Well Development Method | | | | | Airlift | | | | | | | AirLift | Airlift |
| Duration of Development(hrs) | | | | | 1 | | | | | | | 1 | 1 |
| Borehole Filters | | | | | | | | | | | | Gravel Pack | |
| Depth at slot size1 | | | | | | | | | | | | 34.5 | |
| Depth at slot size2 | | | | | | | | | | | | 40 | |
| Depth at slot size3 | | | | | | | | | | | | 48.25 | |
| Depth at slot size4 | | | | | | | | | | | | | |
| Depth at slot size5 | | | | | | | | | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Slot Size1 | | | | | | | | | | | | 1 | |
| Slot Size2 | | | | | | | | | | | | 1 | |
| Slot Size3 | | | | | | | | | | | | 1 | |
| Slot Size4 | | | | | | | | | | | | | |
| Slot Size5 | | | | | | | | | | | | | |
| Total Drilled Depth(m b.g.l) | 0 | 0 | 0 | 0 | 55 | 0 | 0 | 0 | 0 | 0 | 0 | 52 | 66 |
| Date of Installation | | | | | | | | | | | | 23-02-2018 | 21-01-2014 |
| Pump Type | | | | | | | | | | | | Hand pump | Hand pump |
| Name of Pump | | | | | | | | | | | | U2 | U-2 |
| Pump Capacity(m3/hr) | | | | | | | | | | | | 1 | 1 |
| Pump Installation Depth(m.b.gl) | | | | | | | | | | | | 18 | 27 |
| Riser Pipe material | | | | | | | | | | | | PVC | PVC |
| Riser Pipe Diameter(mm) | | | | | | | | | | | | 32 | 32 |
| Pump Rod Material | | | | | | | | | | | | Stainless steel | Stainless steel |
| Pump Rod Diameter(mm) | | | | | | | | | | | | 12 | 12 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth to Bedrock(m b.g.l) | 0 | 0 | 0 | 0 | 33 | 0 | 0 | 0 | 0 | 0 | 0 | 42 | 24 |
| Overall Geological Setting | | | | | | | | | | | | | |
| Lithology Depth1 | | | | | | | | | | | | 1 | 3 |
| Lithology Depth2 | | | | | | | | | | | | 6 | 15 |
| Lithology Depth3 | | | | | | | | | | | | 18 | 24 |
| Lithology Depth4 | | | | | | | | | | | | 42 | 66 |
| Lithology Depth5 | | | | | | | | | | | | 52 | |
| Lithology Depth6 | | | | | | | | | | | | | |
| Lithology Depth7 | | | | | | | | | | | | | |
| Lithology Description1 | | | | | | | | | | | | BLACK TOP SOIL | CLAY SOIL |
| Lithology Description2 | | | | | | | | | | | | BROWN HARD CLAY | LATERITIC CLAY |
| Lithology Description3 | | | | | | | | | | | | SAND | WEATHERED CLAY FORMATION |
| Lithology Description4 | | | | | | | | | | | | WEATHERED GRANITE | FRACTURED HARD AMPHOBOLITE |
| Lithology Description5 | | | | | | | | | | | | FRESH GRANITE | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lithology Description6 | | | | | | | | | | | | | |
| Lithology Description7 | | | | | | | | | | | | | |
| DepthToWaterStrike1 | | | | | | | | | | | | 27 | 24 |
| EstimatedYield1 | | | | | | | | | | | | 5 | 0.3 |
| AquiferType1 | | | | | | | | | | | | Fractured Bedrock | Other |
| OtherAquifer1 | | | | | | | | | | | | | INTERFACE |
| DepthToWaterStrike2 | | | | | | | | | | | | | |
| EstimatedYield2 | | | | | | | | | | | | | |
| AquiferType2 | | | | | | | | | | | | | |
| OtherAquifer2 | | | | | | | | | | | | | |
| DepthToWaterStrike3 | | | | | | | | | | | | | |
| EstimatedYield3 | | | | | | | | | | | | | |
| AquiferType3 | | | | | | | | | | | | | |
| OtherAquifer3 | | | | | | | | | | | | | |
| DepthToWaterStrike4 | | | | | | | | | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EstimatedYield4 | | | | | | | | | | | | | |
| AquiferType4 | | | | | | | | | | | | | |
| OtherAquifer4 | | | | | | | | | | | | | |
| DepthToWaterStrike5 | | | | | | | | | | | | | |
| EstimatedYield5 | | | | | | | | | | | | | |
| AquiferType5 | | | | | | | | | | | | | |
| OtherAquifer5 | | | | | | | | | | | | | |
| Table Height(m a.g.l) | | | | | | | | | | | | 0.5 | |
| Length of Drilling Rods(m) | | | | | | | | | | | | 3 | |
| Length of Drill Bit(m) | | | | | | | | | | | | 0.5 | |
| Measuring Point(m a.g.l) | | | | | | | | | | | | 0.5 | 0.7 |
| Pump Installation Depth(m.b.MP) | | | | | | | | | | | | 50 | 42 |
| Static Water Level(m.b.MP) | | | | | | | | | | | | 10.78 | 17.88 |
| Disharge(m3/hr) Step1 | | | | | | | | | | | | | |
| Disharge(m3/hr) Step2 | | | | | | | | | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Disharge(m3/hr) Step3 | | | | | | | | | | | | | |
| Disharge(m3/hr) Step4 | | | | | | | | | | | | | |
| Disharge(m3/hr) Step5 | | | | | | | | | | | | | |
| Step Test Drawdown(m b.g.l) | | | | | | | | | | | | 3.53 | 4.41 |
| Step Test Duration(min) | | | | | | | | | | | | 180 | 180 |
| Step Test Recovery(%) | | | | | | | | | | | | 0.9887 | 0.9252 |
| Constant Test Pump Installation Depth(m b.M.P) | | | | | | | | | | | | | |
| Constant Test Static Water Level(m b.g.l) | | | | | | | | | | | | | |
| Constant Test Dynamic Water Level(m b.g.l) | | | | | | | | | | | | | |
| Constant Test Discharge(m b.g.l) | | | | | | | | | | | | | |
| Constant Test Duration(min) | | | | | | | | | | | | | |
| Constant Test Recovery(%) | | | | | | | | | | | | | |
| Depth(m)1 | | | | | | | | | | | | | |
| BackfillMaterial1 | | | | | | | | | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth(m)2 | | | | | | | | | | | | | |
| BackfillMaterial2 | | | | | | | | | | | | | |
| Depth(m)3 | | | | | | | | | | | | | |
| BackfillMaterial3 | | | | | | | | | | | | | |
| Depth(m)4 | | | | | | | | | | | | | |
| BackfillMaterial4 | | | | | | | | | | | | | |
| Depth(m)5 | | | | | | | | | | | | | |
| BackfillMaterial5 | | | | | | | | | | | | | |
| Transmissivity(m2/day) | | | | | | | | | | | | | |
| Specific Capacity(m3/hr/m) | | | | | | | | | | | | 0.2857 | 1 |
| Water Quality Certificate Issued by | | | | | | | | | | | | NWSC | NWSC |
| Sample Number | | | | | | | | | | | | K639//2018 | K064/14/C |
| Serial Number | | | | | | | | | | | | ES/RF/2018/235 | INV/2014/38-2 |
| Bi-Carbonates | | | | | | | | | | | | 278.16 | 130 |
| Calcium | | | | | | | | | | | | 46.4 | 0 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chloride | | | | | | | | | | | | 0 | 4.5 |
| Color(apparent) | | | | | | | | | | | | 6 | 0 |
| Conductivity | | | | | | | | | | | | 403 | 340 |
| Fluoride | | | | | | | | | | | | 0 | 0.25 |
| Magnesium | | | | | | | | | | | | 8.64 | 9.6 |
| Manganese | | | | | | | | | | | | 0 | 0.006 |
| Nitrate | | | | | | | | | | | | 0 | 0.02 |
| PH | | | | | | | | | | | | 6.91 | 6.69 |
| Sodium | | | | | | | | | | | | 0 | 0 |
| Sulphates | | | | | | | | | | | | 3 | 7 |
| Sulphide | | | | | | | | | | | | 0 | 0 |
| Total Alkalinity | | | | | | | | | | | | 228 | 130 |
| Total Dissolved Solids | | | | | | | | | | | | 257.92 | 173 |
| Total Hardness | | | | | | | | | | | | 152 | 140 |
| Total Iron | | | | | | | | | | | | 0.016 | 0.13 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Suspended Solids | | | | | | | | | | | | 0 | 0 |
| Turbidity | | | | | | | | | | | | 0.62 | 0.1 |

# APPENDIX C: Slope stability analysis_slip surfaces tables

## 1. INITIAL CONDITIONS

### a. Unconsolidated Undrained

| X | Y | PWP | Base Normal Stress | Frictional Strength | Cohesive Strength | Suction Strength | Column Base Material | |
|---|---|---|---|---|---|---|---|---|
| Column 1 | 62.50000 m | 304.98116 m | 0 kPa | 48.88412 kPa | 12.251635 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 2 | 87.50000 m | 267.93947 m | 0 kPa | 305.60876 kPa | 76.593524 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 3 | 110.26786 m | 238.62252 m | 572.85821 kPa | 737.30238 kPa | 41.214 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 4 | 130.80357 m | 215.26554 m | 708.47343 kPa | 919.58921 kPa | 52.911121 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 5 | 151.33929 m | 194.18328 m | 821.78046 kPa | 1,072.6306 kPa | 62.869588 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 6 | 171.87500 m | 175.04977 m | 915.9761 kPa | 1,203.6947 kPa | 72.109787 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 7 | 192.41071 m | 157.62148 m | 993.44857 kPa | 1,318.3363 kPa | 81.425341 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 8 | 212.94643 m | 141.71099 m | 1,056.0361 kPa | 1,420.8452 kPa | 91.430684 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 9 | 233.48214 m | 127.17060 m | 1,105.187 kPa | 1,514.5046 kPa | 102.58565 kPa | 37.04 kPa | 0 kPa | New Material |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Column 10 | 254.01786 m | 113.88173 m | 1,142.0642 kPa | 1,601.731 kPa | 115.2045 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 11 | 274.55357 m | 101.74779 m | 1,167.6151 kPa | 1,684.136 kPa | 129.45362 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 12 | 295.08929 m | 90.68907 m | 1,182.6212 kPa | 1,762.5336 kPa | 145.34117 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 13 | 315.62500 m | 80.63926 m | 1,187.733 kPa | 1,836.9126 kPa | 162.70134 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 14 | 336.16071 m | 71.54275 m | 1,183.4958 kPa | 1,906.3933 kPa | 181.17696 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 15 | 356.69643 m | 63.35268 m | 1,170.3691 kPa | 1,969.1909 kPa | 200.20558 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 16 | 377.23214 m | 56.02949 m | 1,148.741 kPa | 2,022.615 kPa | 219.01562 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 17 | 397.76786 m | 49.53970 m | 1,118.9396 kPa | 2,063.1363 kPa | 236.64032 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 18 | 418.30357 m | 43.85511 m | 1,081.2417 kPa | 2,086.5501 kPa | 251.95651 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 19 | 438.83929 m | 38.95204 m | 1,035.8794 kPa | 2,088.2548 kPa | 263.7527 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 20 | 459.37500 m | 34.81080 m | 983.04588 kPa | 2,063.6449 kPa | 270.8263 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 21 | 479.91071 m | 31.41528 m | 922.89899 kPa | 2,008.5918 kPa | 272.10294 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 22 | 500.44643 m | 28.75262 m | 855.56497 kPa | 1,919.9574 kPa | 266.76449 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 23 | 520.98214 m | 26.81294 m | 781.14078 kPa | 1,796.0659 kPa | 254.3667 kPa | 37.04 kPa | 0 kPa | New Material |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Column 24 | 541.51786 m | 25.58913 m | 699.69594 kPa | 1,637.0482 kPa | 234.92492 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 25 | 562.05357 m | 25.07678 m | 611.27385 kPa | 1,444.9807 kPa | 208.94869 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 26 | 582.58929 m | 25.27405 m | 515.89255 kPa | 1,223.7705 kPa | 177.41267 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 27 | 603.12500 m | 26.18164 m | 413.54512 kPa | 978.77957 kPa | 141.66249 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 28 | 623.66071 m | 27.80282 m | 304.19947 kPa | 716.23324 kPa | 103.26641 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 29 | 644.19643 m | 30.14350 m | 187.79779 kPa | 442.50277 kPa | 63.835709 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 30 | 664.73214 m | 33.21228 m | 64.255524 kPa | 163.38159 kPa | 24.843577 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 31 | 675.18863 m | 34.96498 m | 0 kPa | 23.406801 kPa | 5.8663548 kPa | 37.04 kPa | 0 kPa | New Material |

## b. Consolidated Drained

| X | Y | PWP | Base Normal Stress | Frictional Strength | Cohesive Strength | Suction Strength | Column Base Material | |
|---|---|---|---|---|---|---|---|---|
| Column 1 | 62.50000 m | 305.08129 m | 0 kPa | 132.9303 kPa | 90.33934 kPa | 4 kPa | 0 kPa | New Material |
| Column 2 | 87.50000 m | 268.18627 m | 0 kPa | 402.41823 kPa | 273.48315 kPa | 4 kPa | 0 kPa | New Material |
| Column 3 | 110.64815 m | 238.50096 m | 572.31979 kPa | 855.15604 kPa | 192.21531 kPa | 4 kPa | 0 kPa | New Material |
| Column 4 | 131.94444 m | 214.38433 m | 711.92391 kPa | 1,055.0352 kPa | 233.17822 kPa | 4 kPa | 0 kPa | New Material |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Column 5 | 153.24074 m | 192.66875 m | 827.98094 kPa | 1,223.6878 kPa | 268.92213 kPa | 4 kPa | 0 kPa | New Material |
| Column 6 | 174.53704 m | 173.00477 m | 923.91795 kPa | 1,369.2734 kPa | 302.66323 kPa | 4 kPa | 0 kPa | New Material |
| Column 7 | 195.83333 m | 155.13271 m | 1,002.2815 kPa | 1,498.055 kPa | 336.92733 kPa | 4 kPa | 0 kPa | New Material |
| Column 8 | 217.12963 m | 138.85360 m | 1,065.0231 kPa | 1,614.8841 kPa | 373.68517 kPa | 4 kPa | 0 kPa | New Material |
| Column 9 | 238.42593 m | 124.01120 m | 1,113.6747 kPa | 1,723.4684 kPa | 414.41536 kPa | 4 kPa | 0 kPa | New Material |
| Column 10 | 259.72222 m | 110.48053 m | 1,149.4624 kPa | 1,826.5006 kPa | 460.11469 kPa | 4 kPa | 0 kPa | New Material |
| Column 11 | 281.01852 m | 98.16003 m | 1,173.3818 kPa | 1,925.6899 kPa | 511.26799 kPa | 4 kPa | 0 kPa | New Material |
| Column 12 | 302.31481 m | 86.96619 m | 1,186.2521 kPa | 2,021.7251 kPa | 567.78689 kPa | 4 kPa | 0 kPa | New Material |
| Column 13 | 323.61111 m | 76.82973 m | 1,188.7527 kPa | 2,114.1924 kPa | 628.92814 kPa | 4 kPa | 0 kPa | New Material |
| Column 14 | 344.90741 m | 67.69272 m | 1,181.4517 kPa | 2,201.4747 kPa | 693.20696 kPa | 4 kPa | 0 kPa | New Material |
| Column 15 | 366.20370 m | 59.50655 m | 1,164.8257 kPa | 2,280.6712 kPa | 758.32779 kPa | 4 kPa | 0 kPa | New Material |
| Column 16 | 387.50000 m | 52.23032 m | 1,139.2761 kPa | 2,347.5817 kPa | 821.16362 kPa | 4 kPa | 0 kPa | New Material |
| Column 17 | 408.79630 m | 45.82961 m | 1,105.1402 kPa | 2,396.8145 kPa | 877.82099 kPa | 4 kPa | 0 kPa | New Material |
| Column 18 | 430.09259 m | 40.27558 m | 1,062.7008 kPa | 2,422.0699 kPa | 923.82633 kPa | 4 kPa | 0 kPa | New Material |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Column 19 | 451.38889 m | 35.54424 m | 1,012.1933 kPa | 2,416.6324 kPa | 954.45582 kPa | 4 kPa | 0 kPa | New Material |
| Column 20 | 472.68519 m | 31.61585 m | 953.8114 kPa | 2,374.0654 kPa | 965.20362 kPa | 4 kPa | 0 kPa | New Material |
| Column 21 | 493.98148 m | 28.47450 m | 887.71097 kPa | 2,289.0424 kPa | 952.34386 kPa | 4 kPa | 0 kPa | New Material |
| Column 22 | 515.27778 m | 26.10776 m | 814.01384 kPa | 2,158.1908 kPa | 913.50172 kPa | 4 kPa | 0 kPa | New Material |
| Column 23 | 536.57407 m | 24.50647 m | 732.81007 kPa | 1,980.7804 kPa | 848.11976 kPa | 4 kPa | 0 kPa | New Material |
| Column 24 | 557.87037 m | 23.66447 m | 644.15981 kPa | 1,759.0854 kPa | 757.70263 kPa | 4 kPa | 0 kPa | New Material |
| Column 25 | 579.16667 m | 23.57859 m | 548.0944 kPa | 1,498.2943 kPa | 645.75521 kPa | 4 kPa | 0 kPa | New Material |
| Column 26 | 600.46296 m | 24.24848 m | 444.61704 kPa | 1,205.9378 kPa | 517.39304 kPa | 4 kPa | 0 kPa | New Material |
| Column 27 | 621.75926 m | 25.67670 m | 333.7028 kPa | 890.92249 kPa | 378.6861 kPa | 4 kPa | 0 kPa | New Material |
| Column 28 | 643.05556 m | 27.86870 m | 215.29819 kPa | 562.37332 kPa | 235.87202 kPa | 4 kPa | 0 kPa | New Material |
| Column 29 | 664.35185 m | 30.83295 m | 89.320064 kPa | 228.54279 kPa | 94.615669 kPa | 4 kPa | 0 kPa | New Material |
| Column 30 | 681.64148 m | 33.75470 m | 0 kPa | 33.899029 kPa | 23.037756 kPa | 4 kPa | 0 kPa | New Material |

## 2. STEADY STATE CONDITIONS

### Unconsolidated Undrained

| X | Y | PWP | Base Normal Stress | Frictional Strength | Cohesive Strength | Suction Strength | Column Base Material | |
|---|---|---|---|---|---|---|---|---|
| Column 1 | 40.13337 m | 309.25599 m | 0 kPa | 113.25283 kPa | 28.384111 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 2 | 62.50000 m | 276.11190 m | 0 kPa | 428.88464 kPa | 107.48968 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 3 | 87.50000 m | 243.50019 m | 0 kPa | 681.33084 kPa | 170.75928 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 4 | 111.88919 m | 215.43820 m | -672.50222 kPa | 892.9334 kPa | 223.7924 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 5 | 135.66758 m | 191.04897 m | -453.03879 kPa | 1,073.8282 kPa | 269.12934 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 6 | 159.44596 m | 169.09613 m | -257.46901 kPa | 1,236.145 kPa | 309.81017 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 7 | 183.22435 m | 149.25411 m | -82.600082 kPa | 1,384.0639 kPa | 346.88251 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 8 | 206.17686 m | 131.84449 m | 69.099351 kPa | 1,524.2969 kPa | 364.71046 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 9 | 228.30350 m | 116.57448 m | 200.5006 kPa | 1,652.1602 kPa | 363.82375 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 10 | 250.43013 m | 102.63555 m | 318.84784 kPa | 1,764.0365 kPa | 362.20196 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 11 | 272.55677 m | 89.92724 m | 425.12648 kPa | 1,861.9382 kPa | 360.10248 kPa | 37.04 kPa | 0 kPa | New Material |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Column 12 | 294.68341 m | 78.36660 m | 520.14987 kPa | 1,947.03 kPa | 357.61337 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 13 | 316.81004 m | 67.88457 m | 604.59533 kPa | 2,019.7114 kPa | 354.665 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 14 | 338.93668 m | 58.42327 m | 679.0306 kPa | 2,079.6739 kPa | 351.03772 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 15 | 362.50000 m | 49.44738 m | 715.52722 kPa | 2,129.2049 kPa | 354.30448 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 16 | 387.50000 m | 41.03920 m | 713.27834 kPa | 2,166.2511 kPa | 364.15287 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 17 | 412.50000 m | 33.76772 m | 699.8818 kPa | 2,182.3837 kPa | 371.55364 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 18 | 437.50000 m | 27.59274 m | 675.73187 kPa | 2,172.9827 kPa | 375.25011 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 19 | 462.50000 m | 22.48160 m | 639.56501 kPa | 2,133.2494 kPa | 374.35626 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 20 | 487.50000 m | 18.40824 m | 591.63675 kPa | 2,058.4053 kPa | 367.61044 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 21 | 512.50000 m | 15.35252 m | 518.19675 kPa | 1,946.1456 kPa | 357.88122 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 22 | 537.50000 m | 13.29965 m | 419.38995 kPa | 1,793.7587 kPa | 344.45264 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 23 | 562.50000 m | 12.23987 m | 359.01104 kPa | 1,591.6026 kPa | 308.91958 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 24 | 587.50000 m | 12.16818 m | 337.10898 kPa | 1,342.044 kPa | 251.86293 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 25 | 612.50000 m | 13.08424 m | 302.16356 kPa | 1,057.8357 kPa | 189.39114 kPa | 37.04 kPa | 0 kPa | New Material |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Column 26 | 637.50000 m | 14.99237 m | 254.13248 kPa | 745.83333 kPa | 123.23305 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 27 | 652.98789 m | 16.55710 m | 222.01195 kPa | 543.26833 kPa | 80.515227 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 28 | 665.48789 m | 18.26345 m | 196.42453 kPa | 417.47003 kPa | 55.399767 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 29 | 687.50000 m | 21.82606 m | 145.89573 kPa | 265.95288 kPa | 30.089454 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 30 | 713.47880 m | 27.02207 m | 86.085204 kPa | 139.56044 kPa | 13.402289 kPa | 37.04 kPa | 0 kPa | New Material |

## 3. TRASIENT CONDITIONS

### a. Unconsolidated Undrained

| X | Y | PWP | Base Normal Stress | Frictional Strength | Cohesive Strength | Suction Strength | Column Base Material | |
|---|---|---|---|---|---|---|---|---|
| Column 1 | 62.50000 m | 304.90329 m | 0 kPa | 87.346714 kPa | 21.891364 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 2 | 87.50000 m | 267.69628 m | 0 kPa | 380.18201 kPa | 95.283525 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 3 | 110.76003 m | 237.65637 m | -737.24281 kPa | 614.1128 kPa | 153.91268 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 4 | 132.28008 m | 213.13655 m | -499.10693 kPa | 802.34986 kPa | 201.0898 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 5 | 153.80014 m | 191.08472 m | -285.17457 kPa | 970.72324 kPa | 243.28856 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 6 | 175.32019 m | 171.13639 m | -91.871238 kPa | 1,123.142 kPa | 281.48868 kPa | 37.04 kPa | 0 kPa | New Material |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Column 7 | 196.32521 m | 153.41665 m | 79.632078 kPa | 1,273.5753 kPa | 299.2333 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 8 | 216.81518 m | 137.65095 m | 232.02787 kPa | 1,416.1684 kPa | 296.7765 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 9 | 237.30515 m | 123.22344 m | 371.30001 kPa | 1,539.4567 kPa | 292.77054 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 10 | 257.79513 m | 110.02076 m | 498.56025 kPa | 1,646.0932 kPa | 287.60169 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 11 | 278.28510 m | 97.95019 m | 614.71791 kPa | 1,737.9237 kPa | 281.50467 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 12 | 298.77507 m | 86.93500 m | 720.52538 kPa | 1,816.1 kPa | 274.57957 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 13 | 319.26504 m | 76.91116 m | 816.61077 kPa | 1,881.1599 kPa | 266.80376 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 14 | 339.75501 m | 67.82482 m | 903.50208 kPa | 1,933.0903 kPa | 258.04166 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 15 | 361.43467 m | 59.20742 m | 972.48256 kPa | 1,972.7025 kPa | 250.68119 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 16 | 384.30402 m | 51.12087 m | 1,022.9449 kPa | 1,997.7978 kPa | 244.32355 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 17 | 407.17336 m | 44.05084 m | 1,063.4384 kPa | 2,003.491 kPa | 235.6017 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 18 | 434.30402 m | 37.03549 m | 1,098.0213 kPa | 2,038.9 kPa | 235.80875 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 19 | 462.50000 m | 30.96215 m | 1,107.7654 kPa | 2,074.6306 kPa | 242.32164 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 20 | 487.50000 m | 26.81499 m | 1,088.3933 kPa | 2,052.189 kPa | 241.55234 kPa | 37.04 kPa | 0 kPa | New Material |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Column 21 | 512.50000 m | 23.73953 m | 1,055.3996 kPa | 1,988.0453 kPa | 233.74532 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 22 | 537.50000 m | 21.71930 m | 1,008.9462 kPa | 1,878.9322 kPa | 218.04118 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 23 | 562.50000 m | 20.74364 m | 944.68974 kPa | 1,718.8343 kPa | 194.02081 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 24 | 587.50000 m | 20.80748 m | 862.68027 kPa | 1,509.3088 kPa | 162.06198 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 25 | 612.50000 m | 21.91115 m | 768.89678 kPa | 1,260.8746 kPa | 123.30248 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 26 | 637.50000 m | 24.06040 m | 663.28276 kPa | 979.31538 kPa | 79.206015 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 27 | 662.50000 m | 27.26657 m | 579.68127 kPa | 705.79819 kPa | 31.60819 kPa | 37.04 kPa | 0 kPa | New Material |
| Column 28 | 677.46479 m | 29.56783 m | 545.27223 kPa | 564.88573 kPa | 4.9156535 kPa | 37.04 kPa | 0 kPa | New Material |

b. Consolidated Drained

| X | Y | PWP | Base Normal Stress | Frictional Strength | Cohesive Strength | Suction Strength | Column Base Material | |
|---|---|---|---|---|---|---|---|---|
| Column 1 | 62.50000 m | 312.94495 m | 0 kPa | 83.689564 kPa | 56.875369 kPa | 4 kPa | 0 kPa | New Material |
| Column 2 | 87.50000 m | 289.61519 m | 0 kPa | 246.67837 kPa | 167.64245 kPa | 4 kPa | 0 kPa | New Material |
| Column 3 | 110.32789 m | 269.56603 m | -1,050.1341 kPa | 380.85009 kPa | 258.82545 kPa | 4 kPa | 0 kPa | New Material |
| Column 4 | 130.98367 m | 252.47241 m | -884.73326 kPa | 490.56198 kPa | 333.38558 kPa | 4 kPa | 0 kPa | New Material |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Column 5 | 151.63945 m | 236.26169 m | -727.99115 kPa | 591.2374 kPa | 401.80452 kPa | 4 kPa | 0 kPa | New Material |
| Column 6 | 172.29523 m | 220.88205 m | -579.39939 kPa | 683.85673 kPa | 464.74855 kPa | 4 kPa | 0 kPa | New Material |
| Column 7 | 192.95101 m | 206.28800 m | -438.51194 kPa | 769.13324 kPa | 522.70241 kPa | 4 kPa | 0 kPa | New Material |
| Column 8 | 213.60679 m | 192.43941 m | -304.93522 kPa | 847.51902 kPa | 575.97333 kPa | 4 kPa | 0 kPa | New Material |
| Column 9 | 234.26257 m | 179.30069 m | -178.3202 kPa | 919.21002 kPa | 624.69448 kPa | 4 kPa | 0 kPa | New Material |
| Column 10 | 254.91835 m | 166.84015 m | -58.356027 kPa | 984.15158 kPa | 668.82872 kPa | 4 kPa | 0 kPa | New Material |
| Column 11 | 275.84046 m | 154.88536 m | 56.619395 kPa | 1,046.9519 kPa | 673.0293 kPa | 4 kPa | 0 kPa | New Material |
| Column 12 | 297.02890 m | 143.42659 m | 166.70145 kPa | 1,103.3546 kPa | 636.54885 kPa | 4 kPa | 0 kPa | New Material |
| Column 13 | 318.21734 m | 132.59995 m | 270.58429 kPa | 1,147.0055 kPa | 595.61525 kPa | 4 kPa | 0 kPa | New Material |
| Column 14 | 339.40578 m | 122.38328 m | 368.48504 kPa | 1,178.4759 kPa | 550.46922 kPa | 4 kPa | 0 kPa | New Material |
| Column 15 | 361.43467 m | 112.39849 m | 450.83773 kPa | 1,198.3263 kPa | 507.99272 kPa | 4 kPa | 0 kPa | New Material |
| Column 16 | 384.30402 m | 102.67328 m | 517.37043 kPa | 1,206.2748 kPa | 468.17895 kPa | 4 kPa | 0 kPa | New Material |
| Column 17 | 407.17336 m | 93.59343 m | 577.57424 kPa | 1,201.3286 kPa | 423.903 kPa | 4 kPa | 0 kPa | New Material |
| Column 18 | 426.45603 m | 86.38506 m | 623.94781 kPa | 1,215.4525 kPa | 401.9862 kPa | 4 kPa | 0 kPa | New Material |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Column 19 | 442.15201 m | 80.87342 m | 658.20496 kPa | 1,252.6569 kPa | 403.9891 kPa | 4 kPa | 0 kPa | New Material |
| Column 20 | 462.50000 m | 74.20350 m | 683.69745 kPa | 1,275.2028 kPa | 401.98662 kPa | 4 kPa | 0 kPa | New Material |
| Column 21 | 487.50000 m | 66.58067 m | 698.41116 kPa | 1,275.8896 kPa | 392.45395 kPa | 4 kPa | 0 kPa | New Material |
| Column 22 | 512.50000 m | 59.64717 m | 703.25336 kPa | 1,252.6448 kPa | 373.366 kPa | 4 kPa | 0 kPa | New Material |
| Column 23 | 537.50000 m | 53.38861 m | 698.36517 kPa | 1,203.8997 kPa | 343.56092 kPa | 4 kPa | 0 kPa | New Material |
| Column 24 | 562.50000 m | 47.79234 m | 679.42314 kPa | 1,124.261 kPa | 302.31147 kPa | 4 kPa | 0 kPa | New Material |
| Column 25 | 587.50000 m | 42.84732 m | 646.53558 kPa | 1,014.1267 kPa | 249.81463 kPa | 4 kPa | 0 kPa | New Material |
| Column 26 | 612.50000 m | 38.54399 m | 605.77845 kPa | 881.13103 kPa | 187.12942 kPa | 4 kPa | 0 kPa | New Material |
| Column 27 | 637.50000 m | 34.87420 m | 557.23179 kPa | 727.3249 kPa | 115.59516 kPa | 4 kPa | 0 kPa | New Material |
| Column 28 | 661.87866 m | 31.89165 m | 534.81478 kPa | 592.20538 kPa | 39.002611 kPa | 4 kPa | 0 kPa | New Material |

# APPENDIX C: Pictures

| | |
|---|---|
|  |  |
| Site visit and sample collection in SHIKURUWE VILLAGE | Specific gravity test |

| | |
|---|---|
|  |  |
| Falling head permeability test | Sample preparation of Triaxial test specimen |

F/FORM/SO/06 ISSUE 02

2

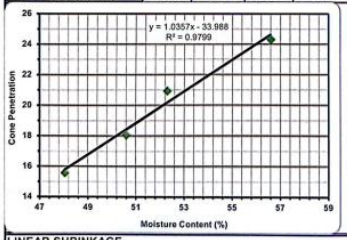
GETLAB LTD
YOUR RELIABLE ENGINEERING LABORATORY

## DETERMINIATION OF LIQUID LIMIT & PLASTIC LIMIT

BS 1377-2:1990

| | |
|---|---|
| Project: | HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION |
| STUDENT | MAMFA MAYALA and AHABWE MARTHA |
| Sample Location: | SHIRURUWE VILLAGE |
| Sample Reference: | 165,1 |
| Sample Depth (m): | 1m |
| Sampling Date: | 1/20/2025 |
| Testing Date: | 25/Jan/25 |
| Technician: | BAKAKI MICHAEL |
| Client Reference | TP03 |

| LIQUID LIMIT | | | | | | | | | PLASTIC LIMIT | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TEST NO. | 1 | | 2 | | 3 | | 4 | | 1 | 2 | Average |
| Initial dial gauge reading mm | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| Final dial gauge reading mm | 15.60 | 15.60 | 18.10 | 18.10 | 20.96 | 20.96 | 24.33 | 24.33 | | | |
| Average penetration mm | 15.6 | | 18.1 | | 21.0 | | 24.3 | | | | |
| Container No. | 44 | 165 | 70 | BM6 | AI | 74 | 69 | SG3 | 156 | 142 | |
| Mass of wet soil + container (a) | 28.17 | 28.85 | 29.07 | 29.43 | 29.07 | 29.04 | 30.45 | 30.40 | 22.36 | 22.77 | |
| Mass of dry soil + container (b) | 23.95 | 22.81 | 23.91 | 23.67 | 23.72 | 23.76 | 24.42 | 24.24 | 20.15 | 20.72 | |
| Mass of container (c ) | 13.94 | 11.64 | 13.71 | 12.29 | 13.61 | 13.64 | 13.77 | 13.35 | 13.12 | 13.58 | |
| Mass of moisture (d = a-b) | 4.21 | 6.04 | 5.16 | 5.76 | 5.35 | 5.28 | 6.03 | 6.16 | 2.21 | 2.05 | |
| Mass of dry soil (e = b-c) | 10.02 | 11.17 | 10.20 | 11.38 | 10.21 | 10.12 | 10.65 | 10.89 | 7.03 | 7.14 | |
| Moisture content (w =100X(d)/(e) | 42.02 | 54.07 | 50.59 | 50.62 | 52.40 | 52.17 | 56.62 | 56.57 | 31.44 | 28.71 | |
| Average Moisture content | 48.0 | | 50.6 | | 52.3 | | 56.6 | | 30.1 | | |




| | | |
|---|---|---|
| Natural moisture content | | % |
| Sample Preparation | | |
| a) as received | | |
| b) air dried | | °C |
| c) washed on 0.425 ㎛ | | |
| d) oven dried | 105-110 | °C |
| e) unknown | | |
| Proportion pasing 0.425 ㎛ | | % |
| Liquid limit; LL | 52.1 | % |
| Plastic limit PL | 30.1 | % |
| Plastic Index PI | 22.1 | % |

### LINEAR SHRINKAGE

| | | | | | |
|---|---|---|---|---|---|
| Initial length $L_o$ mm | 140 | mm | Oven-dried length $L_D$ mm | 127.5 | mm |
| Linear shrinkage, LS = 100X(1-$L_D$/$L_o$) % | 9.1 | % | Shrinkage Product, SP=LSX %<425 µm | 0 | |

*Checked by:* Laboratory Engineer

*Approved by:* Senior Laboratory Engineer

GETLAB LTD Geotechnical Engineering & Technology Laboratory Ltd P.O. Box 10081, Kampala

30 JAN 2025

/FORM/SO/06 ISSUE 02

1

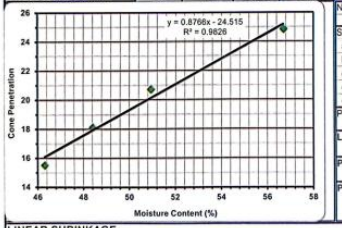
GETLAB LTD
YOUR RELIABLE ENGINEERING LABORATORY

## DETERMINIATION OF LIQUID LIMIT & PLASTIC LIMIT

BS 1377-2:1990

| | |
|---|---|
| Project: | HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION |
| STUDENT | MAMFA MAYALA and AHABWE MARTHA |
| Sample Location: | SHIKURUWE Village |
| Sample Reference: | 165,2 |
| Sample Depth (m): | 1m |
| Sampling Date: | 1/20/2025 |
| Testing Date: | 25/Jan/25 |
| Technician: | BAKAKI MICHAEL |
| Client Reference | TP03 |

| LIQUID LIMIT | | | | | | | | | PLASTIC LIMIT | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TEST NO. | 1 | | 2 | | 3 | | 4 | | 1 | 2 | Average |
| Initial dial gauge reading mm | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| Final dial gauge reading mm | 15.55 | 15.55 | 18.15 | 18.15 | 20.75 | 20.75 | 24.86 | 24.86 | | | |
| Average penetration mm | 15.6 | | 18.2 | | 20.8 | | 24.9 | | | | |
| Container No. | 69 | AV | 990 | TN | 23 | 67 | 154 | 164 | 59 | BM7 | |
| Mass of wet soil + container (a) | 30.53 | 30.54 | 31.93 | 31.62 | 32.94 | 32.86 | 34.52 | 34.07 | 22.82 | 22.64 | |
| Mass of dry soil + container (b) | 25.21 | 24.85 | 25.81 | 25.55 | 26.27 | 26.24 | 26.65 | 26.13 | 20.82 | 20.43 | |
| Mass of container (c ) | 13.76 | 12.52 | 13.09 | 13.09 | 13.33 | 13.08 | 12.90 | 11.99 | 13.68 | 13.56 | |
| Mass of moisture (d = a-b) | 5.32 | 5.69 | 6.12 | 6.07 | 6.67 | 6.62 | 7.87 | 7.94 | 2.00 | 2.21 | |
| Mass of dry soil (e = b-c) | 11.45 | 12.33 | 12.72 | 12.46 | 12.94 | 13.16 | 13.75 | 14.14 | 7.14 | 6.87 | |
| Moisture content (w =100X(d)/(e) | 46.46 | 46.15 | 48.11 | 48.72 | 51.55 | 50.30 | 57.24 | 56.15 | 28.01 | 32.17 | |
| Average Moisture content | 46.3 | | 48.4 | | 50.9 | | 56.7 | | 30.1 | | |




| | | |
|---|---|---|
| Natural moisture content | | % |
| Sample Preparation | | |
| a) as received | | |
| b) air dried | | °C |
| c) washed on 0.425 ㎛ | | |
| d) oven dried | 105-110 | °C |
| e) unknown | | |
| Proportion pasing 0.425 ㎛ | | % |
| Liquid limit; LL | 50.8 | % |
| Plastic limit PL | 30.1 | % |
| Plastic Index PI | 20.7 | % |

### LINEAR SHRINKAGE

| | | | | | |
|---|---|---|---|---|---|
| Initial length $L_o$ mm | 140 | mm | Oven-dried length $L_D$ mm | 127.5 | mm |
| Linear shrinkage, LS = 100X(1-$L_D$/$L_o$) % | 9.1 | % | Shrinkage Product, SP=LSX %<425 µm | 0 | |

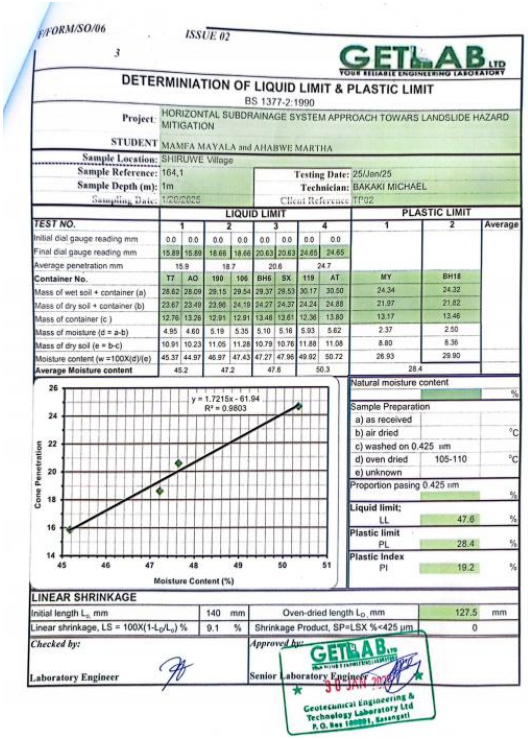
*Checked by:* Laboratory Engineer

*Approved by:* Senior Laboratory Engineer

GETLAB LTD Geotechnical Engineering & Technology Laboratory Ltd P.O. Box 10081, Kampala

30 JAN 2025

Atterberg Limit test for pit 1



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GETLAB LTD — YOUR RELIABLE ENGINEERING LABORATORY

**DETERMINIATION OF LIQUID LIMIT & PLASTIC LIMIT**

BS 1377-2:1990

Project: HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

STUDENT: MAMFA MAYALA and AHABWE MARTHA

Sample Location: SHIRUWE Village
Sample Reference: 164,1
Sample Depth (m): 1m
Sampling Date: 1/06/2025
Testing Date: 25/Jan/25
Technician: BAKAKI MICHAEL
Client Reference: TP02

| LIQUID LIMIT | | | | | | | | | PLASTIC LIMIT | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TEST NO. | 1 | | 2 | | 3 | | 4 | | 1 | 2 | Average |
| Initial dial gauge reading mm | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| Final dial gauge reading mm | 15.89 | 15.89 | 18.66 | 18.66 | 20.63 | 20.63 | 24.65 | 24.65 | | | |
| Average penetration mm | 15.9 | | 18.7 | | 20.6 | | 24.7 | | | | |
| Container No. | T7 | AO | 100 | 106 | BH6 | 5X | 119 | AT | MY | BH18 | |
| Mass of wet soil + container (a) | 28.62 | 28.09 | 29.15 | 29.54 | 29.37 | 29.53 | 30.17 | 30.50 | 24.34 | 24.32 | |
| Mass of dry soil + container (b) | 23.67 | 23.49 | 23.96 | 24.19 | 24.27 | 24.37 | 24.24 | 24.86 | 21.97 | 21.82 | |
| Mass of container (c ) | 12.76 | 13.26 | 12.91 | 12.91 | 13.48 | 13.61 | 12.36 | 13.80 | 13.17 | 13.46 | |
| Mass of moisture (d = a-b) | 4.95 | 4.60 | 5.19 | 5.35 | 5.10 | 5.16 | 5.93 | 5.62 | 2.37 | 2.50 | |
| Mass of dry soil (e = b-c) | 10.91 | 10.23 | 11.05 | 11.28 | 10.79 | 10.76 | 11.88 | 11.08 | 8.80 | 8.36 | |
| Moisture content (w =100X(d)/(e) | 45.37 | 44.97 | 46.97 | 47.43 | 47.27 | 47.96 | 49.92 | 50.72 | 26.93 | 29.90 | |
| Average Moisture content | 45.2 | | 47.2 | | 47.6 | | 50.3 | | 28.4 | | |




Natural moisture content: %

Sample Preparation
a) as received
b) air dried °C
c) washed on 0.425 µm
d) oven dried 105-110 °C
e) unknown

Proportion pasing 0.425 µm: %

Liquid limit; LL: 47.6 %

Plastic limit PL: 28.4 %

Plastic Index PI: 19.2 %

**LINEAR SHRINKAGE**

| | | | | | |
|---|---|---|---|---|---|
| Initial length $L_o$ mm | 140 | mm | Oven-dried length $L_D$ mm | 127.5 | mm |
| Linear shrinkage, LS = 100X(1-$L_D$/$L_o$) % | 9.1 | % | Shrinkage Product, SP=LSX %<425 µm | 0 | |

Checked by: Laboratory Engineer

Approved by: Senior Laboratory Engineer

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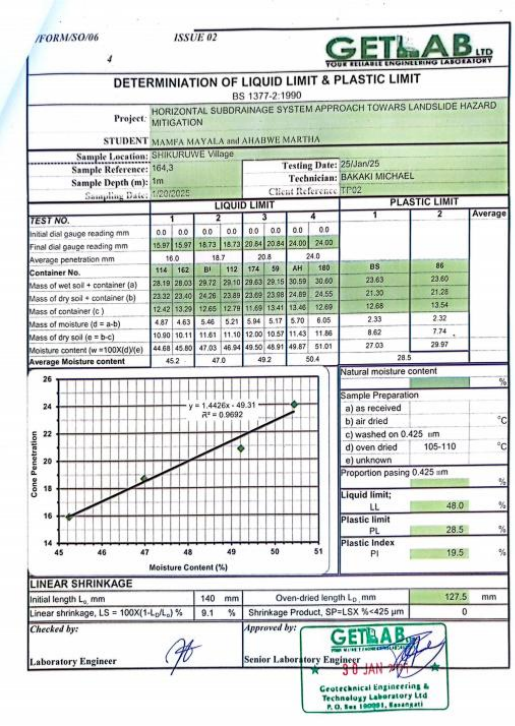

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GETLAB LTD — YOUR RELIABLE ENGINEERING LABORATORY

**DETERMINIATION OF LIQUID LIMIT & PLASTIC LIMIT**

BS 1377-2:1990

Project: HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

STUDENT: MAMFA MAYALA and AHABWE MARTHA

Sample Location: SHIKURUWE Village
Sample Reference: 164,3
Sample Depth (m): 1m
Sampling Date: 1/06/2025
Testing Date: 25/Jan/25
Technician: BAKAKI MICHAEL
Client Reference: TP02

| LIQUID LIMIT | | | | | | | | | PLASTIC LIMIT | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TEST NO. | 1 | | 2 | | 3 | | 4 | | 1 | 2 | Average |
| Initial dial gauge reading mm | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| Final dial gauge reading mm | 15.97 | 15.97 | 18.73 | 18.73 | 20.84 | 20.84 | 24.09 | 24.09 | | | |
| Average penetration mm | 16.0 | | 18.7 | | 20.8 | | 24.0 | | | | |
| Container No. | 114 | 162 | B1 | 112 | 174 | 59 | AH | 180 | B5 | B6 | |
| Mass of wet soil + container (a) | 28.19 | 28.03 | 29.72 | 29.10 | 29.63 | 29.15 | 30.59 | 30.60 | 23.63 | 23.60 | |
| Mass of dry soil + container (b) | 23.32 | 23.40 | 24.26 | 23.89 | 23.69 | 23.98 | 24.89 | 24.55 | 21.30 | 21.28 | |
| Mass of container (c ) | 12.42 | 13.29 | 12.65 | 12.79 | 11.69 | 13.41 | 13.46 | 12.89 | 12.88 | 13.54 | |
| Mass of moisture (d = a-b) | 4.87 | 4.63 | 5.46 | 5.21 | 5.94 | 5.17 | 5.70 | 6.05 | 2.33 | 2.32 | |
| Mass of dry soil (e = b-c) | 10.90 | 10.11 | 11.61 | 11.10 | 12.00 | 10.57 | 11.43 | 11.86 | 8.62 | 7.74 | |
| Moisture content (w =100X(d)/(e) | 44.68 | 45.80 | 47.03 | 46.94 | 49.50 | 48.91 | 49.87 | 51.01 | 27.03 | 29.97 | |
| Average Moisture content | 45.2 | | 47.0 | | 49.2 | | 50.4 | | 28.5 | | |




Natural moisture content: %

Sample Preparation
a) as received
b) air dried °C
c) washed on 0.425 µm
d) oven dried 105-110 °C
e) unknown

Proportion pasing 0.425 µm: %

Liquid limit; LL: 48.0 %

Plastic limit PL: 28.5 %

Plastic Index PI: 19.5 %

**LINEAR SHRINKAGE**

| | | | | | |
|---|---|---|---|---|---|
| Initial length $L_o$ mm | 140 | mm | Oven-dried length $L_D$ mm | 127.5 | mm |
| Linear shrinkage, LS = 100X(1-$L_D$/$L_o$) % | 9.1 | % | Shrinkage Product, SP=LSX %<425 µm | 0 | |

Checked by: Laboratory Engineer

Approved by: Senior Laboratory Engineer

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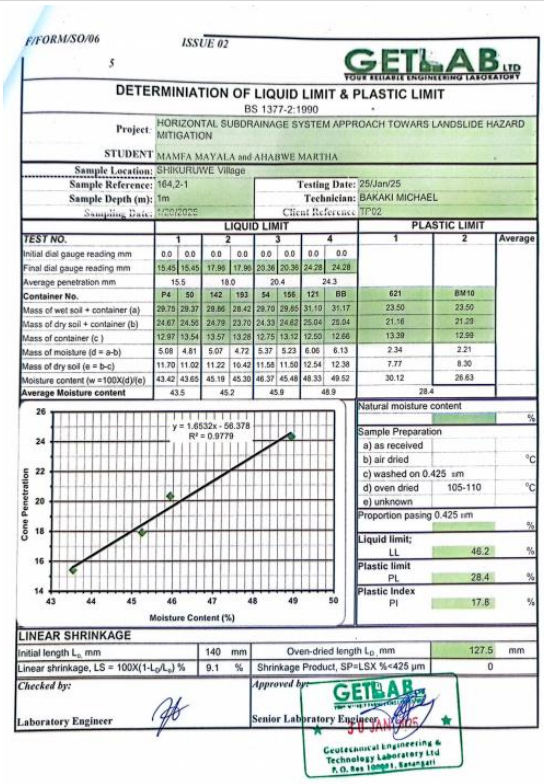

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GETLAB LTD — YOUR RELIABLE ENGINEERING LABORATORY

**DETERMINIATION OF LIQUID LIMIT & PLASTIC LIMIT**

BS 1377-2:1990

Project: HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

STUDENT: MAMFA MAYALA and AHABWE MARTHA

Sample Location: SHIKURUWE Village
Sample Reference: 164,2-1
Sample Depth (m): 1m
Sampling Date: 1/06/2025
Testing Date: 25/Jan/25
Technician: BAKAKI MICHAEL
Client Reference: TP02

| LIQUID LIMIT | | | | | | | | | PLASTIC LIMIT | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TEST NO. | 1 | | 2 | | 3 | | 4 | | 1 | 2 | Average |
| Initial dial gauge reading mm | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| Final dial gauge reading mm | 15.45 | 15.45 | 17.96 | 17.96 | 20.36 | 20.36 | 24.28 | 24.28 | | | |
| Average penetration mm | 15.5 | | 18.0 | | 20.4 | | 24.3 | | | | |
| Container No. | P4 | 50 | 142 | 193 | 54 | 156 | 121 | BB | 621 | BM10 | |
| Mass of wet soil + container (a) | 29.75 | 29.37 | 28.86 | 28.42 | 28.70 | 29.85 | 31.10 | 31.17 | 23.50 | 23.50 | |
| Mass of dry soil + container (b) | 24.67 | 24.56 | 24.79 | 23.70 | 24.33 | 24.62 | 25.04 | 25.04 | 21.16 | 21.29 | |
| Mass of container (c ) | 12.97 | 13.54 | 13.57 | 13.28 | 12.75 | 13.12 | 12.50 | 12.66 | 13.39 | 12.99 | |
| Mass of moisture (d = a-b) | 5.08 | 4.81 | 5.07 | 4.72 | 5.37 | 5.23 | 6.06 | 6.13 | 2.34 | 2.21 | |
| Mass of dry soil (e = b-c) | 11.70 | 11.02 | 11.22 | 10.42 | 11.58 | 11.50 | 12.54 | 12.38 | 7.77 | 8.30 | |
| Moisture content (w =100X(d)/(e) | 43.42 | 43.65 | 45.19 | 45.30 | 46.37 | 45.48 | 48.33 | 49.52 | 30.12 | 26.63 | |
| Average Moisture content | 43.5 | | 45.2 | | 45.9 | | 48.9 | | 28.4 | | |




Natural moisture content: %

Sample Preparation
a) as received
b) air dried °C
c) washed on 0.425 µm
d) oven dried 105-110 °C
e) unknown

Proportion pasing 0.425 µm: %

Liquid limit; LL: 46.2 %

Plastic limit PL: 28.4 %

Plastic Index PI: 17.8 %

**LINEAR SHRINKAGE**

| | | | | | |
|---|---|---|---|---|---|
| Initial length $L_o$ mm | 140 | mm | Oven-dried length $L_D$ mm | 127.5 | mm |
| Linear shrinkage, LS = 100X(1-$L_D$/$L_o$) % | 9.1 | % | Shrinkage Product, SP=LSX %<425 µm | 0 | |

Checked by: Laboratory Engineer

Approved by: Senior Laboratory Engineer

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Atterberg Limit test for pit 2

FORM/SO/06 ISSUE 02

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GETLAB LTD
YOUR RELIABLE ENGINEERING LABORATORY

## DETERMINIATION OF LIQUID LIMIT & PLASTIC LIMIT

BS 1377-2:1990

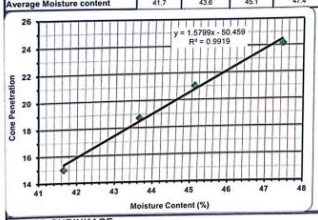
**Project:** HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

**STUDENT** MAMFA MAYALA and AHABWE MARTHA

**Sample Location:** SHIKURUWE Village
**Sample Reference:** 163,2
**Sample Depth (m):** 1m
Sampling Date: 1/20/2025

**Testing Date:** 25/Jan/25
**Technician:** BAKAKI MICHAEL
Client Reference: TP01

| TEST NO. | LIQUID LIMIT 1 | | 2 | | 3 | | 4 | | PLASTIC LIMIT 1 | 2 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial dial gauge reading mm | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| Final dial gauge reading mm | 15.03 | 15.03 | 18.75 | 18.75 | 21.07 | 21.07 | 24.20 | 24.20 | | | |
| Average penetration mm | 15.0 | | 18.8 | | 21.1 | | 24.2 | | | | |
| Container No. | BL | 35 | BH3 | 21 | 26 | BM2 | X05 | 192 | 13 | 89 | |
| Mass of wet soil + container (a) | 28.28 | 28.69 | 29.60 | 29.82 | 28.93 | 28.71 | 32.97 | 32.22 | 22.64 | 22.64 | |
| Mass of dry soil + container (b) | 23.70 | 24.25 | 24.52 | 24.86 | 23.89 | 23.84 | 26.64 | 26.17 | 20.45 | 20.54 | |
| Mass of container (c ) | 12.61 | 13.68 | 12.79 | 13.57 | 12.60 | 13.14 | 13.14 | 13.56 | 12.64 | 12.49 | |
| Mass of moisture (d = a-b) | 4.58 | 4.44 | 5.08 | 4.96 | 5.04 | 4.87 | 6.33 | 6.05 | 2.19 | 2.10 | |
| Mass of dry soil (e = b-c) | 11.09 | 10.57 | 11.73 | 11.29 | 11.29 | 10.70 | 13.50 | 12.61 | 7.61 | 8.05 | |
| Moisture content (w =100X(d)/(e) | 41.30 | 42.01 | 43.31 | 43.93 | 44.64 | 45.51 | 46.89 | 47.98 | 28.78 | 26.09 | |
| Average Moisture content | 41.7 | | 43.6 | | 45.1 | | 47.4 | | 27.4 | | |




Natural moisture content %

Sample Preparation
a) as received
b) air dried °C
c) washed on 0.425 ωm
d) oven dried 105-110 °C
e) unknown
Proportion pasing 0.425 ωm %

Liquid limit; LL 44.6 %
Plastic limit PL 27.4 %
Plastic Index PI 17.2 %

**LINEAR SHRINKAGE**

| | | | | |
|---|---|---|---|---|
| Initial length $L_o$ mm | 140 mm | Oven-dried length $L_D$ mm | | 127.5 mm |
| Linear shrinkage, LS = 100X(1-$L_D$/$L_o$) % | 9.1 % | Shrinkage Product, SP=LSX %<425 µm | | 0 |

*Checked by:* Laboratory Engineer

*Approved by:* Senior Laboratory Engineer

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FORM/SO/06 ISSUE 02

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GETLAB LTD
YOUR RELIABLE ENGINEERING LABORATORY

## DETERMINIATION OF LIQUID LIMIT & PLASTIC LIMIT

BS 1377-2:1990

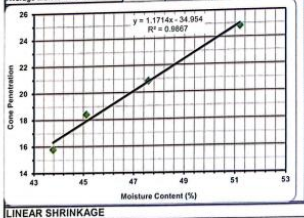
**Project:** HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

**STUDENT** MAMFA MAYALA and AHABWE MARTHA

**Sample Location:** SHIKURUWE Village
**Sample Reference:** 163,3
**Sample Depth (m):** 1m
Sampling Date: 1/20/2025

**Testing Date:** 25/Jan/25
**Technician:** BAKAKI MICHAEL
Client Reference: TP01

| TEST NO. | LIQUID LIMIT 1 | | 2 | | 3 | | 4 | | PLASTIC LIMIT 1 | 2 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial dial gauge reading mm | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| Final dial gauge reading mm | 15.82 | 15.82 | 18.44 | 18.44 | 20.88 | 20.88 | 24.85 | 24.85 | | | |
| Average penetration mm | 15.8 | | 18.4 | | 20.9 | | 24.9 | | | | |
| Container No. | SG3 | S5 | MS | 17 | 176 | 24 | SG4 | 46 | AY | 155 | |
| Mass of wet soil + container (a) | 23.63 | 23.87 | 25.99 | 25.67 | 29.57 | 29.99 | 31.33 | 31.99 | 21.32 | 21.96 | |
| Mass of dry soil + container (b) | 20.50 | 20.43 | 22.07 | 21.92 | 23.85 | 24.53 | 25.26 | 25.73 | 19.54 | 20.20 | |
| Mass of container (c ) | 13.36 | 12.57 | 13.50 | 13.49 | 11.88 | 13.19 | 13.41 | 13.49 | 13.38 | 13.29 | |
| Mass of moisture (d = a-b) | 3.13 | 3.44 | 3.92 | 3.75 | 5.72 | 5.37 | 6.07 | 6.26 | 1.78 | 1.76 | |
| Mass of dry soil (e = b-c) | 7.15 | 7.86 | 8.57 | 8.43 | 11.97 | 11.34 | 11.85 | 12.24 | 6.16 | 6.91 | |
| Moisture content (w =100X(d)/(e) | 43.78 | 43.77 | 45.74 | 44.48 | 47.79 | 47.35 | 51.22 | 51.14 | 28.90 | 25.47 | |
| Average Moisture content | 43.8 | | 45.1 | | 47.6 | | 51.2 | | 27.2 | | |




Natural moisture content %

Sample Preparation
a) as received
b) air dried °C
c) washed on 0.425 ωm
d) oven dried 105-110 °C
e) unknown
Proportion pasing 0.425 ωm %

Liquid limit; LL 46.9 %
Plastic limit PL 27.2 %
Plastic Index PI 19.7 %

**LINEAR SHRINKAGE**

| | | | | |
|---|---|---|---|---|
| Initial length $L_o$ mm | 140 mm | Oven-dried length $L_D$ mm | | 127.5 mm |
| Linear shrinkage, LS = 100X(1-$L_D$/$L_o$) % | 9.1 % | Shrinkage Product, SP=LSX %<425 µm | | 0 |

*Checked by:* Laboratory Engineer

*Approved by:* Senior Laboratory Engineer

GETLAB LTD — 30 JAN 2025 — Geotechnical Engineering & Technology Laboratory Ltd P. O. Box 100081, Kasangati

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GETLAB LTD
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## DETERMINIATION OF LIQUID LIMIT & PLASTIC LIMIT

BS 1377-2:1990

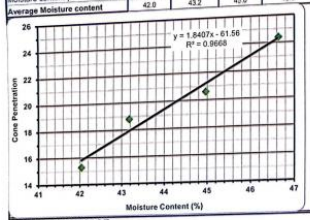
**Project:** HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

**STUDENT** MAMFA MAYALA and AHABWE MARTHA

**Sample Location:** SHIKURUWE Village
**Sample Reference:** 163,1
**Sample Depth (m):** 1m
Sampling Date: 1/20/2025

**Testing Date:** 25/Jan/25
**Technician:** BAKAKI MICHAEL
Client Reference: TP01

| TEST NO. | LIQUID LIMIT 1 | | 2 | | 3 | | 4 | | PLASTIC LIMIT 1 | 2 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial dial gauge reading mm | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | | |
| Final dial gauge reading mm | 15.33 | 15.33 | 18.83 | 18.83 | 20.63 | 20.63 | 24.41 | 24.41 | | | |
| Average penetration mm | 15.3 | | 18.8 | | 20.6 | | 24.4 | | | | |
| Container No. | 90 | 163 | BH1 | 67 | BY | 33 | 180 | 178 | WX | 181 | |
| Mass of wet soil + container (a) | 28.02 | 28.15 | 29.54 | 29.60 | 29.81 | 29.20 | 32.14 | 32.42 | 22.66 | 22.01 | |
| Mass of dry soil + container (b) | 23.70 | 23.64 | 24.34 | 25.09 | 24.49 | 24.21 | 26.26 | 26.31 | 20.59 | 20.01 | |
| Mass of container (c ) | 13.48 | 12.78 | 12.39 | 13.86 | 12.69 | 13.08 | 13.62 | 13.24 | 13.68 | 12.58 | |
| Mass of moisture (d = a-b) | 4.32 | 4.54 | 5.20 | 4.81 | 5.32 | 4.99 | 5.88 | 6.11 | 2.07 | 2.00 | |
| Mass of dry soil (e = b-c) | 10.22 | 10.86 | 11.95 | 11.23 | 11.80 | 11.13 | 12.64 | 13.07 | 6.91 | 7.43 | |
| Moisture content (w =100X(d)/(e) | 42.27 | 41.80 | 43.51 | 42.83 | 45.08 | 44.83 | 46.52 | 46.75 | 29.96 | 26.92 | |
| Average Moisture content | 42.0 | | 43.2 | | 45.0 | | 46.6 | | 28.4 | | |




Natural moisture content %

Sample Preparation
a) as received
b) air dried °C
c) washed on 0.425 ωm
d) oven dried 105-110 °C
e) unknown
Proportion pasing 0.425 ωm %

Liquid limit; LL 44.3 %
Plastic limit PL 28.4 %
Plastic Index PI 15.9 %

**LINEAR SHRINKAGE**

| | | | | |
|---|---|---|---|---|
| Initial length $L_o$ mm | 140 mm | Oven-dried length $L_D$ mm | | 127.5 mm |
| Linear shrinkage, LS = 100X(1-$L_D$/$L_o$) % | 9.1 % | Shrinkage Product, SP=LSX %<425 µm | | 0 |

*Checked by:* Laboratory Engineer

*Approved by:* Senior Laboratory Engineer

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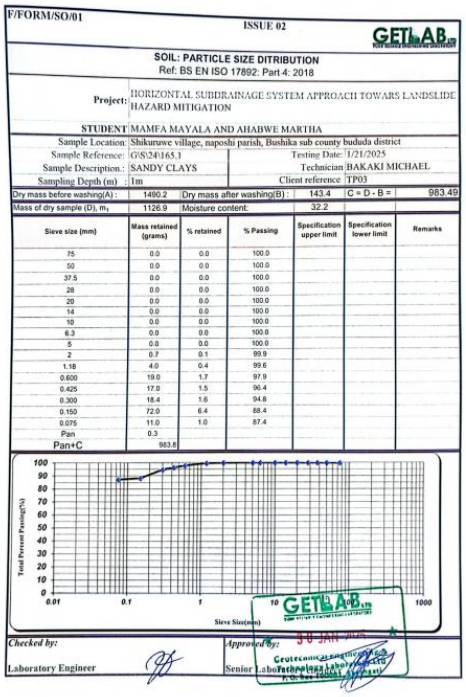
Atterberg test for pit 3



F/FORM/SO/01 ISSUE 02

SOIL: PARTICLE SIZE DITRIBUTION
Ref: BS EN ISO 17892: Part 4: 2018

Project: HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

STUDENT: MAMFA MAYALA AND AHABWE MARTHA

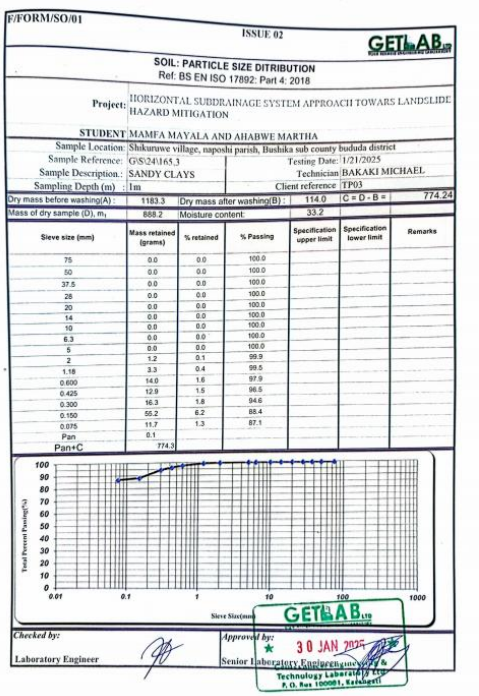
Sample Location: Shikuruwe village, naposhi parish, Bushika sub county bududa district
Sample Reference: G\S\24\165.1 — Testing Date: 1/21/2025
Sample Description.: SANDY CLAYS — Technician: BAKAKI MICHAEL
Sampling Depth (m): 1m — Client reference: TP03

Dry mass before washing(A): 1490.2 — Dry mass after washing(B): 143.4 — C = D - B = 983.49
Mass of dry sample (D), $m_1$: 1126.9 — Moisture content: 32.2

| Sieve size (mm) | Mass retained (grams) | % retained | % Passing | Specification upper limit | Specification lower limit | Remarks |
|---|---|---|---|---|---|---|
| 75 | 0.0 | 0.0 | 100.0 | | | |
| 50 | 0.0 | 0.0 | 100.0 | | | |
| 37.5 | 0.0 | 0.0 | 100.0 | | | |
| 28 | 0.0 | 0.0 | 100.0 | | | |
| 20 | 0.0 | 0.0 | 100.0 | | | |
| 14 | 0.0 | 0.0 | 100.0 | | | |
| 10 | 0.0 | 0.0 | 100.0 | | | |
| 6.3 | 0.0 | 0.0 | 100.0 | | | |
| 5 | 0.0 | 0.0 | 100.0 | | | |
| 2 | 0.7 | 0.1 | 99.9 | | | |
| 1.18 | 4.0 | 0.4 | 99.6 | | | |
| 0.600 | 19.0 | 1.7 | 97.9 | | | |
| 0.425 | 17.0 | 1.5 | 96.4 | | | |
| 0.300 | 18.4 | 1.6 | 94.8 | | | |
| 0.150 | 72.0 | 6.4 | 88.4 | | | |
| 0.075 | 11.0 | 1.0 | 87.4 | | | |
| Pan | 0.3 | | | | | |
| Pan+C | 983.8 | | | | | |



Checked by: Laboratory Engineer
Approved by: Senior Laboratory Engineer — 30 JAN 2025 — Geotechnical Engineering Laboratory Ltd, P. O. Box 150081, Kampala



F/FORM/SO/01 ISSUE 02

SOIL: PARTICLE SIZE DITRIBUTION
Ref: BS EN ISO 17892: Part 4: 2018

Project: HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

STUDENT: MAMFA MAYALA AND AHABWE MARTHA

Sample Location: Shikuruwe village, naposhi parish, Bushika sub county bududa district
Sample Reference: G\S\24\165.3 — Testing Date: 1/21/2025
Sample Description.: SANDY CLAYS — Technician: BAKAKI MICHAEL
Sampling Depth (m): 1m — Client reference: TP03

Dry mass before washing(A): 1183.3 — Dry mass after washing(B): 114.0 — C = D - B = 774.24
Mass of dry sample (D), $m_1$: 888.2 — Moisture content: 33.2

| Sieve size (mm) | Mass retained (grams) | % retained | % Passing | Specification upper limit | Specification lower limit | Remarks |
|---|---|---|---|---|---|---|
| 75 | 0.0 | 0.0 | 100.0 | | | |
| 50 | 0.0 | 0.0 | 100.0 | | | |
| 37.5 | 0.0 | 0.0 | 100.0 | | | |
| 28 | 0.0 | 0.0 | 100.0 | | | |
| 20 | 0.0 | 0.0 | 100.0 | | | |
| 14 | 0.0 | 0.0 | 100.0 | | | |
| 10 | 0.0 | 0.0 | 100.0 | | | |
| 6.3 | 0.0 | 0.0 | 100.0 | | | |
| 5 | 0.0 | 0.0 | 100.0 | | | |
| 2 | 1.2 | 0.1 | 99.9 | | | |
| 1.18 | 3.3 | 0.4 | 99.5 | | | |
| 0.600 | 14.0 | 1.6 | 97.9 | | | |
| 0.425 | 12.9 | 1.5 | 96.5 | | | |
| 0.300 | 16.3 | 1.8 | 94.6 | | | |
| 0.150 | 55.2 | 6.2 | 88.4 | | | |
| 0.075 | 11.7 | 1.3 | 87.1 | | | |
| Pan | 0.1 | | | | | |
| Pan+C | 774.3 | | | | | |



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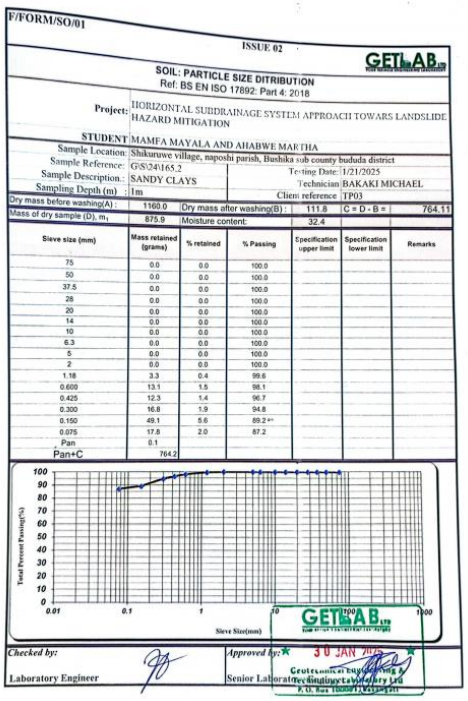

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SOIL: PARTICLE SIZE DITRIBUTION
Ref: BS EN ISO 17892: Part 4: 2018

Project: HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

STUDENT: MAMFA MAYALA AND AHABWE MARTHA

Sample Location: Shikuruwe village, naposhi parish, Bushika sub county bududa district
Sample Reference: G\S\24\165.2 — Testing Date: 1/21/2025
Sample Description.: SANDY CLAYS — Technician: BAKAKI MICHAEL
Sampling Depth (m): 1m — Client reference: TP03

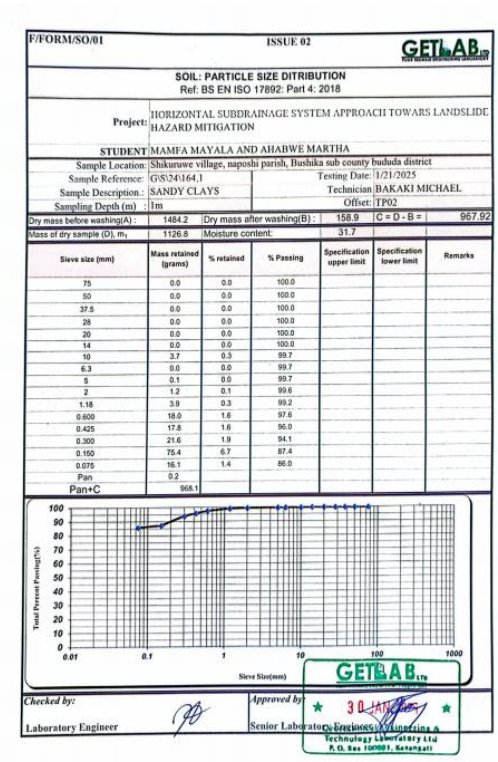
Dry mass before washing(A): 1160.0 — Dry mass after washing(B): 111.8 — C = D - B = 764.11
Mass of dry sample (D), $m_1$: 875.9 — Moisture content: 32.4

| Sieve size (mm) | Mass retained (grams) | % retained | % Passing | Specification upper limit | Specification lower limit | Remarks |
|---|---|---|---|---|---|---|
| 75 | 0.0 | 0.0 | 100.0 | | | |
| 50 | 0.0 | 0.0 | 100.0 | | | |
| 37.5 | 0.0 | 0.0 | 100.0 | | | |
| 28 | 0.0 | 0.0 | 100.0 | | | |
| 20 | 0.0 | 0.0 | 100.0 | | | |
| 14 | 0.0 | 0.0 | 100.0 | | | |
| 10 | 0.0 | 0.0 | 100.0 | | | |
| 6.3 | 0.0 | 0.0 | 100.0 | | | |
| 5 | 0.0 | 0.0 | 100.0 | | | |
| 2 | 0.0 | 0.0 | 100.0 | | | |
| 1.18 | 3.3 | 0.4 | 99.6 | | | |
| 0.600 | 13.1 | 1.5 | 98.1 | | | |
| 0.425 | 12.3 | 1.4 | 96.7 | | | |
| 0.300 | 16.8 | 1.9 | 94.8 | | | |
| 0.150 | 49.1 | 5.6 | 89.2+- | | | |
| 0.075 | 17.8 | 2.0 | 87.2 | | | |
| Pan | 0.1 | | | | | |
| Pan+C | 764.2 | | | | | |



Checked by: Laboratory Engineer
Approved by: Senior Laboratory Engineer — 30 JAN 2025 — Geotechnical Engineering Laboratory Ltd, P. O. Box 150081, Kampala

Particle size distribution for pit 1



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SOIL: PARTICLE SIZE DITRIBUTION
Ref: BS EN ISO 17892: Part 4: 2018

| | |
|---|---|
| Project: | HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION |
| STUDENT | MAMFA MAYALA AND AHABWE MARTHA |
| Sample Location: | Shukuruwe village, naposhi parish, Bushika sub county bududa district |
| Sample Reference: | G\S\24\164.1 |
| Sample Description.: | SANDY CLAYS |
| Sampling Depth (m) : | 1m |
| Testing Date: | 1/21/2025 |
| Technician | BAKAKI MICHAEL |
| Offset: | TP02 |

| | | | | | |
|---|---|---|---|---|---|
| Dry mass before washing(A) : | 1484.2 | Dry mass after washing(B) : | 158.9 | C = D - B = | 967.92 |
| Mass of dry sample (D), $m_1$ | 1126.8 | Moisture content: | 31.7 | | |

| Sieve size (mm) | Mass retained (grams) | % retained | % Passing | Specification upper limit | Specification lower limit | Remarks |
|---|---|---|---|---|---|---|
| 75 | 0.0 | 0.0 | 100.0 | | | |
| 50 | 0.0 | 0.0 | 100.0 | | | |
| 37.5 | 0.0 | 0.0 | 100.0 | | | |
| 28 | 0.0 | 0.0 | 100.0 | | | |
| 20 | 0.0 | 0.0 | 100.0 | | | |
| 14 | 0.0 | 0.0 | 100.0 | | | |
| 10 | 3.7 | 0.3 | 99.7 | | | |
| 6.3 | 0.0 | 0.0 | 99.7 | | | |
| 5 | 0.1 | 0.0 | 99.7 | | | |
| 2 | 1.2 | 0.1 | 99.6 | | | |
| 1.18 | 3.9 | 0.3 | 99.2 | | | |
| 0.600 | 18.0 | 1.6 | 97.6 | | | |
| 0.425 | 17.8 | 1.6 | 96.0 | | | |
| 0.300 | 21.6 | 1.9 | 94.1 | | | |
| 0.150 | 75.4 | 6.7 | 87.4 | | | |
| 0.075 | 16.1 | 1.4 | 86.0 | | | |
| Pan | 0.2 | | | | | |
| Pan+C | 968.1 | | | | | |




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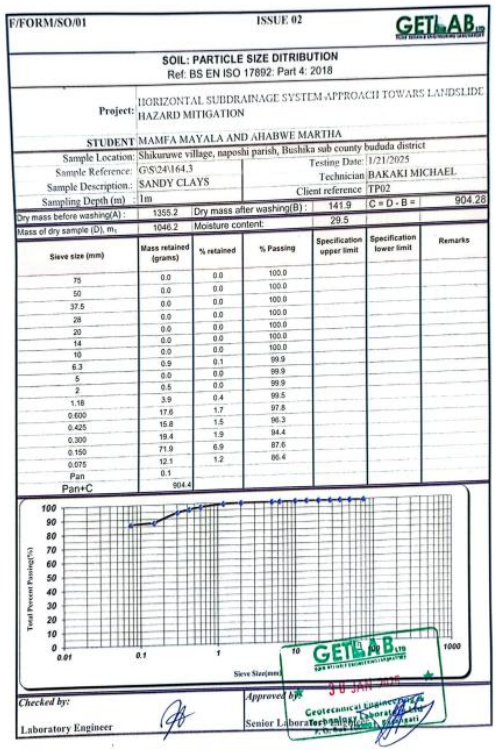

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SOIL: PARTICLE SIZE DITRIBUTION
Ref: BS EN ISO 17892: Part 4: 2018

| | |
|---|---|
| Project: | HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION |
| STUDENT | MAMFA MAYALA AND AHABWE MARTHA |
| Sample Location: | Shukuruwe village, naposhi parish, Bushika sub county bududa district |
| Sample Reference: | G\S\24\164.3 |
| Sample Description.: | SANDY CLAYS |
| Sampling Depth (m) : | 1m |
| Testing Date: | 1/21/2025 |
| Technician | BAKAKI MICHAEL |
| Client reference | TP02 |

| | | | | | |
|---|---|---|---|---|---|
| Dry mass before washing(A) : | 1355.2 | Dry mass after washing(B) : | 141.9 | C = D - B = | 904.28 |
| Mass of dry sample (D), $m_1$ | 1046.2 | Moisture content: | 29.5 | | |

| Sieve size (mm) | Mass retained (grams) | % retained | % Passing | Specification upper limit | Specification lower limit | Remarks |
|---|---|---|---|---|---|---|
| 75 | 0.0 | 0.0 | 100.0 | | | |
| 50 | 0.0 | 0.0 | 100.0 | | | |
| 37.5 | 0.0 | 0.0 | 100.0 | | | |
| 28 | 0.0 | 0.0 | 100.0 | | | |
| 20 | 0.0 | 0.0 | 100.0 | | | |
| 14 | 0.0 | 0.0 | 100.0 | | | |
| 10 | 0.0 | 0.0 | 100.0 | | | |
| 6.3 | 0.9 | 0.1 | 99.9 | | | |
| 5 | 0.0 | 0.0 | 99.9 | | | |
| 2 | 0.5 | 0.0 | 99.9 | | | |
| 1.18 | 3.9 | 0.4 | 99.5 | | | |
| 0.600 | 17.6 | 1.7 | 97.8 | | | |
| 0.425 | 15.8 | 1.5 | 96.3 | | | |
| 0.300 | 19.4 | 1.9 | 94.4 | | | |
| 0.150 | 71.9 | 6.9 | 87.6 | | | |
| 0.075 | 12.1 | 1.2 | 86.4 | | | |
| Pan | 0.1 | | | | | |
| Pan+C | 904.4 | | | | | |




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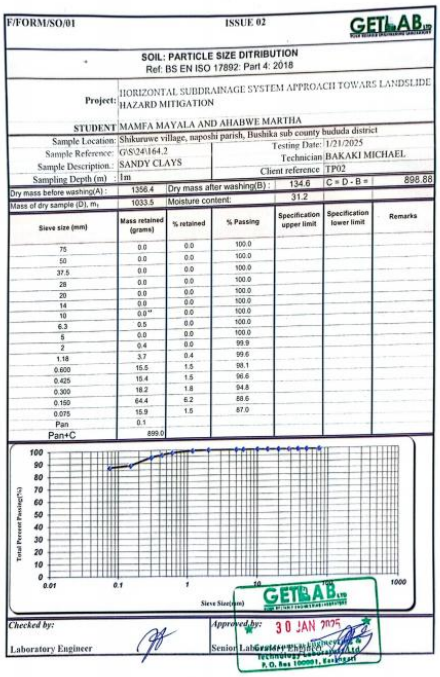

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SOIL: PARTICLE SIZE DITRIBUTION
Ref: BS EN ISO 17892: Part 4: 2018

| | |
|---|---|
| Project: | HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION |
| STUDENT | MAMFA MAYALA AND AHABWE MARTHA |
| Sample Location: | Shukuruwe village, naposhi parish, Bushika sub county bududa district |
| Sample Reference: | G\S\24\164.2 |
| Sample Description.: | SANDY CLAYS |
| Sampling Depth (m) : | 1m |
| Testing Date: | 1/21/2025 |
| Technician | BAKAKI MICHAEL |
| Client reference | TP02 |

| | | | | | |
|---|---|---|---|---|---|
| Dry mass before washing(A) : | 1356.4 | Dry mass after washing(B) : | 134.6 | C = D - B = | 898.88 |
| Mass of dry sample (D), $m_1$ | 1033.5 | Moisture content: | 31.2 | | |

| Sieve size (mm) | Mass retained (grams) | % retained | % Passing | Specification upper limit | Specification lower limit | Remarks |
|---|---|---|---|---|---|---|
| 75 | 0.0 | 0.0 | 100.0 | | | |
| 50 | 0.0 | 0.0 | 100.0 | | | |
| 37.5 | 0.0 | 0.0 | 100.0 | | | |
| 28 | 0.0 | 0.0 | 100.0 | | | |
| 20 | 0.0 | 0.0 | 100.0 | | | |
| 14 | 0.0 | 0.0 | 100.0 | | | |
| 10 | 0.0 | 0.0 | 100.0 | | | |
| 6.3 | 0.5 | 0.0 | 100.0 | | | |
| 5 | 0.0 | 0.0 | 99.9 | | | |
| 2 | 0.4 | 0.0 | 99.6 | | | |
| 1.18 | 3.7 | 0.4 | 99.6 | | | |
| 0.600 | 15.5 | 1.5 | 98.1 | | | |
| 0.425 | 15.4 | 1.5 | 96.6 | | | |
| 0.300 | 18.2 | 1.8 | 94.8 | | | |
| 0.150 | 64.4 | 6.2 | 88.6 | | | |
| 0.075 | 15.9 | 1.5 | 87.0 | | | |
| Pan | 0.1 | | | | | |
| Pan+C | 899.0 | | | | | |




Checked by: Laboratory Engineer

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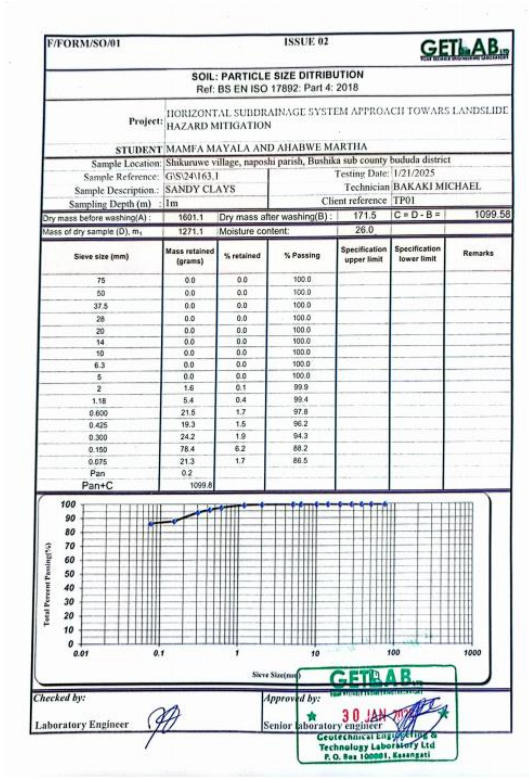
Particle size distribution for pit 2



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SOIL: PARTICLE SIZE DITRIBUTION
Ref: BS EN ISO 17892: Part 4: 2018

Project: HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

STUDENT: MAMFA MAYALA AND AHABWE MARTHA

Sample Location: Shikuruwe village, naposhi parish, Bushika sub county bududa district
Sample Reference: G\S\24\163.1 Testing Date: 1/21/2025
Sample Description.: SANDY CLAYS Technician: BAKAKI MICHAEL
Sampling Depth (m): 1m Client reference: TP01

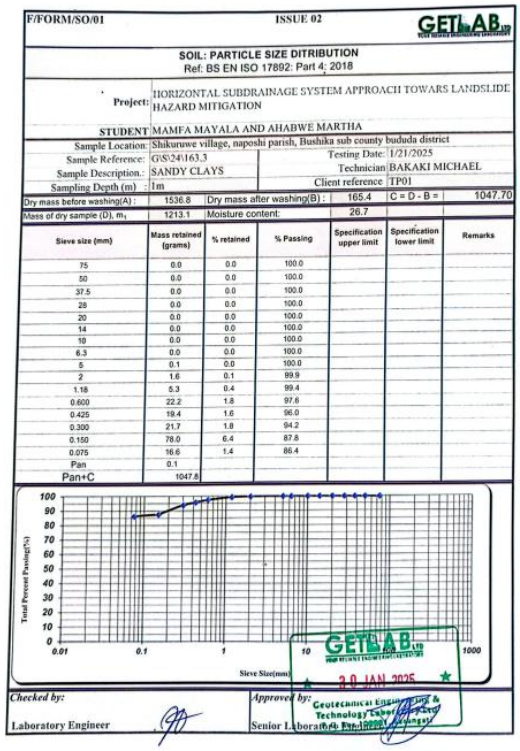
Dry mass before washing(A): 1601.1 Dry mass after washing(B): 171.5 C = D - B = 1099.58
Mass of dry sample (D), $m_s$: 1271.1 Moisture content: 26.0

| Sieve size (mm) | Mass retained (grams) | % retained | % Passing | Specification upper limit | Specification lower limit | Remarks |
|---|---|---|---|---|---|---|
| 75 | 0.0 | 0.0 | 100.0 | | | |
| 50 | 0.0 | 0.0 | 100.0 | | | |
| 37.5 | 0.0 | 0.0 | 100.0 | | | |
| 28 | 0.0 | 0.0 | 100.0 | | | |
| 20 | 0.0 | 0.0 | 100.0 | | | |
| 14 | 0.0 | 0.0 | 100.0 | | | |
| 10 | 0.0 | 0.0 | 100.0 | | | |
| 6.3 | 0.0 | 0.0 | 100.0 | | | |
| 5 | 0.0 | 0.0 | 100.0 | | | |
| 2 | 1.6 | 0.1 | 99.9 | | | |
| 1.18 | 5.4 | 0.4 | 99.4 | | | |
| 0.600 | 21.5 | 1.7 | 97.8 | | | |
| 0.425 | 19.3 | 1.5 | 96.2 | | | |
| 0.300 | 24.2 | 1.9 | 94.3 | | | |
| 0.150 | 78.4 | 6.2 | 88.2 | | | |
| 0.075 | 21.3 | 1.7 | 86.5 | | | |
| Pan | 0.2 | | | | | |
| Pan+C | 1099.8 | | | | | |




Checked by: Laboratory Engineer

Approved by: Senior laboratory engineer 30 JAN 2025
Geotechnical Engineering & Technology Laboratory Ltd P. O. Box 100001, Kasangati



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SOIL: PARTICLE SIZE DITRIBUTION
Ref: BS EN ISO 17892: Part 4: 2018

Project: HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

STUDENT: MAMFA MAYALA AND AHABWE MARTHA

Sample Location: Shikuruwe village, naposhi parish, Bushika sub county bududa district
Sample Reference: G\S\24\163.3 Testing Date: 1/21/2025
Sample Description.: SANDY CLAYS Technician: BAKAKI MICHAEL
Sampling Depth (m): 1m Client reference: TP01

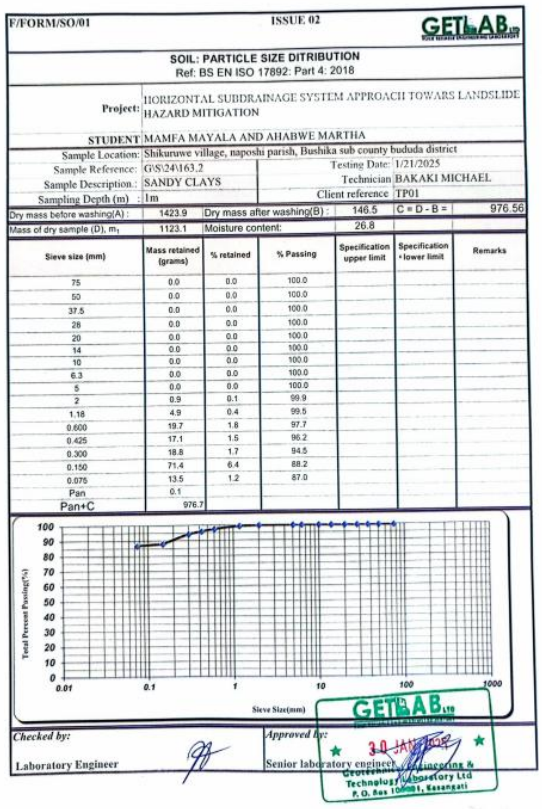
Dry mass before washing(A): 1536.8 Dry mass after washing(B): 165.4 C = D - B = 1047.70
Mass of dry sample (D), $m_s$: 1213.1 Moisture content: 26.7

| Sieve size (mm) | Mass retained (grams) | % retained | % Passing | Specification upper limit | Specification lower limit | Remarks |
|---|---|---|---|---|---|---|
| 75 | 0.0 | 0.0 | 100.0 | | | |
| 50 | 0.0 | 0.0 | 100.0 | | | |
| 37.5 | 0.0 | 0.0 | 100.0 | | | |
| 28 | 0.0 | 0.0 | 100.0 | | | |
| 20 | 0.0 | 0.0 | 100.0 | | | |
| 14 | 0.0 | 0.0 | 100.0 | | | |
| 10 | 0.0 | 0.0 | 100.0 | | | |
| 6.3 | 0.0 | 0.0 | 100.0 | | | |
| 5 | 0.1 | 0.0 | 100.0 | | | |
| 2 | 1.6 | 0.1 | 99.9 | | | |
| 1.18 | 5.3 | 0.4 | 99.4 | | | |
| 0.600 | 22.2 | 1.8 | 97.6 | | | |
| 0.425 | 19.4 | 1.6 | 96.0 | | | |
| 0.300 | 21.7 | 1.8 | 94.2 | | | |
| 0.150 | 78.0 | 6.4 | 87.8 | | | |
| 0.075 | 16.6 | 1.4 | 86.4 | | | |
| Pan | 0.1 | | | | | |
| Pan+C | 1047.8 | | | | | |




Checked by: Laboratory Engineer

Approved by: Senior Laboratory Engineer 30 JAN 2025
Geotechnical Engineering & Technology Laboratory Ltd P. O. Box 100001, Kasangati



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SOIL: PARTICLE SIZE DITRIBUTION
Ref: BS EN ISO 17892: Part 4: 2018

Project: HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

STUDENT: MAMFA MAYALA AND AHABWE MARTHA

Sample Location: Shikuruwe village, naposhi parish, Bushika sub county bududa district
Sample Reference: G\S\24\163.2 Testing Date: 1/21/2025
Sample Description.: SANDY CLAYS Technician: BAKAKI MICHAEL
Sampling Depth (m): 1m Client reference: TP01

Dry mass before washing(A): 1423.9 Dry mass after washing(B): 146.5 C = D - B = 976.56
Mass of dry sample (D), $m_s$: 1123.1 Moisture content: 26.8

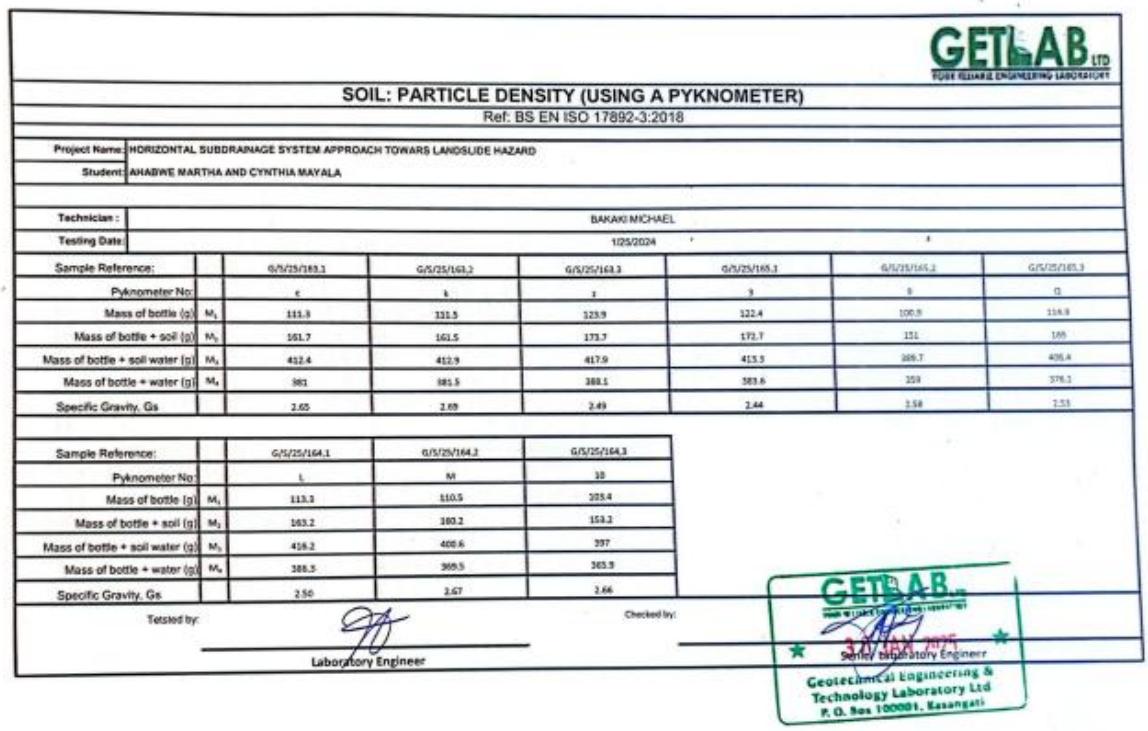
| Sieve size (mm) | Mass retained (grams) | % retained | % Passing | Specification upper limit | Specification lower limit | Remarks |
|---|---|---|---|---|---|---|
| 75 | 0.0 | 0.0 | 100.0 | | | |
| 50 | 0.0 | 0.0 | 100.0 | | | |
| 37.5 | 0.0 | 0.0 | 100.0 | | | |
| 28 | 0.0 | 0.0 | 100.0 | | | |
| 20 | 0.0 | 0.0 | 100.0 | | | |
| 14 | 0.0 | 0.0 | 100.0 | | | |
| 10 | 0.0 | 0.0 | 100.0 | | | |
| 6.3 | 0.0 | 0.0 | 100.0 | | | |
| 5 | 0.0 | 0.0 | 100.0 | | | |
| 2 | 0.9 | 0.1 | 99.9 | | | |
| 1.18 | 4.9 | 0.4 | 99.5 | | | |
| 0.600 | 19.7 | 1.8 | 97.7 | | | |
| 0.425 | 17.1 | 1.5 | 96.2 | | | |
| 0.300 | 18.8 | 1.7 | 94.5 | | | |
| 0.150 | 71.4 | 6.4 | 88.2 | | | |
| 0.075 | 13.5 | 1.2 | 87.0 | | | |
| Pan | 0.1 | | | | | |
| Pan+C | 976.7 | | | | | |




Checked by: Laboratory Engineer

Approved by: Senior laboratory engineer 30 JAN 2025
Geotechnical Engineering & Technology Laboratory Ltd P. O. Box 100001, Kasangati

Particle size distribution for pit 1



GETLAB LTD

SOIL: PARTICLE DENSITY (USING A PYKNOMETER)

Ref: BS EN ISO 17892-3:2018

| | |
|---|---|
| Project Name: | HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD |
| Student: | AHABWE MARTHA AND CYNTHIA MAYALA |
| Technician : | BAKAKI MICHAEL |
| Testing Date: | 1/25/2024 |

| Sample Reference: | | G/S/25/163.1 | G/S/25/163.2 | G/S/25/163.3 | G/S/25/165.1 | G/S/25/165.2 | G/S/25/165.3 |
|---|---|---|---|---|---|---|---|
| Pyknometer No: | | c | k | z | 9 | 8 | G |
| Mass of bottle (g) | $M_1$ | 111.3 | 131.5 | 123.9 | 122.4 | 100.9 | 116.9 |
| Mass of bottle + soil (g) | $M_2$ | 161.7 | 161.5 | 173.7 | 172.7 | 151 | 169 |
| Mass of bottle + soil water (g) | $M_3$ | 412.4 | 412.9 | 417.9 | 413.3 | 389.7 | 406.4 |
| Mass of bottle + water (g) | $M_4$ | 381 | 381.5 | 388.1 | 383.6 | 359 | 376.1 |
| Specific Gravity, Gs | | 2.65 | 2.69 | 2.49 | 2.44 | 2.58 | 2.53 |

| Sample Reference: | | G/S/25/164.1 | G/S/25/164.2 | G/S/25/164.3 |
|---|---|---|---|---|
| Pyknometer No: | | L | M | 10 |
| Mass of bottle (g) | $M_1$ | 113.3 | 110.5 | 105.4 |
| Mass of bottle + soil (g) | $M_2$ | 163.2 | 160.2 | 153.2 |
| Mass of bottle + soil water (g) | $M_3$ | 416.2 | 408.6 | 397 |
| Mass of bottle + water (g) | $M_4$ | 388.5 | 369.5 | 365.9 |
| Specific Gravity, Gs | | 2.50 | 2.67 | 2.66 |

Tested by:

Laboratory Engineer

Checked by:

Senior Laboratory Engineer

GETLAB LTD

30 JAN 2025

Geotechnical Engineering & Technology Laboratory Ltd
P. O. Box 100001, Kasangati

Specific gravity test for pit 1,2,and 3

# CHC ANALYSIS UG LIMITED

## WORK SHEET

CHC

Report No : C25026S

Document No.CHC-WS-028

DETERMINATION OF PERMEABILITY OF SOIL (FALLING HEAD)

Test method: BS EN ISO 17892-11:2019

| | | | | | |
|---|---|---|---|---|---|
| Project: | N/A | | | | |
| Project location | | | Sample depth (m) | N/A | |
| Lab number | C25026S001 | | Trial Pit Number | N/A | |
| Sample Description | Soil | | | | |
| Preparation method | Prepared in accordance with BS 1377-1-2016 | | | | |
| | | Test Records | | | |
| DETAILS OF THE SPECIMEN | | Wet Weight of the sample +Ring | 323 | Initial Moisture content (%) | 35.8 |
| Specimen Diameter( D) cm | 6.00 | Dry Weight of the sample +Ring | 265.0 | Final Moisture content (%) | 35.6 |
| Specimen Height (L) cm | 4.00 | | | | |
| Specimen area (A) cm2 | 28.3 | Bulky Density (kg/m3) | 1938 | Void Ratio e | 0.89 |
| Water Temperature( T) $^{0}$C | 24.5 | Dry Density (kg/m3) | 1402 | | |
| Stand Pipe Area a (cm2) | 0.33 | Specific Gravity | 2.65 | Degree of saturation | 106 |
| Hydrauli gradient | 1.25 | | | | |
| MDD (kg/m3) | 1355 | Compaction(%) | | 103 | |

| Serial No. | Lab No. | Start Time/Date | End Time/Date | Change inTime(sec) Δt | Discharge Q (ml) | Δht1(cm) | Δht2 (cm) | k(m/s) | Average |
|---|---|---|---|---|---|---|---|---|---|
| 1 | C25026S001 | 1:27pm (28/1/2025) | 3:27pm (28/1/2025) | 7200 | 1.659 | 90.0 | 85.0 | 3.73E-09 | 2.44E-09 |
| | | 3:27pm (28/1/2025) | 9:29am (29/1/2025) | 64920 | 8.030 | 85.0 | 60.8 | 2.42E-09 | |
| | | 9:29am (29/1/2025) | 1:01pm (29/1/2025) | 12720 | 0.630 | 60.8 | 58.9 | 1.17E-09 | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

Technician:Barbrah Checked Titus Date: 29/01/2025



Falling Head permeability test for pit 1

# CHC ANALYSIS UG LIMITED

## WORK SHEET

CHC

Report No : C25026S

Document No.CHC-WS-028

DETERMINATION OF PERMEABILITY OF SOIL (FALLING HEAD)

Test method: BS EN ISO 17892-11:2019

| | | | | | |
|---|---|---|---|---|---|
| Project: | N/A | | | | |
| Project location | | Sample depth (m) | N/A | | |
| Lab number | C25026S002 | Trial Pit Number | N/A | | |
| Sample Description | Soil | | | | |
| Preparation method | Prepared in accordance with BS 1377-1-2016 | | | | |
| | Test Records | | | | |
| DETAILS OF THE SPECIMEN | | Wet Weight of the sample +Ring | 321 | Initial Moisture content (%) | 37.0 |
| Specimen Diameter( D) cm | 6.00 | Dry Weight of the sample +Ring | 263.2 | Final Moisture content (%) | 35.8 |
| Specimen Height (L) cm | 4.00 | | | | |
| Specimen area (A) cm2 | 28.3 | Bulky Density (kg/m3) | 1928 | Void Ratio e | 0.91 |
| Water Temperature( T) $^0$C | 24.5 | Dry Density (kg/m3) | 1386 | | |
| Stand Pipe Area a (cm2) | 0.33 | Specific Gravity | 2.65 | Degree of saturation | 104 |
| Hydrauli gradient | 6.15 | | | | |
| MDD (kg/m3) | 1325 | Compaction(%) | 105 | | |

| Serial No. | Lab No. | Start Time/Date | End Time/Date | Change inTime(sec) Δt | Discharge Q (ml) | Δht1(cm) | Δht2 (cm) | k(m/s) | Average |
|---|---|---|---|---|---|---|---|---|---|
| 1 | C25026S002 | 1:41pm (28/1/2025) | 1:52pm (28/1/2025) | 660 | 8.163 | 90.5 | 65.9 | 2.26E-07 | 1.58E-07 |
| | | 1:52pm (28/1/2025) | 2:34pm (28/1/2025) | 2520 | 15.131 | 65.9 | 20.3 | 2.19E-07 | |
| | | 2:37pm (28/1/2025) | 2:56pm (28/1/2025) | 1140 | 9.955 | 90.5 | 60.5 | 1.66E-07 | |
| | | 2:58pm (28/1/2025) | 4:02pm (28/1/2025) | 3840 | 12.610 | 60.5 | 22.5 | 1.21E-07 | |
| | | 4:03pm (28/1/2025) | 4:25pm (28/1/2025) | 1320 | 8.661 | 90.5 | 64.5 | 1.21E-07 | |
| | | 4:25pm (28/1/2025) | 5:31pm (28/1/2025) | 3960 | 11.913 | 64.5 | 28.6 | 9.64E-08 | |
| | | | | | | | | | |
| | | | | | | | | | |

Technician:Barbrah Checked Titus Date: 29/01/2025

Falling Head Permeability test for pit 2

# CHC ANALYSIS UG LIMITED

## WORK SHEET

CHC

Report No : C25026S

Document No.CHC-WS-028

DETERMINATION OF PERMEABILITY OF SOIL (FALLING HEAD)

Test method: BS EN ISO 17892-11:2019

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Project: | N/A | | | | | | | |
| Project location | | | | Sample depth (m) | N/A | | | |
| Lab number | C25026S003 | | | Trial Pit Number | N/A | | | |
| Sample Description | Soil | | | | | | | |
| Preparation method | Prepared in accordance with BS 1377-1-2016 | | | | | | | |
| | | Test Records | | | | | | |
| DETAILS OF THE SPECIMEN | | Wet Weight of the sample +Ring | 324 | Initial Moisture content (%) | 34.4 | | | |
| Specimen Diameter( D) cm | 6.00 | Dry Weight of the sample +Ring | 265.9 | Final Moisture content (%) | 35.0 | | | |
| Specimen Height (L) cm | 4.00 | | | | | | | |
| Specimen area (A) cm2 | 28.3 | Bulky Density (kg/m3) | 1935 | Void Ratio e | 0.88 | | | |
| Water Temperature( T) $^{0}$C | 24.5 | Dry Density (kg/m3) | 1410 | | | | | |
| Stand Pipe Area a (cm2) | 0.33 | Specific Gravity | 2.65 | Degree of saturation | 105 | | | |
| Hydrauli gradient | 5.50 | | | | | | | |
| MDD (kg/m3) | 1385 | Compaction(%) | | 102 | | | | |

| Serial No. | Lab No. | Start Time/Date | End Time/Date | Change inTime(sec) Δt | Discharge Q (ml) | Δht1(cm) | Δht2 (cm) | k(m/s) | Average |
|---|---|---|---|---|---|---|---|---|---|
| 1 | C25026S003 | 1:37pm (28/1/2025) | 1:43pm (28/1/2025) | 360 | 7.30 | 90.0 | 68.0 | 3.66E-07 | 1.51E-07 |
| | | 1:43pm (28/1/2025) | 2:35pm (28/1/2025) | 3120 | 15.30 | 68.0 | 21.9 | 1.70E-07 | |
| | | 2:38pm (28/1/2025) | 2:57pm (28/1/2025) | 1140 | 8.50 | 91.0 | 65.4 | 1.36E-07 | |
| | | 2:58pm (28/1/2025) | 4:02pm (28/1/2025) | 3840 | 12.34 | 65.4 | 28.2 | 1.03E-07 | |
| | | 4:03pm (28/1/2025) | 4:30pm (28/1/2025) | 1620 | 7.47 | 91.0 | 68.5 | 8.23E-08 | |
| | | 4:30pm (28/1/2025) | 5:31pm (28/1/2025) | 3660 | 7.30 | 68.5 | 46.5 | 4.97E-08 | |
| | | | | | | | | | |
| | | | | | | | | | |

Technician:Barbrah Checked Titus Date: 29/01/2025

Falling Head Permeability test fort pit 3

# WORK SHEET

## Bulk Density

CHC

Documet No:CHC-WS-5002

Project No. C25026S

| Reference: | CHC Test 1.2:Ref.BS EN ISO 17892-2-2014 | | | Instrument Name: | | Balance | |
|---|---|---|---|---|---|---|---|
| | | | | Instrument No: | | CHC-LAB-0181 | |
| Room conditions | | | Temperature: | 25°C | Humidity: | 55%RH | |
| Lab No. | Ring No. | $M_{ring}$ | $M_{ring+soil}$ | $M_{soil}$ | $V_{ring}$ | ρ | Average |
| | | g | g | g | $cm^3$ | $g/cm^3$ | ρ |
| C25026S001 | T | 100.92 | 320.11 | 219.19 | 113.10 | 1.94 | 1.938 |
| C25026S002 | S | 102.25 | 320.34 | 218.09 | 113.10 | 1.93 | 1.928 |
| C25026S003 | B | 102.15 | 321.05 | 218.90 | 113.10 | 1.94 | 1.935 |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

Technician:BARBRAH Checked:FRANK Date: 1/28/2025

Bulk density test for pit 1, 2, and 3

DETERMINATION OF THE UNDRAINEGD STRENGTH IN TRIAXIAL COMPRESSION
Tested in accordance to BS: 1377:1990: Part 7: Clause 8

**TEST REPORT**

| | | | |
|---|---|---|---|
| Project Location | Shikuruwe village, naposhi parish, Bushika sub county bududa district | | |
| Client | MAMFA MAYALA AND AHABWE MARTHA | Sample Depth | 1.0 |
| BH/TP Location | TP01 | Sample Type | U -Sample |
| Sample Description | SANDY CLAYS | Sampled by | W.M |
| Tested by | BAKAKI MICHAEL OWEN | Sampling Date | N.A |
| Checked by | Lab Engineer | Test Date | Tuesday, January 21, 2025 |

**DETERMINATION OF MOISTURE CONTENT**

| CONTAINER NO. | Mass of Wet Soil + Container | Mass of Dry Soil + Container | Mass of Container | Mass of Moisture | Mass of Dry Soil | Moisture Content | Average |
|---|---|---|---|---|---|---|---|
| ALL | 239.9 | 186.7 | 39.3 | 53.3 | 147.4 | 36.1 | 36.3 |
| ROO | 225.2 | 177.3 | 46.0 | 47.9 | 131.3 | 36.5 | |

| SPECIMEN DETAILS | | *Specimen 1* | | *Specimen 2* | | *Specimen 3* | | *Average* |
|---|---|---|---|---|---|---|---|---|
| Height [mm] | 76 | Mass (g) | 198.9 | Mass (g) | 198.9 | Mass (g) | 198.9 | 198.9 |
| Diameter [Do] | 38 | Volume ($cm^3$) | 86.2 | Volume ($cm^3$) | 86.2 | Volume ($cm^3$) | 86.2 | 86.2 |
| Initial Length [Lo] | 76 | Bulk Density ($Mg/m^3$) | 2.307 | Bulk Density ($Mg/m^3$) | 2.307 | Bulk Density ($Mg/m^3$) | 2.307 | 2.307 |
| Area [Ao] | 1134.6 | Unit Weight ($KN/m^3$) | 22.6 | Unit Weight ($KN/m^3$) | 22.6 | Unit Weight ($KN/m^3$) | 22.6 | 22.63 |
| Rate of Strain ε, (%/min) | 2 | Dry Density ( Mg/m3) | 1.692 | Dry Density ( Mg/m3) | 1.692 | Dry Density ( Mg/m3) | 1.692 | 1.692 |

**SPECIMEN 1**

| Force | t | ΔL | ΔL/L | ε | 1−ε | Area | $\sigma_1-\sigma_3$ | ε |
|---|---|---|---|---|---|---|---|---|
| N | mm | mm | mm | mm | mm | $mm^2$ | Kpa | % |
| 0 | 0.0 | 0.0 | 0.0000 | 0.0000 | 1.000 | 1134.6 | 0.0 | 0.0 |
| 150 | 1.4 | 1.4 | 0.0184 | 0.0184 | 0.982 | 1155.9 | 129.8 | 1.8 |
| 162 | 3.3 | 1.9 | 0.0250 | 0.0434 | 0.957 | 1186.1 | 136.6 | 4.3 |
| 165 | 5.1 | 1.8 | 0.0237 | 0.0671 | 0.933 | 1216.2 | 135.7 | 6.7 |
| 167 | 6.6 | 1.5 | 0.0197 | 0.0868 | 0.913 | 1242.5 | 134.4 | 8.7 |
| 171 | 8.2 | 1.6 | 0.0211 | 0.1079 | 0.892 | 1271.8 | 134.5 | 10.8 |
| 175 | 9.8 | 1.6 | 0.0211 | 0.1289 | 0.871 | 1302.5 | 134.4 | 12.9 |
| 182 | 11.5 | 1.7 | 0.0224 | 0.1513 | 0.849 | 1336.9 | 136.1 | 15.1 |
| 185 | 13.1 | 1.6 | 0.0211 | 0.1724 | 0.828 | 1370.9 | 135.0 | 17.2 |
| 190 | 14.6 | 1.5 | 0.0197 | 0.1921 | 0.808 | 1404.4 | 135.3 | 19.2 |
| 195 | 16.7 | 2.1 | 0.0276 | 0.2197 | 0.780 | 1454.1 | 134.1 | 22.0 |

**SPECIMEN 2**

| Force | Displacement | ΔL | ΔL/L | ε | 1−ε | Area | $\sigma_1-\sigma_3$ | ε |
|---|---|---|---|---|---|---|---|---|
| N | mm | mm | mm | mm | mm | $mm^2$ | Kpa | % |
| 0 | 0.0 | 0.0 | 0.0000 | 0.0000 | 1.000 | 1134.6 | 0.0 | 0.0 |
| 185 | 1.6 | 1.6 | 0.0211 | 0.0211 | 0.979 | 1159.0 | 159.6 | 2.1 |
| 230 | 3.3 | 1.9 | 0.0250 | 0.0461 | 0.954 | 1189.3 | 193.4 | 4.6 |
| 242 | 5.1 | 1.8 | 0.0237 | 0.0697 | 0.930 | 1219.6 | 198.4 | 7.0 |
| 247 | 6.6 | 1.5 | 0.0197 | 0.0895 | 0.911 | 1246.1 | 198.2 | 8.9 |
| 249 | 8.5 | 1.9 | 0.0250 | 0.1145 | 0.886 | 1281.2 | 194.3 | 11.4 |
| 251 | 10.2 | 2.0 | 0.0263 | 0.1408 | 0.859 | 1320.5 | 190.1 | 14.1 |
| 252 | 11.5 | 1.7 | 0.0224 | 0.1632 | 0.837 | 1355.8 | 185.9 | 16.3 |
| 253 | 13.4 | 1.9 | 0.0250 | 0.1882 | 0.812 | 1397.5 | 181.0 | 18.8 |
| 254 | 14.6 | 1.5 | 0.0197 | 0.2079 | 0.792 | 1432.3 | 177.3 | 20.8 |
| 255 | 16.6 | 2.0 | 0.0263 | 0.2342 | 0.766 | 1481.6 | 172.1 | 23.4 |

**SPECIMEN 3**

| Force | Displacement | ΔL | ΔL/L | ε | 1−ε | Area | $\sigma_1-\sigma_3$ | ε |
|---|---|---|---|---|---|---|---|---|
| N | mm | mm | mm | mm | mm | $mm^2$ | Kpa | % |
| 0 | 0.0 | 0.0 | 0.0000 | 0.0000 | 1.000 | 1134.6 | 0.0 | 0.0 |
| 221 | 1.7 | 1.7 | 0.0224 | 0.0224 | 0.978 | 1160.5 | 190.4 | 2.2 |
| 320 | 3.5 | 2.1 | 0.0276 | 0.0500 | 0.950 | 1194.3 | 267.9 | 5.0 |
| 345 | 5.3 | 2.0 | 0.0263 | 0.0763 | 0.924 | 1228.3 | 280.9 | 7.6 |
| 353 | 6.6 | 1.5 | 0.0197 | 0.0961 | 0.904 | 1255.1 | 281.2 | 9.6 |
| 356 | 8.6 | 2.0 | 0.0263 | 0.1224 | 0.878 | 1292.8 | 275.4 | 12.2 |
| 359 | 10.2 | 2.0 | 0.0263 | 0.1487 | 0.851 | 1332.7 | 269.4 | 14.9 |
| 361 | 11.5 | 1.7 | 0.0224 | 0.1711 | 0.829 | 1368.7 | 263.8 | 17.1 |
| 363 | 13.4 | 1.9 | 0.0250 | 0.1961 | 0.804 | 1411.3 | 257.2 | 19.6 |
| 365 | 15.1 | 2.0 | 0.0263 | 0.2224 | 0.778 | 1459.0 | 250.2 | 22.2 |
| 368 | 16.8 | 2.2 | 0.0289 | 0.2513 | 0.749 | 1515.4 | 242.8 | 25.1 |

Prepared by;
**Lab Technician**

GEOTECHNICAL ENGINEERING AND TECHNOLOGY LABORATORY LTD
GETLAB LTD

Approved by;
**Lab Engineer**

GETLAB LTD
YOUR RELIABLE ENGINEERING LABORATORY

## DETERMINATION OF THE UNDRAINED STRENGTH IN TRIAXIAL COMPRESSION
Tested in accordance to BS: 1377:1990: Part 7: Clause 8

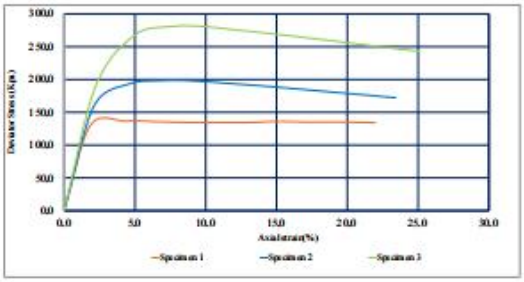
**TEST REPORT**

| | | | |
|---|---|---|---|
| Project Location | Shikunuwe village, naposhi parish, Bushika sub county bududа district | | |
| Client | MAMFA MAYALA AND AHABWE MARTHA | Sample Depth | 1.0 |
| BH/TP Location | TP01 | Sample Type | U - Sample |
| Sample Description | SANDY CLAYS | Sampled by | W.M |
| Tested by | BAKAKI MICHAEL OWEN | Sampling Date | N.A |
| Checked by | Lab Engineer | Test Date | Tuesday, January 21, 2025 |

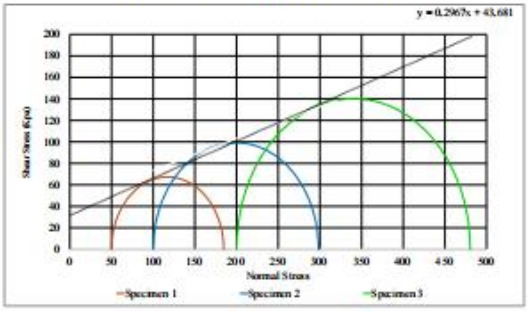
### CONDITIONS AT FAILURE

| STRESSES | *Specimen 1* | *Specimen 2* | *Specimen 3* | *Specimen 1* | *Specimen 2* | *Specimen 3* |
|---|---|---|---|---|---|---|
| *Cell pressure (Kpa)* | 50 | 100 | 200 | | | |
| *Corr. Deviator Stress (Kpa)* | 136.6 | 198.4 | 281.2 | | | |
| *Shear strength (Kpa)* | 68.3 | 99.2 | 140.6 | | | |
| The Cell Confining Pressures of 50Kpa, 100kpa & 200Kpa have been used while conducting the Test | | | | | | |
| EFFECTIVE STRESS ($\sigma_v$) | | 22.63 | (Kpa) | | | |
| ***Mode of failure*** | | | | Barelling | Barelling | Barelling |

### DEVIATOR STRESS(Kpa) AGAINST AXIAL STRAIN (%)




### SHEAR STRESS(Kpa) AGAINST NORMAL STRESS(%)




### UNDRAINED PARAMETERS

| | |
|---|---|
| C | 43.7 |
| ϕ | 16.5 |

### COMMENT

*No Comment*

Prepared by;
**Lab Technician**

GEOTECHNICAL ENGINEERING TECHNOLOGY LABORATORY LTD
GETLAB LTD

Approved by;
**Lab Engineer**

Triaxial Test for pit 1

GETLAB LTD
YOUR RELIABLE ENGINEERING LABORATORY

DETERMINATION OF THE UNDRAINEGD STRENGTH IN TRIAXIAL COMPRESSION
Tested in accordance to BS: 1377:1990: Part 7: Clause 8

**TEST REPORT**

| | | | |
|---|---|---|---|
| Project Location | Shikuruwe village, naposhi parish, Bushika sub county bududa district | | |
| Client | MAMFA MAYALA AND AHABWE MARTHA | Sample Depth | 1.0 |
| BH/TP Location | TP02 | Sample Type | U -Sample |
| Sample Description | SANDY CLAYS | Sampled by | W.M |
| Tested by | BAKAKI MICHAEL | Sampling Date | N.A |
| Checked by | Lab Engineer | Test Date | Tuesday, January 21, 2025 |

**DETERMINATION OF MOISTURE CONTENT**

| CONTAINER NO. | Mass of Wet Soil + Container | Mass of Dry Soil + Container | Mass of Container | Mass of Moisture | Mass of Dry Soil | Moisture Content | Average |
|---|---|---|---|---|---|---|---|
| BIT | 249.7 | 212.2 | 61.4 | 37.5 | 150.8 | 24.9 | 24.7 |
| A54 | 242.4 | 205.6 | 55.2 | 36.8 | 150.4 | 24.5 | |

| SPECIMEN DETAILS | | *Specimen 1* | | *Specimen 2* | | *Specimen 3* | | *Average* |
|---|---|---|---|---|---|---|---|---|
| Height [mm] | 76 | Mass (g) | 200.4 | Mass (g) | 200.4 | Mass (g) | 200.4 | 200.4 |
| Diameter [Do] | 38 | Volume ($cm^3$) | 86.2 | Volume ($cm^3$) | 86.2 | Volume ($cm^3$) | 86.2 | 86.2 |
| Initial Length [Lo] | 76 | Bulk Density ($Mg/m^3$) | 2.324 | Bulk Density ($Mg/m^3$) | 2.324 | Bulk Density ($Mg/m^3$) | 2.324 | 2.324 |
| Area [Ao] | 1134.6 | Unit Weight ($KN/m^3$) | 22.8 | Unit Weight ($KN/m^3$) | 22.8 | Unit Weight ($KN/m^3$) | 22.8 | 22.80 |
| Rate of Strain ε, (%/min) | 2 | Dry Density (Mg/m3) | 1.864 | Dry Density (Mg/m3) | 1.864 | Dry Density (Mg/m3) | 1.864 | 1.864 |

**SPECIMEN 1**

| Force | t | ΔL | ΔL/L | ε | 1−ε | Area | $\sigma_1-\sigma_3$ | ε |
|---|---|---|---|---|---|---|---|---|
| N | mm | mm | mm | mm | mm | $mm^2$ | Kpa | % |
| 0 | 0.0 | 0.0 | 0.0000 | 0.0000 | 1.000 | 1134.6 | 0.0 | 0.0 |
| 84 | 1.4 | 1.4 | 0.0184 | 0.0184 | 0.982 | 1155.9 | 72.7 | 1.8 |
| 102 | 3.3 | 1.9 | 0.0250 | 0.0434 | 0.957 | 1186.1 | 86.0 | 4.3 |
| 126 | 5.1 | 1.8 | 0.0237 | 0.0671 | 0.933 | 1216.2 | 103.6 | 6.7 |
| 141 | 6.6 | 1.5 | 0.0197 | 0.0868 | 0.913 | 1242.5 | 113.5 | 8.7 |
| 152 | 8.2 | 1.6 | 0.0211 | 0.1079 | 0.892 | 1271.8 | 119.5 | 10.8 |
| 155 | 9.7 | 1.5 | 0.0197 | 0.1276 | 0.872 | 1300.6 | 119.2 | 12.8 |
| 156 | 11.6 | 1.9 | 0.0250 | 0.1526 | 0.847 | 1338.9 | 116.5 | 15.3 |
| 156 | 13.2 | 1.6 | 0.0211 | 0.1737 | 0.826 | 1373.0 | 113.6 | 17.4 |
| 156 | 14.8 | 1.6 | 0.0211 | 0.1947 | 0.805 | 1408.9 | 110.7 | 19.5 |
| 156 | 16.3 | 1.5 | 0.0197 | 0.2145 | 0.786 | 1444.3 | 108.0 | 21.4 |

**SPECIMEN 2**

| Force | Displacement | ΔL | ΔL/L | ε | 1−ε | Area | $\sigma_1-\sigma_3$ | ε |
|---|---|---|---|---|---|---|---|---|
| N | mm | mm | mm | mm | mm | $mm^2$ | Kpa | % |
| 0 | 0.0 | 0.0 | 0.0000 | 0.0000 | 1.000 | 1134.6 | 0.0 | 0.0 |
| 106 | 1.8 | 1.8 | 0.0237 | 0.0237 | 0.976 | 1162.1 | 91.2 | 2.4 |
| 151 | 3.5 | 2.1 | 0.0276 | 0.0513 | 0.949 | 1195.9 | 126.3 | 5.1 |
| 168 | 5.2 | 1.9 | 0.0250 | 0.0763 | 0.924 | 1228.3 | 136.8 | 7.6 |
| 177 | 6.6 | 1.5 | 0.0197 | 0.0961 | 0.904 | 1255.1 | 141.0 | 9.6 |
| 198 | 8.4 | 1.8 | 0.0237 | 0.1197 | 0.880 | 1288.9 | 153.6 | 12.0 |
| 210 | 10.2 | 2.0 | 0.0263 | 0.1461 | 0.854 | 1328.6 | 158.1 | 14.6 |
| 226 | 11.6 | 1.9 | 0.0250 | 0.1711 | 0.829 | 1368.7 | 165.1 | 17.1 |
| 240 | 13.5 | 1.9 | 0.0250 | 0.1961 | 0.804 | 1411.3 | 170.1 | 19.6 |
| 254 | 14.8 | 1.6 | 0.0211 | 0.2171 | 0.783 | 1449.2 | 175.3 | 21.7 |
| 255 | 16.3 | 1.5 | 0.0197 | 0.2368 | 0.763 | 1486.7 | 171.5 | 23.7 |

**SPECIMEN 3**

| Force | Displacement | ΔL | ΔL/L | ε | 1−ε | Area | $\sigma_1-\sigma_3$ | ε |
|---|---|---|---|---|---|---|---|---|
| N | mm | mm | mm | mm | mm | $mm^2$ | Kpa | % |
| 0 | 0.0 | 0.0 | 0.0000 | 0.0000 | 1.000 | 1134.6 | 0.0 | 0.0 |
| 131 | 2.0 | 2.0 | 0.0263 | 0.0263 | 0.974 | 1165.2 | 112.4 | 2.6 |
| 220 | 3.4 | 2.0 | 0.0263 | 0.0526 | 0.947 | 1197.6 | 183.7 | 5.3 |
| 254 | 5.2 | 1.9 | 0.0250 | 0.0776 | 0.922 | 1230.1 | 206.5 | 7.8 |
| 282 | 6.8 | 1.7 | 0.0224 | 0.1000 | 0.900 | 1260.6 | 223.7 | 10.0 |
| 285 | 8.5 | 1.9 | 0.0250 | 0.1250 | 0.875 | 1296.7 | 219.8 | 12.5 |
| 294 | 10.2 | 2.0 | 0.0263 | 0.1513 | 0.849 | 1336.9 | 219.9 | 15.1 |
| 296 | 11.6 | 1.9 | 0.0250 | 0.1763 | 0.824 | 1377.4 | 214.9 | 17.6 |
| 298 | 13.4 | 1.8 | 0.0237 | 0.2000 | 0.800 | 1418.2 | 210.1 | 20.0 |
| 296 | 14.9 | 1.7 | 0.0224 | 0.2224 | 0.778 | 1459.0 | 202.9 | 22.2 |
| 300 | 16.5 | 1.7 | 0.0224 | 0.2447 | 0.755 | 1502.2 | 199.7 | 24.5 |

Prepared by:
**Lab Technician**

GEOTECHNICAL ENGINEERING AND TECHNOLOGY LABORATORY LTD
GETLAB LTD

Approved by:
**Lab Engineer**

GETLAB LTD
YOUR RELIABLE ENGINEERING LABORATORY

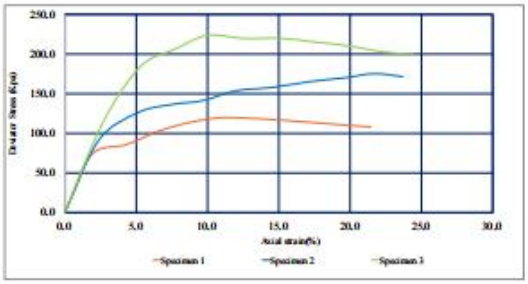
DETERMINATION OF THE UNDRAINED STRENGTH IN TRIAXIAL COMPRESSION
Tested in accordance to BS: 1377:1990: Part 7: Clause 8
**TEST REPORT**

| | | | |
|---|---|---|---|
| Project Location | Shikuruwe village, naposhi parish, Bushika sub county bududa district | | |
| Client | MAMFA MAYALA AND AHABWE MARTHA | Sample Depth | 1.0 |
| BH/TP Location | TP02 | Sample Type | U -Sample |
| Sample Description | SANDY CLAYS | Sampled by | W.M |
| Tested by | BAKAKI MICHAEL | Sampling Date | N.A |
| Checked by | Lab Engineer | Test Date | Tuesday, January 21, 2025 |

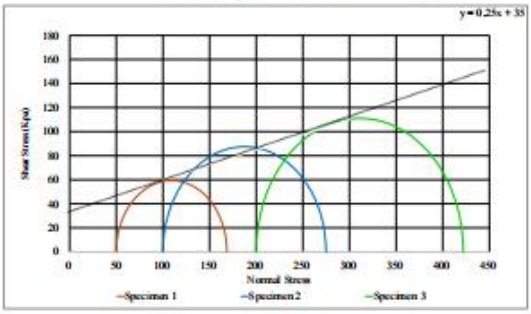
CONDITIONS AT FAILURE

| STRESSES | *Specimen 1* | *Specimen 2* | *Specimen 3* | *Specimen 1* | *Specimen 2* | *Specimen 3* |
|---|---|---|---|---|---|---|
| *Cell pressure (Kpa)* | 50 | 100 | 200 | | | |
| *Corr. Deviator Stress (Kpa)* | 119.5 | 175.3 | 223.7 | | | |
| *Shear strength (Kpa)* | 59.8 | 87.6 | 111.8 | | | |
| The Cell Confining Pressures of 50Kpa,100kpa & 200Kpa have been used while conducting the Test | | | | | | |
| EFFECTIVE STRESS ($\sigma_t$) | | 22.80 | (Kpa) | | | |
| *Mode of failure* | | | | Barelling | Barelling | Barelling |

DEVIATOR STRESS(Kpa) AGAINST AXIAL STRAIN (%)




SHEAR STRESS(Kpa) AGAINST NORMAL STRESS(%)




UNDRAINED PARAMETERS

| | |
|---|---|
| C | 35.0 |
| ϕ | 14.0 |

COMMENT

*No Comment*

Prepared by:
**Lab Technician**

GEOTECHNICAL ENGINEERING LABORATORY
GETLAB LTD
TECHNOLOGY LABORATORY LTD

Approved by:
**Lab Engineer**

Triaxial Test for pit 2

GETLAB LTD
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DETERMINATION OF THE UNDRAINEGD STRENGTH IN TRIAXIAL COMPRESSION
Tested in accordance to BS: 1377:1990: Part 7: Clause 8
**TEST REPORT**

| | | | |
|---|---|---|---|
| Project Location | Shikuuruwe village, naposhi parish, Bushika sub county bududa district | | |
| Client | MAMFA MAYALA AND AHABWE MARTHA | Sample Depth | 1.0 |
| BH/TP Location | TP03 | Sample Type | U -Sample |
| Sample Description | Sandy clays | Sampled by | W.M |
| Tested by | BAKAKI MICHAEL OWEN | Sampling Date | N.A |
| Checked by | Lab Engineer | Test Date | Tuesday, January 21, 2025 |

**DETERMINATION OF MOISTURE CONTENT**

| CONTAINER NO. | Mass of Wet Soil+ Container | Mass of Dry Soil + Container | Mass of Container | Mass of Moisture | Mass of Dry Soil | Moisture Content | Average |
|---|---|---|---|---|---|---|---|
| IUE | 225.5 | 192.0 | 54.4 | 33.5 | 137.6 | 24.3 | 23.7 |
| AE | 268.6 | 229.2 | 58.6 | 39.4 | 170.6 | 23.1 | |

| SPECIMEN DETAILS | | *Specimen 1* | | *Specimen 2* | | *Specimen 3* | | *Average* |
|---|---|---|---|---|---|---|---|---|
| Height [mm] | 76 | Mass (g) | 210.5 | Mass (g) | 210.5 | Mass (g) | 210.5 | 210.5 |
| Diameter [Do] | 38 | Volume ($cm^3$) | 86.2 | Volume ($cm^3$) | 86.2 | Volume ($cm^3$) | 86.2 | 86.2 |
| Initial Length [Lo] | 76 | Bulk Density ($Mg/m^3$) | 2.441 | | 2.441 | Bulk Density ($Mg/m^3$) | 2.441 | 2.441 |
| Area [Ao] | 1134.6 | Unit Weight ($KN/m^3$) | 23.9 | Unit Weight ($KN/m^3$) | 23.9 | Unit Weight ($KN/m^3$) | 23.9 | 23.95 |
| Rate of Strain ε, (%/min) | 2 | Dry Density (Mg/m3) | 1.973 | Dry Density (Mg/m3) | 1.973 | Dry Density (Mg/m3) | 1.973 | 1.973 |

**SPECIMEN 1**

| Force | Displacement | ΔL | ΔL/L | ε | 1−ε | Area | $\sigma_1-\sigma_3$ | ε |
|---|---|---|---|---|---|---|---|---|
| N | mm | mm | mm | mm | mm | $mm^2$ | Kpa | % |
| 0 | 0.0 | 0.0 | 0.0000 | 0.0000 | 1.000 | 1134.6 | 0.0 | 0.0 |
| 75 | 1.3 | 1.3 | 0.0171 | 0.0171 | 0.983 | 1154.3 | 65.0 | 1.7 |
| 88 | 3.3 | 2.0 | 0.0263 | 0.0434 | 0.957 | 1186.1 | 74.2 | 4.3 |
| 106 | 5.1 | 1.8 | 0.0237 | 0.0671 | 0.933 | 1216.2 | 87.2 | 6.7 |
| 116 | 6.6 | 1.5 | 0.0197 | 0.0868 | 0.913 | 1242.5 | 93.4 | 8.7 |
| 124 | 8.5 | 1.9 | 0.0250 | 0.1118 | 0.888 | 1277.4 | 97.1 | 11.2 |
| 133 | 10.1 | 1.6 | 0.0211 | 0.1329 | 0.867 | 1308.5 | 101.6 | 13.3 |
| 136 | 11.6 | 1.5 | 0.0197 | 0.1526 | 0.847 | 1338.9 | 101.6 | 15.3 |
| 143 | 13.1 | 1.5 | 0.0197 | 0.1724 | 0.828 | 1370.9 | 104.3 | 17.2 |
| 146 | 14.8 | 1.7 | 0.0224 | 0.1947 | 0.805 | 1408.9 | 103.6 | 19.5 |
| 153 | 16.5 | 1.7 | 0.0224 | 0.2171 | 0.783 | 1449.2 | 105.6 | 21.7 |

**SPECIMEN 2**

| Force | Displacement | ΔL | ΔL/L | ε | 1−ε | Area | $\sigma_1-\sigma_3$ | ε |
|---|---|---|---|---|---|---|---|---|
| N | mm | mm | mm | mm | mm | $mm^2$ | Kpa | % |
| 0 | 0.0 | 0.0 | 0.0000 | 0.0000 | 1.000 | 1134.6 | 0.0 | 0.0 |
| 106 | 1.5 | 1.5 | 0.0197 | 0.0197 | 0.980 | 1157.4 | 91.6 | 2.0 |
| 127 | 3.3 | 2.0 | 0.0263 | 0.0461 | 0.954 | 1189.3 | 106.8 | 4.6 |
| 141 | 5.1 | 1.8 | 0.0237 | 0.0697 | 0.930 | 1219.6 | 115.6 | 7.0 |
| 151 | 6.7 | 1.6 | 0.0211 | 0.0908 | 0.909 | 1247.9 | 121.0 | 9.1 |
| 155 | 8.6 | 2.0 | 0.0263 | 0.1171 | 0.883 | 1285.1 | 120.6 | 11.7 |
| 158 | 10.2 | 1.7 | 0.0224 | 0.1395 | 0.861 | 1318.5 | 119.8 | 13.9 |
| 160 | 11.5 | 1.4 | 0.0184 | 0.1579 | 0.842 | 1347.3 | 118.8 | 15.8 |
| 166 | 13.4 | 1.8 | 0.0237 | 0.1816 | 0.818 | 1386.3 | 119.7 | 18.2 |
| 171 | 14.6 | 1.5 | 0.0197 | 0.2013 | 0.799 | 1420.6 | 120.4 | 20.1 |
| 178 | 16.8 | 2.0 | 0.0263 | 0.2276 | 0.772 | 1469.0 | 121.2 | 22.8 |

**SPECIMEN 3**

| Force | Displacement | ΔL | ΔL/L | ε | 1−ε | Area | $\sigma_1-\sigma_3$ | ε |
|---|---|---|---|---|---|---|---|---|
| N | mm | mm | mm | mm | mm | $mm^2$ | Kpa | % |
| 0 | 0.0 | 0.0 | 0.0000 | 0.0000 | 1.000 | 1134.6 | 0.0 | 0.0 |
| 172 | 1.8 | 1.8 | 0.0230 | 0.0230 | 0.977 | 1161.3 | 148.1 | 2.3 |
| 173 | 3.4 | 2.1 | 0.0276 | 0.0507 | 0.949 | 1195.1 | 144.8 | 5.1 |
| 192 | 5.3 | 2.0 | 0.0263 | 0.0770 | 0.923 | 1229.2 | 156.2 | 7.7 |
| 212 | 6.5 | 1.4 | 0.0184 | 0.0954 | 0.905 | 1254.2 | 169.0 | 9.5 |
| 217 | 8.5 | 1.9 | 0.0250 | 0.1204 | 0.880 | 1289.9 | 168.2 | 12.0 |
| 223 | 10.3 | 1.8 | 0.0237 | 0.1441 | 0.856 | 1325.6 | 168.2 | 14.4 |
| 226 | 10.7 | 0.6 | 0.0079 | 0.1520 | 0.848 | 1337.9 | 168.9 | 15.2 |
| 232 | 12.3 | 0.7 | 0.0092 | 0.1612 | 0.839 | 1352.6 | 171.5 | 16.1 |
| 236 | 15.0 | 1.9 | 0.0250 | 0.1862 | 0.814 | 1394.1 | 169.3 | 18.6 |
| 241 | 16.7 | 1.9 | 0.0250 | 0.2112 | 0.789 | 1438.3 | 167.6 | 21.1 |

Prepared by:
Lab Technician

GEOTECHNICAL ENGINEERING AND TECHNOLOGY LABORATORY LTD
GETLAB LTD

Approved by:
Lab Engineer

GETLAB LTD
YOUR RELIABLE ENGINEERING LABORATORY

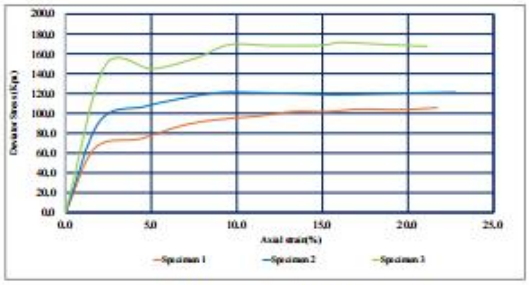
DETERMINATION OF THE UNDRAINED STRENGTH IN TRIAXIAL COMPRESSION
Tested in accordance to BS: 1377:1990: Part 7: Clause 8
TEST REPORT

| | | | |
|---|---|---|---|
| Project Location | Shikuruwe village, naposhi parish, Bushika sub county bududa district | | |
| Client | MAMFA MAYALA AND AHABWE MARTHA | Sample Depth | 1.0 |
| BH/TP Location | TP03 | Sample Type | U -Sample |
| Sample Description | Sandy clays | Sampled by | W.M |
| Tested by | BAKAKI MICHAEL OWEN | Sampling Date | N.A |
| Checked by | Lab Engineer | Test Date | Tuesday, January 21, 2025 |

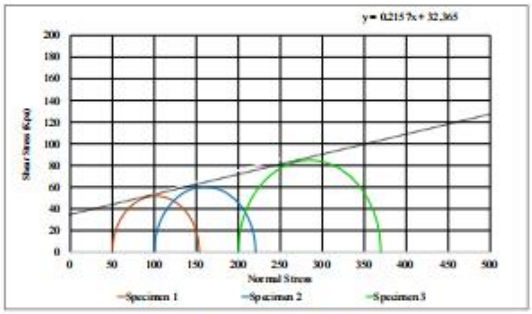
CONDITIONS AT FAILURE

| STRESSES | Specimen 1 | Specimen 2 | Specimen 3 | Specimen 1 | Specimen 2 | Specimen 3 |
|---|---|---|---|---|---|---|
| Cell pressure (Kpa) | 50 | 100 | 200 | | | |
| Corr. Deviator Stress (Kpa) | 105.6 | 121.2 | 171.5 | | | |
| Shear strength (Kpa) | 52.8 | 60.6 | 85.8 | | | |
| The Cell Confining Pressures of 50Kpa,100kpa & 200Kpa have been used while conducting the Test | | | | | | |
| EFFECTIVE STRESS ($\sigma_3$) | | 23.95 | (Kpa) | | | |
| Mode of failure | | | | Barelling | Barelling | Barelling |

DEVIATOR STRESS(Kpa) AGAINST AXIAL STRAIN (%)




SHEAR STRESS(Kpa) AGAINST NORMAL STRESS(%)




UNDRAINED PARAMETERS

| | |
|---|---|
| C | 32.4 |
| $\phi$ | 12.2 |

COMMENT

*No Comment*

Prepared by;
Lab Technician

GEOTECHNICAL ENGINEERING CO. GETLAB LTD TECHNOLOGY LABORATORY LTD

Approved by;
Lab Engineer

Triaxial test for pit 3

F/FORM/SO/17 ISSUE 02

GETLAB LTD
YOUR RELIABLE ENGINEERING LABORATORY

## DIRECT SHEAR BOX TEST OF SOILS (BS EN ISO 17892-7:2017)

| | |
|---|---|
| Project: | HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION |
| Client | MAMFA MAYALA AND AHABWE MARTHA |
| Location | Pit 01, Sample 2 |
| Depth (m): | 1.00 |
| Date Tested: | 27/02/25 |

| Bulk Density | Normal Stress | Shear Strength | Cohesion | Angle of Internal Friction | Soil Description |
|---|---|---|---|---|---|
| $\gamma_b$ | $\delta_n$ | $\tau_s$ | C | $\phi$ | |
| $Mg/m^3$ | kPa | kPa | kPa | (Degree) | |
| 1.96 | 30.0 | 26.0 | 4.5 | 34.7 | Moist loose reddish brown sandy clays |
| | 60.0 | 45.0 | | | |
| | 120.0 | 88.0 | | | |


Approved by:

Laboratory Engineer

Sen. Laboratory Engineer

GETLAB LTD
0 4 MAR 2025
Geotechnical Engineering & Technology Laboratory Ltd
P. O. Box 100001, Kasangati

Direct Shear box test for pit 1

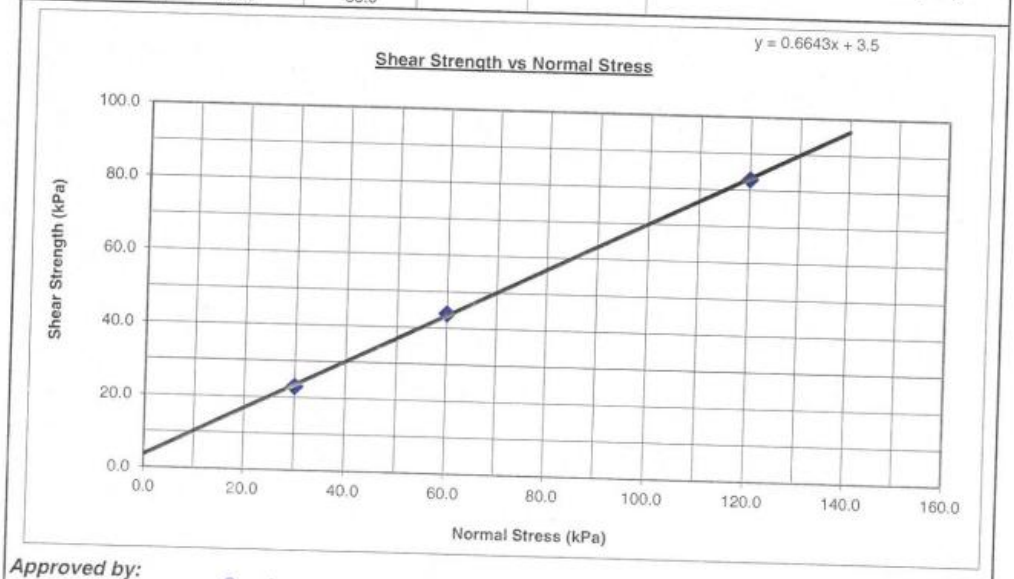
F/FORM/SO/17 ISSUE 02

GETLAB LTD
YOUR RELIABLE ENGINEERING LABORATORY

## DIRECT SHEAR BOX TEST OF SOILS (BS EN ISO 17892-7:2017)

| | |
|---|---|
| Project: | HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION |
| Client | MAMFA MAYALA AND AHABWE MARTHA |
| Location | Pit 01, Sample 1 |
| Depth (m): | 1.00 |
| Date Tested: | 27/02/25 |

| Bulk Density | Normal Stress | Shear Strength | Cohesion | Angle of Internal Friction | Soil Description |
|---|---|---|---|---|---|
| $\gamma_b$ | $\delta_n$ | $\tau_s$ | C | $\phi$ | |
| $Mg/m^3$ | kPa | kPa | kPa | (Degree) | |
| 1.93 | 30.0 | 23.0 | 3.5 | 33.6 | Moist loose reddish brown sandy clays |
| | 60.0 | 44.0 | | | |
| | 120.0 | 83.0 | | | |




Approved by:

Laboratory Engineer

Sen. Laboratory Engineer

GETLAB LTD
★ 0 7 MAR 2025 ★
Geotechnical Engineering & Technology Laboratory Ltd
P. O. Box 100001, Kasangati

Direct Shear box test for Pit 2