# The potential clogging and filter performance of selected geotextiles with different soil types under unidirectional flow conditions in sub-soil drainage applications.

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Presented in partial fulfilment of the requirements for the Master of Science degree in Engineering Geology in the Faculty of Natural and Agricultural Sciences at the University Of Pretoria

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# Declaration

I, **Fhulufhelo Vincent Mukwevho**, declare that the work in this dissertation, which I hereby submit for the degree Master of Science (MSc) in Engineering Geology at the University of Pretoria, is my own work and has not previously been submitted by anyone else at this or another institution. I further declare that I have correctly cited and referenced the original sources

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# Abstract

Non-woven and woven geotextiles have long been used as a cost effective solution in different applications such as separation, reinforcement, protection, filtration and drainage. One of the most common use of geotextiles is as filters in sub-soil drainage systems. The main function of a filter is to retain particles of the base soil whilst maintaining a good flow of water through the system. There's still a lot of uncertainties concerning the long term performance of geotextile filters in filtration and drainage applications. However, there's a lot of ongoing research to better understand the performance of these products.

The purpose of this study is to determine the range of problematic soils in the particle size distribution graph and soil-geotextile compatibility of the different soils with selected geotextiles. In order to achieve the ultimate objective of the study, analysis of the permeability, gradient ratio, coefficient of uniformity and clogging potential of the soil-geotextile systems was achieved through the filtration compatibility test (Long Term Gradient Ratio test) of five different geotextiles against 3 soil types. The soil-geotextile systems were subjected to a maximum waterhead of 1420 mm for a maximum of 1008 hours or until the system has reached equilibrium. The results have shown that soils with high clay/silt fractions tend cause blocking, blinding, and clogging which can close most of the geotextile filter pores. Larger sand/gravel sized particles tend to form a filter bridge that hold back finer soil particles. Sandy gravel with bidim A2 and sandy gravel with bidim A4 were the overall best performers with overall gradient ratios of less than 1 which represents a more open filter. The gradient ratios of the other soil-geotextile combinations were higher than 1 which represents clogging and reduction in permeability. However, no geotextile was completely clogged by the soils.

# Acknowledgement

Whilst a dissertation can only have one name, however, the work it contains is efforts of the author and many other people. In light of this, I would like to express thanks and gratitude to the following people and institutions:

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# List of Symbols and Abbreviations

LTGR = Long Term Gradient Ratio

GR = Gradient Ratio

Cu = Coefficient of Uniformity

ASTM = American Society for Testing and Materials

GSD = Grain Size Distribution

$g/m^2$ = grams per square meter

kN/m = Kilonewtons per meter

kN = Kilonewtons

mm = millimeter

$Sec^{-1}$ = per second

$K_s$ = permeability of soil

$K_f$ = permeability of the geotextile filter

$O_f$ = characteristic opening size of the geotextile filter

# CHAPTER 1: INTRODUCTION

## 1.1. Background

Geotextiles have long been used by engineers as substitutes for traditional granular filters due to their performance, cost effectiveness and convenience (Palmeira *et al*, 2010). With many different geotextile types having different properties, it is a challenge to choose the best one to use as a filter in sub-soil drainage. A filtration system is complex since there are a lot of factors taken into account such as internal base soil erosion, which is one of the most important factors to consider in the whole filtration system. Soil-geotextile filtration compatibility requires no internal erosion resulting from soil loss through the geotextile (Fannin, 2010). Therefore a good geotextile filter is one that retains particles of the base soil, allows continued discharge of water or fluid and facilitates the overall stability of the filter system (Bhatia and Smith 1995; Miszkowska *et al*, 2017).

Over the past years there has been a lot of research on geotextile filters in order to gain more understanding on their performance under different conditions (e.g. Fannin, 2010; Giroud, 2010; Lafleur, 1999; Moraci, 2010). Researchers have developed selection criteria and design procedures to make it less complicated for engineers to choose the best filters for a certain application. The four most important criteria associated with geotextile filter design are retention, permeability, porosity and thickness (Giroud, 2010). There are other important criteria such as survivability criterion and durability criterion which ensures that the geotextile survives installation and it is durable enough to withstand harsh environmental conditions such as effects of pH and UV degradation for instance. Despite the existing and ongoing research and studies, there is still a lot of uncertainty surrounding the selection criteria and design procedures.

This study focuses on the investigation of three non-woven continuous filament needle-punched polyester geotextiles (namely Bidim A2, A4 & A6), two polypropylene woven tape geotextiles, namely Kaytape S120 & S270 and a monofilament mesh of standard size as a control. This would give a better understanding of the performance of different geotextiles filters with different soil types.

## 1.2. Research Problem

The role of a geotextile as a filter is to allow free flow of water or liquid whilst retaining particles of the base soil (Cazzuffi *et al*, 2015; Moraci, 2010). Not all geotextiles are good filters as some would not even permit a good flow of water and some would start as good filters but clog over time.

There are five main mechanisms (section 2.9.2) associated with geotextile filters, these are clogging, blocking blinding, piping and bridging. Clogging occurs when fine soil particles migrate into the pores of the filter causing obstruction. Blocking occurs when particles of the base soil migrate to the surface of the geotextile partially or totally obstructing its pores and is more pertinent to woven geotextiles. Blinding occurs when fine clay or silt sized particles accumulates on the surface of the filter. Piping is when fine clay and silt sized particles are washed through the filter. Bridging occurs when large soil particles forms a *"filter bridge"* that acts as filter for fine particles.. For the purpose of this study, the research will focus more on clogging which is associated with fine particle migration from the base soil into the geotextile. This result in reduction in permeability of the filter, whereby in some cases, particles of the base soil are washed through the geotextile. Another mechanism that causes clogging in geotextile filter is associated with the accumulation of chemical and biological materials in the filter system.

Geotextiles have different hydraulic properties such as pore size, permeability and throughflow, and would therefore perform differently when used with different soil types (Moraci, 2010). It is often a challenge for engineers to specify the right geotextile for a given filtration application due to the complexity of the process and the many variables that have to be considered. There are different guides (e.g. *Kaytech Filter Design Guide*, 2001; Federal Highway Administration, 1990) that were developed to make it easy for engineers to specify geotextiles in filtration and other applications. Application of geotextiles as filters can be classified into two groups, namely critical and non-critical application. Critical applications are defined as those that in an event of failure, can cause significant damage or even a loss of life. The geotextile filter is inaccessible after installation and maintenance or replacement is impossible in these application (*Kaytech Filter Design Guide*, 1995).

Non-critical applications are those applications where the geotextile filter is accessible for replacement or maintenance. Failure of such filters does not cause significant damage. Performance tests (e.g. LTGR) are required in critical application in order to gain understanding of how the geotextile will behave with the in-situ soil (Miszkowska *et al*, 2017; Palmeira *et al*, 2002).

## 1.3. Aim and objective

The main aim of this research is to investigate the potential for clogging and filter performance of three continuous filament needle-punched polyester non-woven geotextiles (A2, A4 & A6), two polypropylene woven tape geotextiles (Kaytape S120 & S270) and a single sized woven monofilament mesh with three different soil types of varying gradations. This will be done through a special laboratory developed method termed Long Term Gradient Ratio (LTGR), which is based on the ASTM D5101 Standard Test Method for Measuring the Filtration Compatibility of Soil-Geotextile Systems. According to this test method, soils with plasticity index of 5 or more are tested using the ASTM D5567 Hydraulic Conductivity Ratio. However, for the purpose of this research, all soils will be tested in accordance with the LTGR. It is also important to note that this test method was developed many years ago and it only simulates steady state flow conditions under constant head with no applied pressure on the system (Blond & Daqoune, 2010).

This research does not aim to replace any existing design guidelines but to add into existing work and further define design parameters that might not have been clearly addressed in the past.

## 1.4. Thesis Structure

This thesis is made up of 5 chapters as summarized in Table 1.1.

***Table 1.1: List of Chapters***

| | |
|---|---|
| Chapter 1 | Introduction |
| Chapter 2 | Literature review theory |
| Chapter 3 | Methodology |
| Chapter 4 | Results and analysis |
| Chapter 5 | Conclusions and recommendation |

Chapter 2 will cover the early history of geotextiles, their purpose or application, problems or disadvantages associated with their use. Subsurface drainage systems will also be defined in this chapter and also the environments in which they are used. Also important to know is the properties of the three soils that fall under Zone 1 – 3 which are the subject of this paper. Chapter 3 describes the methods used for testing the performance of the different geotextiles and the three soil types. Results and the interpretation or analysis will be discussed in chapter 4. Lastly, chapter 5 will summarize the conclusions drawn from chapter 4 and the recommendations for further research.

# CHAPTER 2: REVIEW OF LITERATURE

## 2.1. Introduction

Geosynthetics are permeable fabrics which, when used with soil, rock or other geological/geotechnical material have separation, reinforcement, protection, filtration or drainage ability. Their primary function was originally to be used as filters to replace traditional granular filters and as years went by they became popular and started being used in various other functions as mentioned above (Miszkowska, 2017; Mitra, 2013; Wu et al, 2020). They classified under the following nine categories, geotextiles, geonets, geomembranes, geocells, geogrids, geosynthetic clay liners, geocomposites and geopipes. Geotextiles and geomembranes form two of the largest groups of geosynthetics (Koerner, 2005).

These synthetic products are manufactured using different polymer types which includes but not limited to polyester (PET), polyethylene, polyamide (PA), polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC), chlorosulphonated polyethylene (CSPE) and expanded polystryrene (EPS).

## 2.2. History

The use of geotextiles dates back several centuries with evidence found in the use of woven mats made of reeds in temples of Babylonia and also evidence of tree twigs used in the construction of the Great Wall of China (Pritchard**,** 1999; Zewen *et al*, 1981). In South Africa, geotextiles dates back to the 1960s and ever since there has been rapid growth and success in their use.

There has been a lot of ongoing research on the use of geotextiles as filter (Caleb *et al*, 2009; Cazzuffi *et al*, 2015; Chang *et al*, 2013; Das *et al*, 2017; Fannin, 2008; Fannin, 2010; Giroud, 2010; Miszkowska, 2017; Nizam and Das, 2014; Palmeira and Trejos, 2017). Giround (2010) studied a case history of Valcros Dam, constructed in 1970 in France of which he was the engineer. During construction there was inadequate sand for the filter of the downstream drain, he then resorted to using a needle-punched non-woven continuous filament geotextile that had not been used before as a filter. Tests were done on the geotextile filter after 6 and 22 years and the results were very satisfactory. The reduction in tensile strength of the geotextile was less than 20%, hydraulic conductivity was unaffected and there was no evidence of clogging (Giroud, 2010). The performance of the filter has been satisfactory since the filling of the reservoir and this has led to the development of four criteria which are permeability criterion, retention criterion, porosity criterion and thickness criterion. Other authors such as Christopher and Holtz (1985), Luettich et al. (1992) and many more have also contributed to the development and refinement of existing criteria.

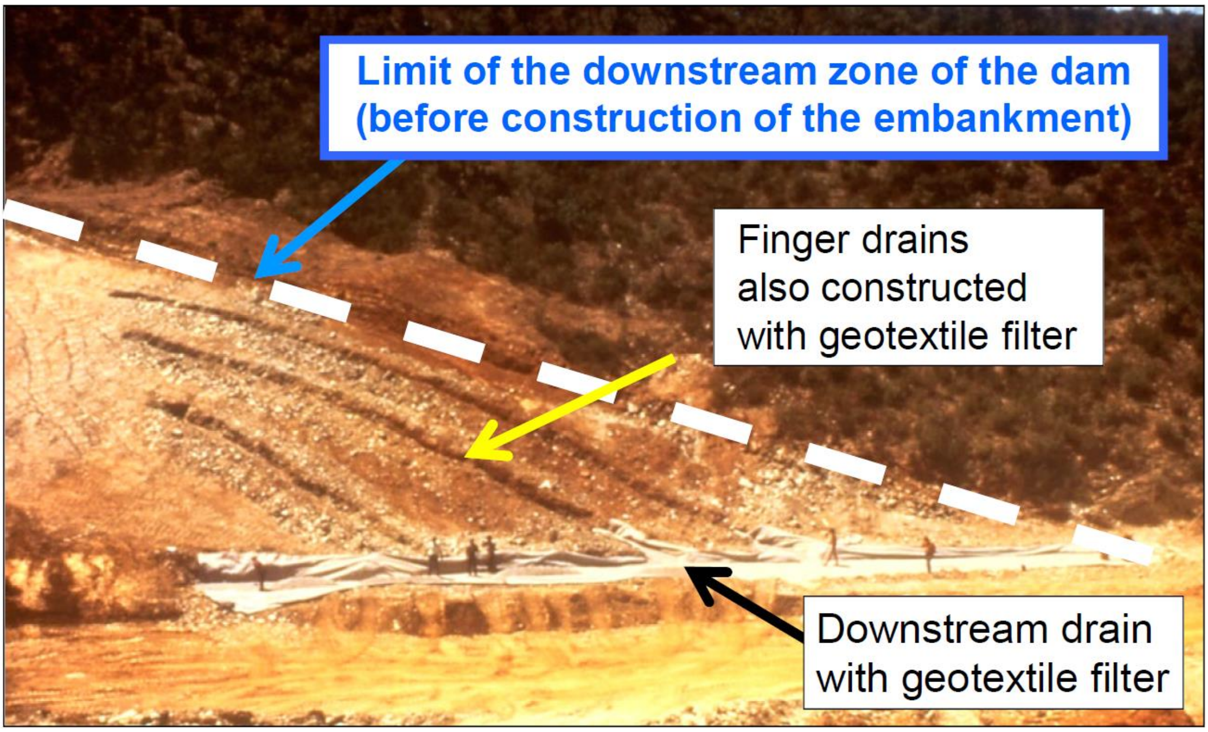


Figure 2.1: Construction of the dam's downstream drain (Giroud, 2010)

## 2.3. Types of geotextiles

Geotextiles are classified under three different sub-categories according to the method from which they are made, namely, woven fabrics, non-woven fabrics and knitted fabrics (Mitra, 2013; Zornberg and Christopher, 2007). The four main polymer types used in the manufacturing of these fabrics are polyester (PET), polyethylene (PE), polyamide (PA) and polypropylene (PP) (Bipin, 2011; Horrocks and Anand, 2000). The oldest of the four polymers is polyethylene which was discovered in 1931, the second oldest is polyamide which was discovered in 1935, polyester discovered in 1941 and more recently polypropylene (Bipin, 2011).

*Polyester (PET):* is manufactured by the process of polymerization of ethylene glycol with dimethyle terephthalate (Zornberg and Christopher, 2007). Fibers made of polyester have high strength modulus and creep resistance.

*Polyethylene (PE):* there are three main groups of polyethylene, namely, low density polyethylene (LDPE), linear low density polyethylene (LLDPE) and high density polyethylene (HDPE) (Bipin, 2011).

*Polyamide (PA):* two main types of amides are available, namely: Nylon 6 and Nylon 6.6 (Bipin, 2011). They are very unpopular and used less in geotextiles due to their proneness to hydrolysis.

*Polypropylene (PP):* two types of polypropylele are homo-polymers and co-polymers. Homo-polymers are used in geotextiles as fibers and yarns (Bipins, 2011)

*Woven fabrics* are made up of individual polymer threads which can be monofilaments, yarns or slit films aligned and interweaved on a loom to form a planar fabric (Fannin, 2010). Wovens and non-wovens are the only two types used in filtration application (fig 2.2A).

*Non-woven fabrics* are made up of layers of randomly orientated polymer strands bonded to form a planar fabric (Fannin, 2010). They can be manufactured from either stable fibre or continuous filament yarn. The process of manufacturing involves mechanical interlocking, thermal or chemical bonding of the individual polymer strands (fig 2.2B).

*Knitted fabrics* are manufactured using a knitting method adopted from the clothing industry which involved interlocking a series of loops of yarn or strands together to make a continuous fabric (Bipin, 2011). This method can also be used in conjunction with a *weaving method* during the manufacture of these fabrics (fig 2.3).

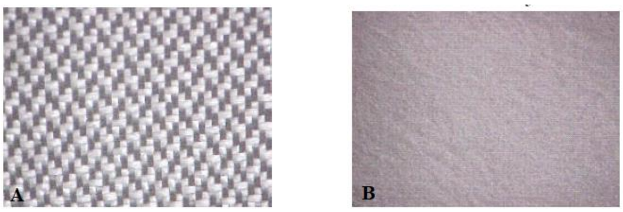


*Figure 2.2. A: Woven fabric geotextile and B: Non-woven fabric geotextile (Bipin, 2011).*

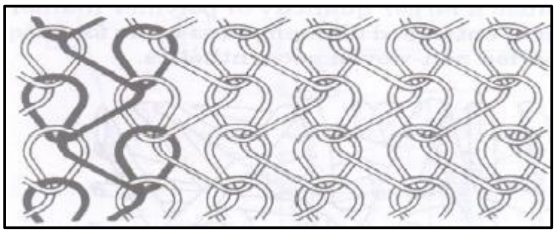


*Figure 2.3: knitted fabric geotextile (Bipin, 2011).*

## 2.4. Properties of Geotextile

Geotextile properties are generally categorized into five main groups, namely, physical, mechanical, hydraulic, endurance and degradation (Horrocks and Anand, 2000; Rawal *et al*, 2010). Each of the groups covers testing that characterizes a different aspect of the geotextile and their performance. Performance tests provide information about the expected behavior of a geotextile for a given application (e.g. the need for filtration tests for a subsoil drainage application). Many of the geotextile strength tests are descendants of tests used for decades in the fabrics industry and they do not provide useful engineering design information. These are described as index tests and they are only used for general characterization of a geotextile product and not appropriate for analytical design. Index tests are performed on the geotextile alone, while performance tests involves both the geotextile and the soil (Atrechian and Ahmadi, 2019).

Physical properties are used to characterize a geotextile and includes mass per unit area, thickness, stiffness and specific gravity. Mechanical properties provides understanding of the geotextile's strength under varying loads. Common mechanical properties includes tensile strength, CBR (California Bearing Ratio), trapezoidal tear strength, puncture resistance and grab tensile strength (Alsalameh *et al*, 2016; Bipin, 2011)

As with mechanical properties, hydraulic properties include both index and performance tests. The ability of a geotextile to transmit water is a function of hydraulic properties. Common hydraulic properties include permeability, transmissivity, percentage open area and porosity (Bipin, 2011).

All the properties described thus far only focuses on the short term behavior of geotextiles. The performance of a geotextile in any application should carry on for the life of the project but due to certain factors such as installation damage the performance can be reduced. Other factors include the migration of soil particles into the pores of the geotextiles. Endurance focuses on long-term behavior of geotextiles. Common testing for endurance properties addresses installation damage, creep behavior, stress relaxation, long-term clogging and abrasion (Bipin, 2011).

Long term performance is also affected by geotextile degradation caused by ultraviolet radiation, chemical reactions with geotextile polymers and thermal degradation. Degradation testing is important in determining the ultimate lifetime of the geotextile (Thomson and Zomberg, 2012).

Table 2.1 lists common geotextile properties and their associated ASTM test methods. This is an overview of the tests commonly reported in literature and manufacturer's specifications.

***Table 2.1: Geotextile properties and associated ASTM test methods***

| Property | Units | Standard Test Designation |
|---|---|---|
| Mass per unit area | g/m$^2$ | ASTM D5261 |
| Thickness | mm | ASTM D5199 |
| Tensile Strength | kN/m | ASTM D4595 |
| Grab Tensile | kN | ASTM D4632 |
| Trapezoidal Tear Strength | kN | ASTM D4533 |
| CBR | kN | ASTM D6241 |
| Permittivity | Sec$^{-1}$ | ASTM D4491 |
| AOS (Apparent Opening Size) | mm | ASTM D4751 |
| Ultraviolet Stability | % | ASTM D4355 |

## 2.5. Functions of Geotextiles

Geotextiles have six main functions in Civil Engineering, namely, filtration, drainage, separation, reinforcement, erosion control and barrier (fig 2.4) (Bipin, 2011; Rawal *et al,* 2010: Mitra, 2013; Zornberh and Christopher, 2007; Rawal *et al*, 2010; Zornberg, 2017). Prior to the development of geotextiles, natural materials such as gravel, sand and rocks were used in earthwork projects to perform these functions. The light weight design of geotextiles give them an advantage over bulky natural materials (Wu *et al*, 2020; Bipin, 2011).

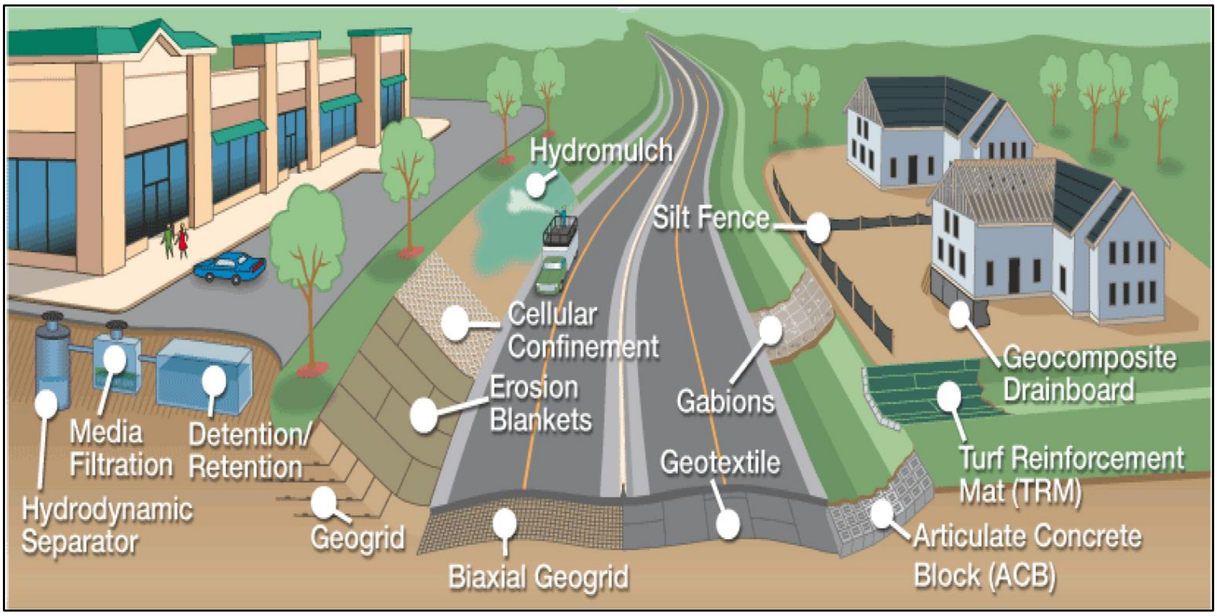


*Figure 2.4: Schematic representation of the application of geotextiles in civil engineering (Bipin, 2011).*

### 2.5.1. Filtration

The flow of water in soils induce the movement of fine particles which gets halted at the filter interface (Nizam, 2014). Geotextile filter allows the movement of fluids or liquids while preventing the movement of soil particles (Müller, 2015). A common application of a geotextile as a filter is in subsurface drains (fig 2.5).

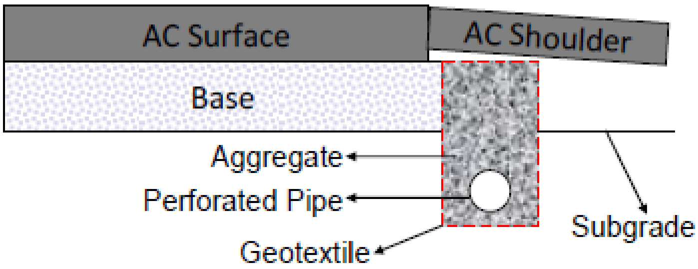


*Figure 2.5: Geotextile as a filter on a pavement shoulder subsurface drainage system (Das SC et al, 2017).*

Filtration refers to cross plane permittivity and is defined as:

$$\Psi = \boldsymbol{k_n/t} \qquad \textit{(2.1)}$$

Where $\boldsymbol{\psi}$ is the permittivity, $\boldsymbol{k_n}$ is cross plane hydraulic conductivity and $\boldsymbol{t}$ is the geotextile thickness under normal pressure.

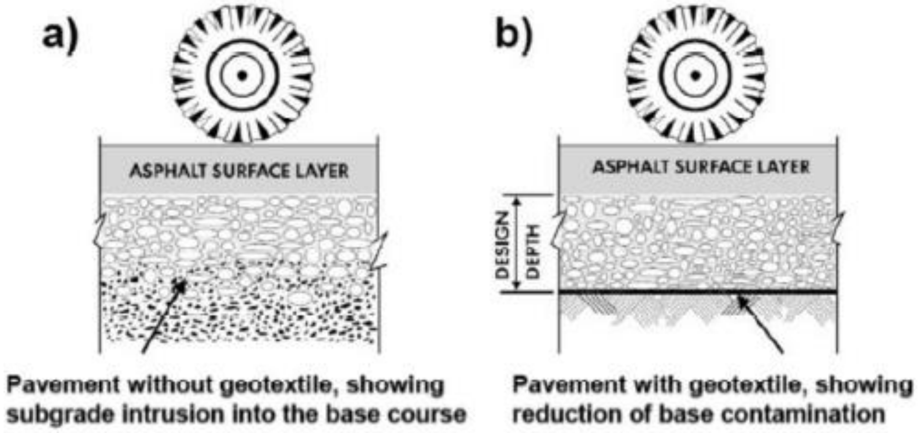
### 2.5.2. Drainage

The drainage function is to collect excess water due to high water table or rainfall and discharge it (Das SC *et al*, 2017). Geotextiles and/or geopipes or a combination thereof, with good permeability and filtration properties can be used for drainage applications.

### 2.5.3. Separation

Geotextiles are used to separate two layers having different properties and also prevent mixing of the layers under load application (Rawal *et al*, 2010; Zornberg and Christopher, 2007). Separation involves the introduction of a porous geotextile with low tensile modulus between two different soils or material layers so that the integrity and functioning of the layers remains intact for the life of the structure (Das SC *et al*, 2017).

As can be seen from figure 2.6, where there is no geotextile, the subgrade intrudes into the base and mix which can lead to pavement failure. In the case where the geotextile is used, there's no mixing or base contamination ((Das SC *et al*, 2017).



Pavement without geotextile, showing subgrade intrusion into the base course

Pavement with geotextile, showing reduction of base contamination

*Figure 2.6: Schematic representation of a) a road pavement without a separation layer and b) pavement with a geotextile as a separator (Das SC et al, 2017).*

### 2.5.4. Reinforcement

Heavy grade geotextiles are used to reinforce structures and due to their high tensile strength as well as high soil to fabric friction coefficient they prevent deformation (Nizam, 2014). The main purpose of geotextiles in reinforcement is to increase the cohesion between particles in a soil structure and also increase its bearing capacity (Das SC *et al*, 2017). High strength composite geotextiles are often used for this application because they offer high modulus characteristic and minimum deformation. The structural stability of the soil is greatly improved by the high tensile strength of the geosynthetic (Bipin, 2011).

### 2.5.5. Erosion Control

Soil erosion is a process whereby soil particles are loosened and transported by natural processes such as rainfall, wind and landslides, as well as man's activities which alter the protective cover of the ground surface (Weggel, 1992).

Geotextiles prevent surface erosion of soil particles due to surface water run-off, wave action in earth embankments and wind forces (Müller, 2015). The main objective for this function is to allow for vegetation to grow without the top soil being washed away. Most geotextiles used for this application are biodegradable and can also act as fertilizers for the vegetation.

### 2.5.6. Barrier

The function of a barrier is to prevent the migration of liquids (Müller, 2015). Most widely used geosynthetic product for this application is a geosynthetic clay liner (GCL). It is made up of two durable geotextiles impregnated with a uniform layer of sodium bentonite to form a hydraulic barrier. This product is used as a barrier in landfills, mine tailings dams, irrigation canals, lagoons and low cost dam construction due to its low permeability and high shear resistance.

## 2.6. Geotextiles as filters

A filter is one that retains particles of the base soil while allowing easy flow of water (Moraci, 2010). A successful filter design can be achieved by adhering to the following principles (*Kaytech Filter Design Guide*, 1995):

- A geotextile should be conformable and have adequate strength to survive installation
- It should have enough pores for adequate flow to be maintained even if some pores gets blocked.
- The four filter criteria should be followed.
- In a critical application, where in an event of failure a loss of life may arise, performance tests should be done to check for soil-geotextile compatibility.
- The permeability of the geotextile should be higher than that of the base soil.
- Larger pores in the geotextile should be smaller than the largest particles of the base soil, therefore the soil will be retained and "piping" will not occur.
- The smaller pores in the geotextile should be large enough for the smaller soil particles to pass through to prevent "clogging" and "blinding".

Geotextile filters are influenced by method of application, groundwater conditions and in-situ soil properties (fig 2.7) (Kaytech Filter Design Guide, 1995).

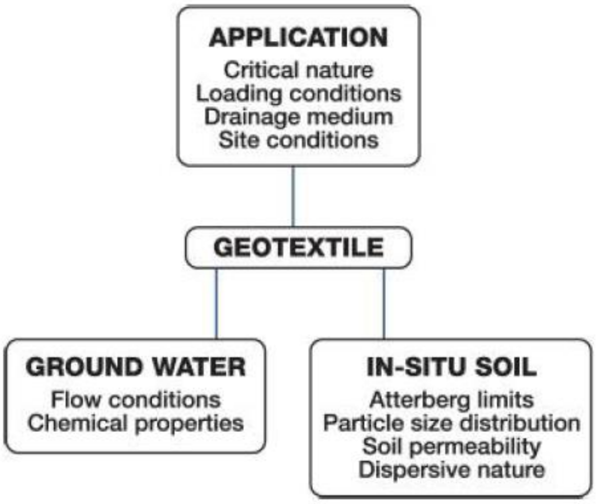


*Figure 2.7: Parameters influencing geotextile selection in a filtration environment (Kaytech Filter Design Guide, 1995).*

There are generally two flow conditions in a filtration environment namely, unidirectional where water/fluid flows in one direction at a constant or variable flow rate. Multi-directional condition is where the flow direction of water changes continuously while the flow rate may change or remain constant.

Ground water can be acidic ($\mathrm{pH} \leq 7$) or alkaline ($\mathrm{pH} \geq 7$). Acidic groundwater can be corrosive. Ground water chemical composition may or may not have an effect on the geotextile filter. Chemical parameters should be clearly defined as different geotextile types react differently to different pH and chemical concentration e.g. Polyester is sensitive to high pH whereas polypropylene less sensitive (Kaytech Filter Design Guide, 1995).

### 2.6.1. Criteria for geotextile filters

There are four main criteria for geotextile filters, namely, permeability, retention, porosity and thickness criterion which are used as part of the design and selection of a suitable filter for a given filtration application (Giroud, 2010; Heibaum, 2014; Moraci, 2010). The following sections will address the importance of these criteria in selecting the best geotextile filter.

#### *Permeability criterion*

The presence of a filter (either less or very permeable) decreases the flow rate of water or liquid in the soil and also causes the development of an internal pressure. This leads to two permeability requirements, namely, pore pressure and flow rate requirements (Cazzuffi *et al*, 2015; Giround, 2010).

***Pore pressure requirement***

As previously mentioned, the presence of a filter increases pore water pressure in the base soil and this can cause negative effects in the soil-filter system. Therefore, the filter selected for a given filtration application should be such that the pore pressure increase is minimal or zero (Giroud, 2010).

*The following three cases may occur (Giroud, 2010):*

*Case 1*: Steady flow of water through the soil without a filter and there is no excess pore pressure as represented in figure 2.8.

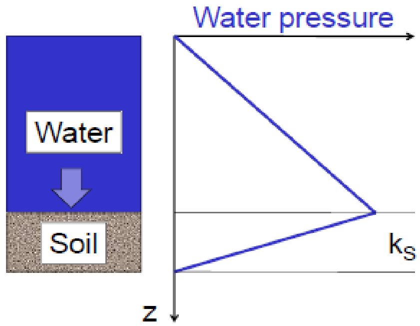


*Figure 2.8: Pore water pressure as a function of depth (Giroud, 2010).*

*Case 2*: The presence of a filter results in build-up of pore pressure as shown in fig 2.9.

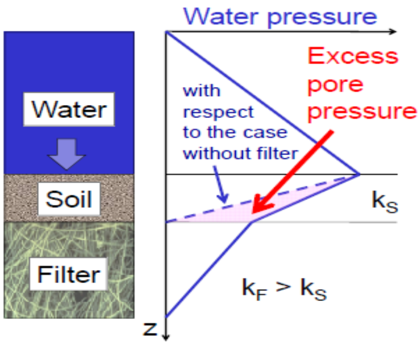


*Figure 2.9: Excess pore pressure caused by the presence of a filter (Giroud, 2010).*

*Case 3*: There is no increase in pore water pressure if the following condition is met, $k_F \geq i_S k_S$, (fig 2.10). Where: $k_F$ = permeability of the filter; $k_S$ = permeability of the soil; and $i_S$ = hydraulic gradient in the soil next to the filter.

In general, permeability of the filter ($k_F$) has to be greater than permeability of soil ($k_S$).

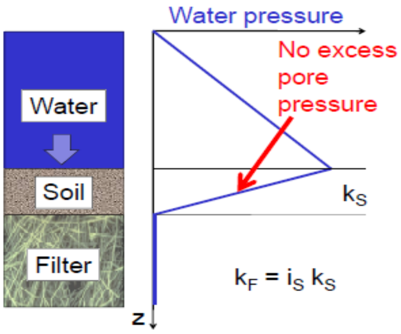


*Figure 2.10: No excess pore water pressure in this case (Giroud, 2010).*

*Flow rate requirement*

The reduction in flow rate of water due to the presence of a filter has been proved to be less than 10% in cases without a filter (Giroud, 2010). This has been proved using Darcy's equation as long as the conditions below are satisfied:

For geotextile filters with thickness from 1 to 10 mm $k_F \geq k_S$

For granular filters with thickness from 250 to 2500 mm $k_F \geq 25\ k_S$

There is an inverse relationship between pore water pressure and flow rate requirement in cases with or without a filter.

Other existing permeability criteria are summarized in table 2.2.

***Table 2.2: Existing geotextile permeability criteria (after Christopher & Fischer, 1992).***

| **Source/author** | **Criterion** | **Remarks** |
|---|---|---|
| e.g. Calhoun (1972); Schober & Teindl (1979); Wates (1980); Carroll (1983); Haliburton *et al*, (1985) and numerous others | $k_f \geq k_s$ | Steady state flow, noncritical application and nonsevere conditions |
| e.g. Carroll (1983); Christopher & Holtz (1985) | $k_f \geq 10\ .\ k_s$ | Critical applications and severe soil or hydraulic conditions |
| Giroud (1982) | $k_f \geq 0.1\ k_s$ | No factor of safety |
| French Committee of geotextiles and geomembranes (1986) | Based on permittivity $\psi \geq 10^{3-5}$ $k_s$ | Critical $10^5$ $k_s$<br>Less critical $10^4$ $k_s$<br>Clean Sand $10^3$ $k_s$ |
| Koerner (1990) | $\psi_{allow} \geq FS.\ \Psi_{req'd}$ | Factor of safety FS based on application and soil conditions |

### *Retention criterion*

This is the most important of the four criteria. It addresses soil density and particle size distribution. A linear coefficient of uniformity is used which is based on a straight line that touches the most linear part of the particle distribution curve (fig 2.11).

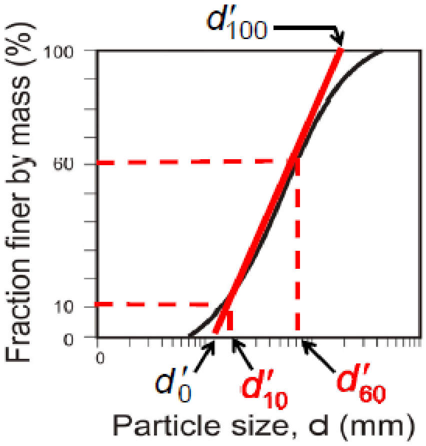


*Figure 2.11: Particle size distribution curve characterized by linear coefficient of uniformity (Giroud, 2010).*

Coefficient of uniformity is defined as:

$$C_u = \frac{d_{60}}{d_{10}} \qquad \textbf{(2.2)}$$

Linear coefficient of uniformity is defined as:

$$C'_u = \frac{d'_{60}}{d'_{10}} \qquad \textbf{(2.3)}$$

*which is equal to:*

$$\sqrt{\frac{d'_{100}}{d'_0}} \qquad \textbf{(2.4)}$$

$d_x$ – linear particle size

Retention criterion also takes into account internal stability of soil. A soil is regarded internally stable if coarse particles form a continuous skeleton that entraps particles that are smaller which entraps particles that are smaller and the network continues to the smallest diameter particles. A geotextile filter must have openings able to retain the skeleton (Giroud, 2010).

*Coefficient of uniformity and soil stability*

A soil with a coefficient of uniformity of 3 or less ($C_u \leq 3$) is regarded internally stable as the coarser particles form a continuous skeleton which traps the smaller particles (fig 2.12).

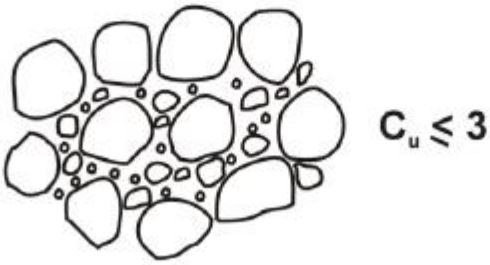


*Figure 2.12: Schematic representation of a tightly interlocked soil skeleton (Giroud, 2010).*

If a soil has a coefficient of uniformity of more than 3, there are more fine particles in the matrix and this prohibit contact between coarse particles. As a result the coarse particles are unable to form a continuous skeleton that hold the finer particles in place (fig 2.13).

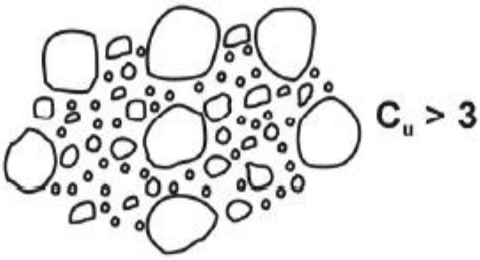


*Figure 2.13: Schematic representation of a soil structure with a coefficient of uniformity of more than 3 (Giroud, 2010).*

In some cases where coefficient of uniformity is greater than 3, the coarse fraction of a soil is removed for the purpose of the development of a retention criterion.

*Filter opening size requirement*

For a filter to fulfill its primary function of retaining the base soil and allowing free flow of water, the pore size of the filter has to be smaller than the particle size of the soil it is retaining (fig 2.14). Internal stability of soil also play an important role in soil retention. The more loosely packed particles are the more the soil is susceptible to internal erosion and it can easily be washed through the filter *(and vice versa).*

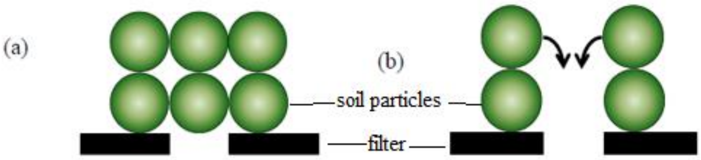


*Figure 2.14: schematic representation of (a) soil particles equal to the filter opening in size & (b) soil particles less than filter opening in size (Giroud, 2010).*

In conclusion, soil density and internal stability are most important factors in the design of a retention criterion for a geotextile filter. Other existing criteria are summarized in table 2.3.

***Table 2.3: Existing geotextile retention criteria (after Fischer et al. (1990).***

| **Source/author** | **Characteristics of the base soil** | | **Retention Criterion** |
|---|---|---|---|
| | **Relative density** | **Grain size distribution** | |
| Calhoun (1972) | | Wovens, soils with ≤ 50% passing<br>No 200 sieve<br>Wovens, cohesive soils | $O_{95}/D_{85} \le 1$<br>$O_{95} \le 0.2$ mm |
| Moraci (1992) | Loose - medium | Wovens and nonwovens, unstable | $d_c < O_F < D_{85}$ ($d_c$ suffusion critical diameter) |
| Zitscher (1975) from Rankilor (1981) | | Wovens, soils with $C_u \le 2$, $D_{50}$ = 0.1 to 0.2 mm<br>Nonwoven, cohesive soil | $O_{50}/D_{50} \le 1.7$-2.7<br>$O_{50}/D_{50} \le 25$ - 37 |
| Ogink (1975) | | Wovens<br>Nonwovens | $O_{90}D_{90} \le 1$<br>$O_{90}/D_{90} \le 1.8$ |
| Mc Keande (1977) | | Nonwovens, stable uniform and broadly graded | $O_{50}/D_{85}$ |
| U.S.C.E. (1977) | | Stable uniform, broadly graded with $D_{50} > 0.074$ mm | 0.149 mm ≤ $O_{95}$ ≤ 0.211 mm |
| Fannin *et al.* (1994) | Dr ≤ 70% | 1 < U < 2 (Uniform) | $O_F/D_{85} < 1.5$ and $O_F/D_{50} < 1.8$ |
| Sweetland (1977) | | Nonwovens, soils with $C_u$ = 1.5<br>Nonwovens, soils with $C_u$ = 4 | $O_{15}D_{85} \le 1$<br>$O_{15}D_{15} \le 1$ |
| Rankilor (1981) | | Nonwovens, soils with $0.02 \le D_{85} \le 0.25$ mm<br>$D_{85} \ge 0.25$ mm | $O_{50}/D_{85} \le 1$<br>$O_{15}/D_{15} \le 1$ |
| Schober & Teindl (1979)<br>With no factor of safety | | Woven and thin nonwovens, dependent on $C_u$<br>thick nonwovens, dependent on $C_u$ | $O_{90}/D_{50} \le 2.5 – 4.5$<br>$O_{90}/D_{50} \le 4.5 – 7.5$ |
| Millar et al. (1980)<br>Giroud (1982) | 35 ≤ Dr ≤ 65% | Wovens and nonwovens<br>Dependent on soil $C_u$ and density<br>Assumes fines in soil migrate for large $C_u$ | $O_{50}/D_{85} \le 1$<br>$O_{95}/D_{50} \le (9 - 18)/C_u$ |
| Carroll (1983)<br>Christopher & Holtz (1985) | | Wovens and nonwovens<br>Dependent on soil type and $C_u$<br>Dynamic, pulsating and cyclic flow, if soil can move beneath fabric | $O_{95}/D_{85} \le 2 – 3$<br>$O_{95}/D_{85} \le 1 – 2$<br>$O_{95}/D_{15} \le 1$ or<br>$O_{50}/D_{85} \le 0.5$ |
| Loudiere (1982) | | Woven, stable uniform U<4<br>Nonwovens, stable broadly U>4 | $O_{95}/D_{50} < 0.8$<br>$O_{95}/D_{85}$ |
| Faure *et al*. (1986) | | Woven, stable uniform ($D_{85}$ = 95 – 240 mm)<br>Nonwoven, stable broadly graded ($D_{85}$ = 95 – 240 mm) 1.4 < U < 10; Stable uniform sand and silt ($D_{85}$ = 51 – 140mµ) 1.2 < U < 3.6 | $O_f/D_{85} < 1.5 \div 2$<br>$O_f/D_{85} < 1 \div 1.2$ |
| French committee of Geotextiles and Geomembranes (1986)<br>Fischer *et al.* (1990) | | Dependent on soil type, compaction, hydraulic and application conditions<br>Based on geotextiles pore size distribution, dependent on $C_u$ of soil | $O_f/D_{85} \le 0.38 – 1.25$<br>$O_{50}/D_{85} \le 0.8$<br>$O_{50}/D_{15} \le 1.8 – 7.0$ |

***Porosity criterion***

Most geotextiles are so permeable that even with a small number of pore openings they meet the permeability criterion and this criterion does not address the number of openings in a filter. It is therefore necessary to have a criterion which is specific to the number of pore openings per unit area of a geotextile filter. This result in the porosity criterion (Giroud, 2010).

A porous media like a geotextile filter has channels which water flow through and these are referred to as flow channels. There is a greater number of flow channels per unit area in the soil than in a filter that meets the retention criterion for that soil (Giroud, 2010). As a result, there is a disturbance in the flow of water at the soil-geotextile interface due to reduction in the number of flow channels. The disturbance in the flow at the interface could result in the accumulation of fine particles on the surface of the filter or in the filter potentially causing clogging. Therefore the number of flow channels per unit area should be as large as possible. The number of openings per unit can be expressed mathematically by the following equations (Giroud, 2010):

*For granular filters:*

$$N_o \approx \frac{0.1}{O_F^2} \qquad \textbf{\textit{(2.5)}}$$

*For woven geotextiles:*

$$N_o = \frac{A_R}{O_F^2} \qquad \textbf{\textit{(2.6)}}$$

Where $\boldsymbol{A_R}$ is the relative open area of woven geotextiles.

The comparison between the two equations above gives $A_R \geq 0.1$.

For non-woven geotextiles it is difficult to determine the number of openings per unit area and therefore an approximate calculation is necessary using equation 2.7.

$$\frac{\left(1-\sqrt{1-n}\right)^2}{O_F^2} \leq N_o \leq \frac{4\left(1+0.4n-\sqrt{1-n}\right)^2}{\sqrt{3}\ O_F^2} \qquad \textbf{\textit{(2.7)}}$$

Where $\boldsymbol{n}$ equals porosity of the nonwoven geotextiles

According to Giroud 2010, comparison between equations *(2.5)* and *(2.6)* and through some mathematical calculations of a wide range of porosities gives a number which ensures that the number of openings in the nonwoven geotextile is at least equal to the number of opening in a granular filter having the same opening size. The porosity of nonwoven geotextiles should be equal to or greater than 0.55. Their porosities are typically 0.7-0.9 and about 0.6-0.8 when subjected to compressive stresses, this means that nonwoven geotextiles always meet the porosity requirement.

Typically, for woven geotextiles $\boldsymbol{A_R} \geq 0.1$ and for nonwoven geotextiles $\boldsymbol{n} \geq 0.55$.

Although most of woven geotextiles used as filters have a relative open area of less than 0.1 and pose a high risk of clogging, it is recommended that for all filtration application woven geotextiles should meet $A_R \geq 0.1$ (Giroud, 2010).

### *Thickness criterion*

Non-woven geotextiles differ in thicknesses and it is necessary to have a criterion that ensures that the filter meets the thickness requirement. The thickness of woven geotextiles (woven tapes) will not be considered as they are generally thin.

In a soil-geotextile filter system, soil particles move in through path or passages known as constrictions (Kenny and Lau, 1985). A constriction is a path between fibres. The size of the constriction is defined as the diameter of the largest sphere that passes through the constriction (Giroud, 2010).

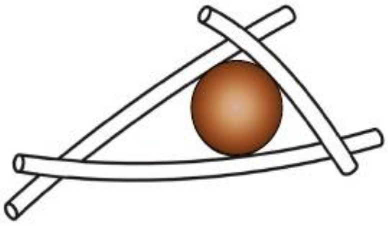


*Figure 2.15: schematic representation of a constriction with a particle in between fibers that make up the constriction (Kenny and Lau 1985).*

Particles move from one constriction to another forming a filtration channel in a filter. Small particles move into the filter, some are trapped inside and some go through the filter. Large particles are stopped on the surface of the filter (fig 2.16).

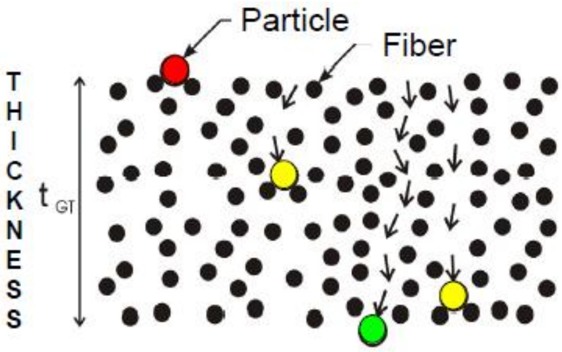


*Figure 2.16: schematic representation of a cross section of a nonwoven geotextile filter (Kenny and Lau 1985).*

A mathematical analysis of the relationship between the opening size and thickness of nonwoven geotextiles has been developed theoretically using experimental data represented by the following equation (Giroud, 2010):

$$\frac{O_F}{d_f} \approx \frac{1}{\sqrt{1-n}} - 1 + \frac{10n}{(1-n)\,t_{GT}\,/\,d_f} \qquad \textbf{(2.8)}$$

*Where:* $\boldsymbol{O_F}$ = nonwoven geotextile filter opening

$\boldsymbol{t_{GT}}$ = nonwoven geotextile thickness

$\boldsymbol{d_f}$ = fiber diameter

Equation (2*.8)* can be represented graphically as a ratio of opening/size as a function of the ratio of thickness/fiber diameter shown in Figure 2.17:

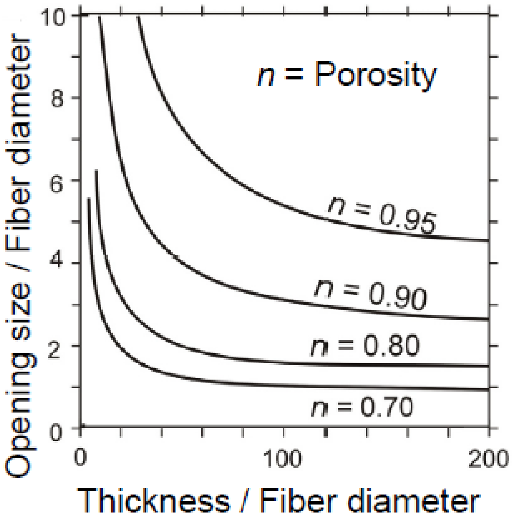


*Figure 2.17: Graphical representation of opening size/fiber diameter ratio as a function of thickness/fiber diameter of nonwoven geotextiles (Giroud, 2010).*

As can be seen from figure 2.17, for a given porosity, the opening size for a nonwoven geotextile filter decreases with increase in thickness of the geotextile.

The number of constrictions ($N_{constrictions}$) in a nonwoven geotextile can also be represented mathematically by the following approximate equation (Giroud, 2010):

$$N_{constrictions} \approx \frac{\mu_{GT}}{\rho_f \, d_f \sqrt{1-n}} \qquad \textbf{(2.9)}$$

In conclusion, a good woven or nonwoven geotextile filter should have a thickness that corresponds to at least 25 constrictions (Giroud, 2010).

### *Clogging Resistance Criteria*

Clogging is a function of the relation between fine particles of the in-situ soil and their ability to clog or block most if not all of the pore openings in the geotextile. The geotextile characteristics to prevent clogging are thus controlled by the relationship between particle size to both the volumetric and diametric pore size distribution (Christopher & Fischer, 1992). These characteristics control clogging potential and neither is addressed by the permeability and retention criteria. Clogging resistance criteria can only be successfully achieved through performance tests like the gradient ratio test, which was originally developed by Calhoun, 1972 and adopted by ASTM. The reason for using performance test for this criteria is because it is dependent on site specific conditions and soils (Table 2.4).

***Table 2.4: Clogging Criteria (after Christopher & Fischer, 1992).***

| |
|---|
| A. **Critical/severe applications** |
| Perform soil/fabric filtration tests.<br>(e.g. Calhoun, 1972; Haliburton et al., 1982; Haliburton & Wood, 1982; Giroud, 1982;<br>Carrol l, 1983; Christopher &cHoltz, 1989, 1989; Koerner, 1990) |
| B. **Less critical/non-severe application** |

1. Perform soil/fabric filtration tests.
2. Minimum pore sizes alternatives for soil containing fines, especially in a noncontinuos matrix:
    (a) $O_{95} \geq 3D_{15}$ for Cu $\geq 3$
    (Christpher & Holtz, 1985 and modified 1989)
    (b) $O_f \geq 4\ D_{15}$
    (French Committee of geotextiles, 1986)
    (c) $O_{15}/D_{15} \geq 0.8$ to 1.2
    $O_{50}/D_{50} \geq 0.2$ to 1
    (Fischer et al., 1990)

3. For Cu $\leq 3$, fabric with maximum opening size from retention criteria should be Specified.

4. Apparent open area qualifiers
    Woven fabrics: Percentage open area: $\geq$ 40% to 6%
    (Calhoun, 1972; Koerner, 1990)
    Nonwoven fabrics: Porosity $\geq$ 30% to 40%
    (Christopher & Holtz, 1985; Koerner, 1990)

### 2.6.2 Long Term Survivability and Durability of Geotextiles

During installation geotextiles may be susceptible to damage due to improper handling or simply being punctured by rocks or other natural factors such as soils that are too acidic or alkaline, therefore, requirements such as survivability, durability, resistance and strength should be included in filter specification. (Heibaum, 2014).

Mechanical properties of geotextiles such as tensile strength, puncture resistance, CBR (California bearing ratio), tear resistance, mass and thickness are often specified to meet survivability requirements (Heibaum, 2014). After installation, geotextiles must be durable enough to survive chemical, mechanical, microbiological and environmental degradation.

#### Survivability Criteria

Geotextiles are often subjected to harsh installation conditions which involves the use of heavy machinery and/or the presence of rocks with sharp edges that could cause puncture or significant damage. Acidic environments such as low pH soils and exposure to direct sunlight can also cause long term damage/degradation to the geotextiles (Zornberg and Thompson, 2012). Table 2.5 lists minimum physical property requirements for drainage and erosion control applications.

*Table 2.5: Minimum physical requirements for construction survivability (after Christopher & Fischer, 1992).*

| Drainage/Erosion Control applications | | | |
|---|---|---|---|
| **Property** | **Class A$^{d}$** | **Class B$^{e}$** | **Test Method** |
| Grab strength, N | 800/890 | 356/400 | ASTM D4632 |
| Elongation, % | Na/15 | Na/15 | ASTM D4632 |
| Seam strength, N | 710/800 | 310/356 | ASTM D4632 |
| Puncture strength, N | 356/356 | 110/180 | ASTM D4833 |
| Burst strength, kPa | 2000/2210 | 896/965 | ASTM D3787 |
| Trapezoid tear, N | 220/220 | 130/130 | ASTM D4533 |
| Ultraviolet degradation | 70% strength retained at 150 h all classes | | ASTM D4355 |

## Chemical degradation

During a previous study by Moncrieff (1975) on the performance and resistance of polymers to specific chemicals found that most geotextile polymeric fibers are resistance to chemical degradation. It was also found that polyester can be degraded by alkalis. Polyamides are readily attached by strong acids but are resistant to alkaline hydrolysis and polypropylene undergoes oxidative degradation.

Further more recent studies were carried out by Troost and den Hoedt (1984), who investigated the reaction of geotextiles made of polyester, polyamide and aramid by submerging them for up to thirty months in solutions with pH ranging from 5 to 9. All the fabrics retained 90% of their strength after the tests (Table 2.6).

*Table 2.6: Chemical and Thermal stability of synthetic fibers (after Cooke & Rebenfield, 1988; Lawson & Curiskis, 1985 and van Zanten, 1986).*

| **Polymer Type** | **Resistant to** | | **Stable between (°C)** | **Remarks** |
|---|---|---|---|---|
| | **Acid Conditions** | **Alkali Conditions** | | |
| Polypropylene | pH ≥ 2 | All | -15 to 120 | Attacked at elevated temperatures by hydrogen peroxide, sulphuric acid and nitric acid.<br>Weakened by certain solvents, e.g. diesel fuel.<br>Insignificant change in strength between 20°C and 35°C. |

| Polymer Type | Resistant to | | Stable between (ºC) | Remarks |
|---|---|---|---|---|
| | Acid Conditions | Alkali Conditions | | |
| Polyester | pH ≥ 3 | pH ≤ 10 | -20 to 220 | Degrades by hydrolysis under strongly alkaline conditions. Therefore concrete must not be cast directly against it.<br>Insignificant change in strength between 20ºC and 35ºC. |
| Polyamide (Nylon 6.6) | pH ≥ 3 | pH ≤ 12 | -20 to 230 | Degrades by hydrolysis under strongly acidic conditions.<br>Reduces in strength by up to 30% when immersed in water or used in saturated environments.<br>Insignificant change in strength between 20ºC and 35ºC. |
| Polyethylene | pH ≥ 2 | All | -20 to 80 | Same as polypropylene, except strength at 35ºC is lower than that at 20ºC by about 20% |

### Microbiological degradation

Some of the polymers (polyester and polyolefins) used today for manufacturing geotextiles are resistant to microbiological attack (Rankilor, 1981). Polymers like polyamids are known to be attached by mildew and bacteria. Lonescu *et al* 1982, immersed 1400 samples of six geotextile types in eight types of soils containing different bacteria for a duration of five to seventeen months. The results showed no sign of biodegradation and no significant reduction in strength. Biological activity is less likely to affect geotextiles since it occurs near the surface rather than at depth.

### Environmental degradation

Environmental factors such as ultraviolet radiation, extreme weathers, and polluted atmosphere can affect geotextiles negatively (Zornberg and Thompson, 2012). In general, the most common risk for an uncovered geotextile is exposure to ultraviolet radiation. The mechanism of degradation is photochemical in nature and it involves absorption of ultraviolet light by the polymers which provides the energy to break key molecular bonds. The resultant free radicals react with oxygen to from peroxy radicals which in turn attack other polymer molecules.

Temperature around the world is well within acceptable range for the application of geotextiles. Raumann (1982), reported outdoor exposure on a range of polyester and polypropylene geotextiles for a period of thirty-six weeks and all samples show significant loss in strength. Some samples lost all their strength from 16 to 24 weeks. Consequently, all polymers used in the manufacturing of geosynthetics must be protected by appropriate additives to minimize the effects of ultraviolet radiation.

**Mechanical degradation**

Geotextiles can be damaged during installation as a result of compaction and abrasive forces. The principal results of these degradation mechanisms are loss of strength and changes in elongation properties (Paula *et al*, 2008). For instance, when a geotextile is punctured during installation on a filtration application, the geotextile filter performance is reduced. Small particles could migrate through the geotextile resulting in localized flow which could potentially block the drainage system.

## 2.7. International Geotextiles Design Criteria

Over the years, researchers have developed many filter design criteria. However, none of these has been internationally accepted as the standard design method. Table 2.7 summaries some of the criteria that have been developed through the years.

***Table 2.7: Retention criteria based on previous studies (Bergado et al, 1996).***

| Source | Criterion | Remarks |
|---|---|---|
| Bergodo *et al* (1992) | $O_{90}/D_{85} \leq 2 \text{ to } 3$<br>$O_{50}/D_{50} \leq 18 \text{ to } 24$ | Nonwovens, clay recommended |
| Ogink (1975) | $O_{90}/D_{85} \leq 1.8$ | Nonwovens, type of soil not specified |
| Carroll (1983) | $O_{90}/D_{85} \leq 2 \text{ to } 3$ | For both wovens and nonwovens, type of soil not specified |
| Christopher and Holtz (1985) | $O_{95} \leq 1.8\, D_{85}$<br>Steady state<br>AOS < 0.3 $D_{85}$ | Nonwovens for soils with greater than 50% particles passing the 0.075 mm sieve |
| Holtz and Christopher (1987) | For steady state<br>$O_{95} \leq 0.5$, $D_{85} \leq 0.3$ *mm*<br>For dynamic flow<br>$O_{50} \leq 0.5\, D_{85}$ | Nonwovens, for silts and clay |
| Calhoun (1972) | $O_{95}/D_{85} \leq 1$ | |
| Chen and Chen (1986) | $O_{90}/D_{85} \leq 1.2$ to 1.8<br>$O_{50}/D_{50} \leq 10$ to 12 | Suitable for geotextile filter with a high percentage of large pores |

| Source | Criterion | Remarks |
|---|---|---|
| Sweetland (1977) | $O_{15}/D_{85} \leq 1$<br>$O_{15}/D_{85} \leq 1$ | |
| Rankilor (1981) | $O_{50}/D_{85} \leq 1$<br>$O_{95}/D_{85} \leq$ 25 to 37<br>$O_{15}/D_{15} \leq 1$ | Nonwovens, soils with $C_u$ = 1.5<br>Nonwovens, soils with $C_u$ = 4<br>Nonwovens, soils with $0.02 \leq D_{85} \leq$ 0.25 mm<br>Nonwovens, cohesive soil<br>Nonwovens, soil with $D_{85} > 0.25$ *mm* |

Although many researchers have developed their own retention and permeability criteria, most countries have adopted what they regard the best practice for their local conditions. These criteria are discussed in more details in the following section.

### 2.7.1. Regional Geotextile Filter Design Criteria (N.W.M. John, 1989).

The following are design criteria accepted only in the listed countries.

#### *Dutch Practice*

For static unidirectional flow, originally $O_{95} < D_{90}$ for wovens and $O_{90} < 1.8d_{90}$ for wovens, both these are released by the Dutch Coastal Works Association.

*Where:* $O_{95}$ represents the opening size of the geotextile which 95% of the pores are this size or smaller.

$D_{90}$ is the particles size of soil which 90% of the particles are this size or smaller

#### *German Practice*

***Table 2.8: German practice in terms of geotextile filter criteria (NWM John, 1989).***

| Soil Description | Geotextile Criteria |
|---|---|
| $d_{40} < 0.06$mm, stable soil | $Dw < 10d_{50}$ and $Dw < 2d_{90}$ |
| $d_{40} < 0.06$mm, problem soil | $Dw < 10d_{50}$ and $Dw < 2d_{90}$ |
| $d_{40} > 0.06$mm, stable soil | $Dw < 5d_{10}U^{1/2}$ and $Dw < 2d_{90}$ |
| $d_{40} > 0.06$mm, problem soil | $Dw < 5d_{10}U^{1/2}$ and $Dw < d_{90}$ |
| Where Dw is the characteristic pore size of the geotextile | |

*Where:*

**$d_x$** is the particle diameter at which x% of the sample's mass comprise of particles with a diameter less than this value.

*And where problem soil are defined as those:*

i. Plasticity index is less than 15% (fine-grained soils only)
ii. Whose average particle size ($d_{50}$) lies between 0.02 and 0.1 mm
iii. Coefficient of uniformity of less than 15 (containing clay and silt size particles.

### *French Practice*

This criteria recognize the base soil coeficient of uniformity (U), soil density, and hydraulic gradient (i).

***Table 2.9: French practice in terms of geotextile filter criteria (NWM John, 1989).***

| **Soil Description** | **Geotextile Criteria** |
|---|---|
| Well graded (U>4) and dense | $4d_{15} \le O_f \le 1.25d_{85}$ |
| Well graded (U>4) and lose | $4d_{15} \le O_f \le d_{85}$ |
| Uniformly graded ($U \le 4$) and dense | $O_f \le d_{85}$ |
| Uniformly graded ($U \le 4$) and loose | $O_f \le 0.8d_{85}$ |

*Where:*

***$d_x$*** is the particle diameter at which x% of the sample's mass comprise of particles with a diameter less than this value.

**$O_f$** is the characteristic opening size of the geotextile filter

When the hydraulic gradient *(i)* in the vicinity of the geotextile filter lies between 5 and 20, then the geotextile pore sizes specified in table 9 above should be reduced by 20%, similarly, if the hydraulic gradient(i) exceeds 20, the pore sizes should be reduced by 40%.

### *American Practice*

Criteria for the American practice is summarized in table 2.10.

***Table 2.10: American practice in terms of geotextile filter criteria (NWM John, 1989).***

| **Soil Description** | | **Geotextile Criteria** |
|---|---|---|
| $d_{40} > 0.075$mm | | $0.297\text{mm} \le O_{95} \le d_{85}$ (wovens)<br>$0.297\text{mm} \le O_{95} \le 1.8d_{85}$ (nonwovens) |
| $d_{50} \le 0.075$mm | $U \le 2$ | $O_{95} \le d_{85}$ |
| | $2 \le U \le 4$ | $O_{95} \le 0.5Ud_{85}$ |
| | $4 \le U \le$ | $O_{95} \le 8d_{85}/U$ |
| | $U \ge 8$ | $O_{95} \le d_{85}$ |

| Soil Description | Geotextile Criteria |
|---|---|
| Where U is the base soil coefficient of uniformity | |

### *English Practice*

The practice is based on the principle that if a characteristic particle size is retained, a reverse filter will form even for broadley graded soils. This is summarized in table 2.11.

***Table 2.11: English practice in terms of geotextile filter criteria (NWM John, 1989).***

| Soil Description | Geotextile Criteria |
|---|---|
| $D_5$ | $d_{50}U^{1-0.9}$ |
| $D_{15}$ | $d_{50}U^{1-0.7}$ |
| $D_{50}$ | $d_{50}$ |
| $D_{60}$ | $d_{50}U^{10.2}$ |
| $d_{85}$ | $d_{50}U^{10.7}$ |
| $d_{90}$ | $d_{50}U^{10.8}$ |
| $d_{95}$ | $d_{50}U^{10.9}$ |
| Where U' is the modified coefficient of uniformity | |

## 2.8. Terzaghi's filter criteria

Karl von Terzaghi (2008) also known as the *"father of modern soil mechanics"* formulated the criteria for granular filters. These criteria are only applicable to cohesionless soils and it comprise of two criteria which are the permeability criterion and retention criterion (Giroud, 2010). It is expressed by the following two equations:

$$d_{15F} \geq 4 \text{ or } 5\ d_{15S} \qquad \textbf{\textit{(2.10)}}$$

$$d_{15F} \leq 4 \text{ or } 5\ d_{85S} \qquad \textbf{\textit{(2.11)}}$$

*Where:*

$d_{15F}$ is $d_{15}$ of the filter; $d_{15S}$ is $d_{15}$ of the soil and $d_{85S}$ is the $d_{85}$ of the soil ($d_x$ is the size of the soil which x% is finer than that size).

Equation (2.10) explains the permeability criterion ($d_{15}$ of the filter must not be too small).

Equation (2.11) explains the retention criterion ($d_{15}$ of the filter must not be too large).

The difference between the two factors 4 and 5 is insignificant

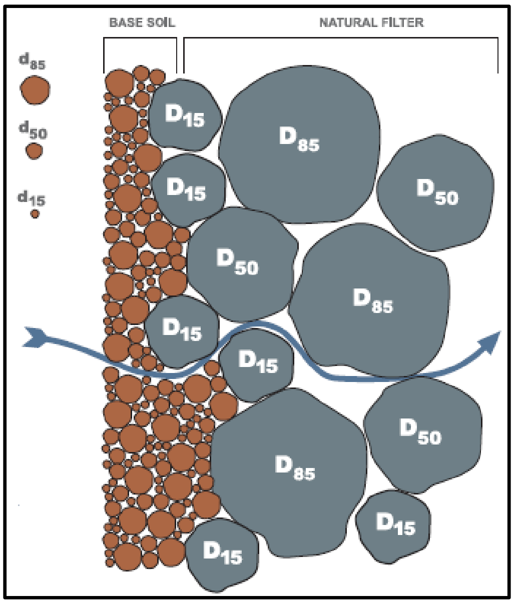


*Figure 2.18: Schematic representation showing Terzaghi type natural filter formation without a geotextile (courtesy: Kaytech).*

A natural filter is formed when large soil particles ($D_{85}$) hold back smaller soil particles ($D_{15}$), which in turn hold back smaller particles *(see section 2.9.3).*

*Terzaghi's rule for autostability:*

$$\frac{D85\ (soil)}{D15\ (granular\ filter)} \leq 5 \qquad \textbf{(2.12)}$$

## 2.9. Geotextile Filtration Mechanisms and Physical Clogging

### 2.9.1. Soil to Geotextile Contact

Soil to geotextile contact is important not only to filtration but also in other applications (Moraci, 2010). Non-woven needle punched geotextile (fig 2.19a) are commonly used for filtration applications due to their high permeability and low tensile modulus. Woven geotextiles (fig 2.19b) are not as permeable and usually have a high tensile modulus which means they cannot conform to rough or uneven surfaces (Kaytech filter design guide, 1995).

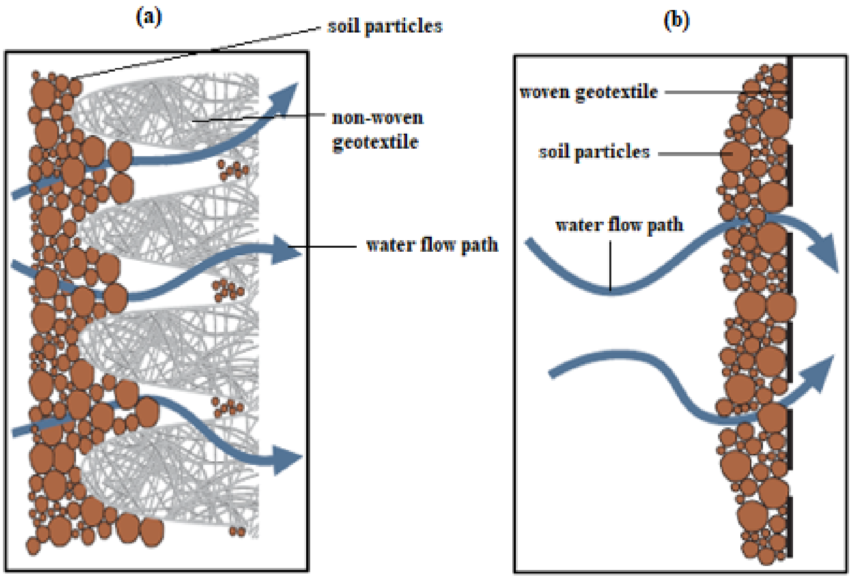


*Figure 2.19: Schematic representation of base soil contact with (a) non-woven needle-punched geotextile and (b) Woven geotextile (Kaytech filter design guide, 2015).*

### 2.9.2. Filtration Mechanisms

Soil filtration by geotextiles is a complex process which involves interaction between the filter and the base soil. In order to optimize long term stability in the soil-filter zone, the opening size ($O_F$) of the geotextile filter must be chosen carefully (Chen *et al*, 2008). As a result of groundwater seepage induced by capillary action, soil particle movement is initiated resulting in changes in grain size distribution, porosity and permeability of both the filter and the base soil. Five main mechanisms have been identified namely, piping, blinding, bridging, blocking and clogging and are discussed below in more detail (Cazzuffi *et al*, 2015; Ghosh and Yasuhara, 2004; Lafleur, 1999):

***Piping*** occurs when most of the base soil particles are finer than $O_F$ and they just wash through the filter. The fine fraction disappears from the grain size distribution and the hydraulic conductivity of the soil in the zone affected increases significantly.

***Blinding*** is a mechanism where soil particles are retained and accumulate upstream of the soil-filter interface. There is a localized decrease in hydraulic conductivity as geotextile opening being blocked by moving particles.

***Bridging*** involves the formation of a self-filtration structure at the soil-filter interface. Finer particles are eroded and the remaining coarser particles form a “filter bridge” that acts as a filter for smaller particles.

***Blocking*** involves the obstruction of the filter pores by coarse soil particles which prevents smaller particles and fluids/water to penetrate through the geotextile.

***Clogging,*** internal clogging can be defined as the migration of fine soil particles into the pores of the geotextile obstructing the filter constrictions.

Figure 2.20 present the first three where the left hand graphs show the soil grain size distribution (GSD) and its variations in vicinity of the geotextile (Lafleur, 1999). The dotted curve shows initial GSD and the solid curve shows final GSD; $R_R = O_f/d_i$ (where $R_R$ is the retention ratio, $O_f$ is the characteristic opening size of the filter and $d_i$ is the indicative particle size of the protected soil. Centre left schematics show the resulting granular structure and center right graphs show the resulting profile of soil hydraulic conductivity as a function of distance to geotextile, where $k_B$ (dotted line) is the initial soil hydraulic conductivity. The graphs on the right-hand side show the evolution of the system hydraulic conductivity ($k_{SYST}$) as a function of time as compared to the original hydraulic conductivity of the filter ($k_F$).

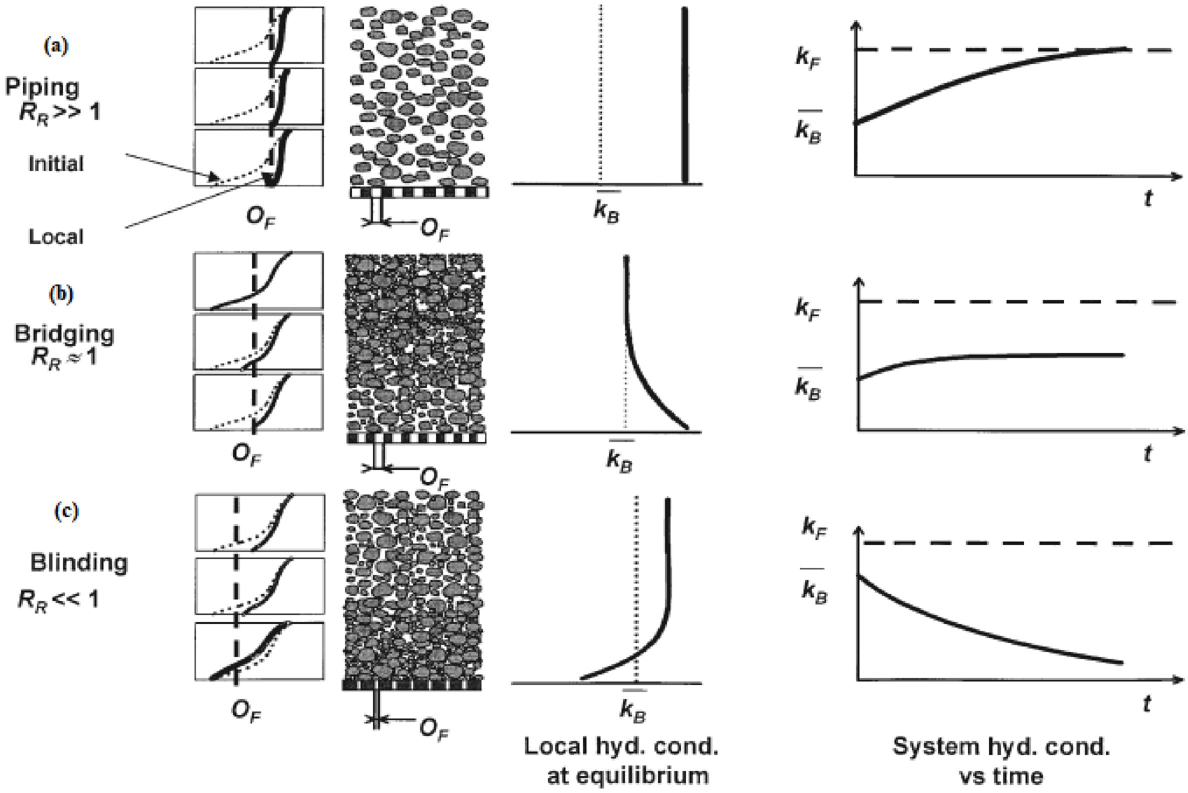


*Figure 2.20: Filtration Mechanisms; (a) Piping; (b) Bridging; and (c) Blinding (after Lafleur, 1999).*

Hydraulic conductivity of the system is defined by the following equation (Lafleur, 1999):

$$k_{SYST} = \frac{Q}{iA} \qquad \textbf{(2.13)}$$

*Where* **Q** is the flow rate, **i** is the total head loss divided by the combined thickness of the base soil and of the geotextile and ***A*** is the cross-sectional area of the sample.

### 2.9.3. Natural filter formation

The effect of filtration is not only confined to the geotextile but also spreads to the soil. Kellner (1991) proposed the use of a granular layer between clayey in-situ soil and geotextile. This would enable the clay to generate its own natural filter zone within the granular layer. When this process starts, there's an initial loss of fine particles through the geotextile filter. Larger particles retain smaller particles according to the rule of autostability. The result is the formation of a stable graded natural filter system (fig 2.21) and this phenomenon is favored in well-graded soil (Rollin and Lombard, 1988).

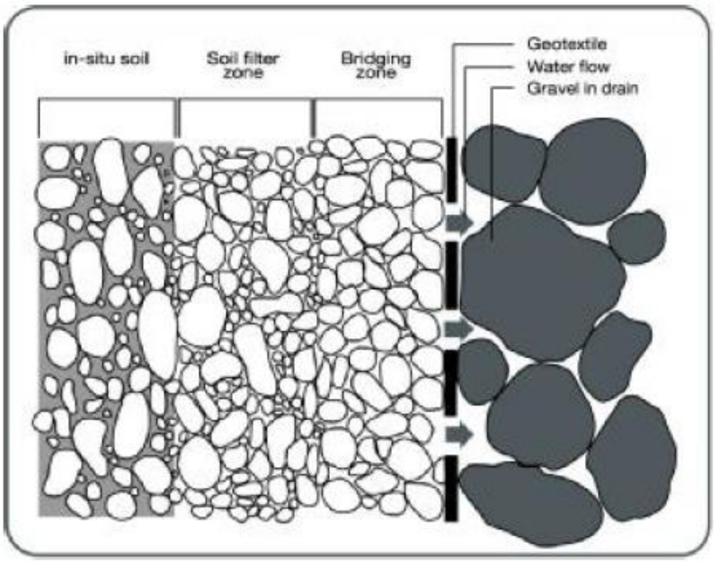


*Figure 2.21: Formation of a graded filter bridge adjacent to geotextile (Kaytech filter design guide, 1995).*

Bourdeaux (1977) pointed out that at flow velocities lower than 10 cm/sec, granular soil particles absorb dispersive clay and form a coating on the grain surface. This is an indication that clay particles have an affinity for granular filter particles rather than for geotextile fibers and it seems to validate the sand-geotextile filter concept for clayey soils (Xiao, 2000).

### 2.9.4. Vault Formation

In soils that are not well graded (gap graded), geotextile filters can be selected to favor vault formation (fig 2.22) (McGown, 1985). Upon formation of the vault network, the geotextile will stop particles that are slightly larger than its pore openings from migrating through it (Rollin and Lombard, 1988). Particles adjacent to the geotextile can rearrange themselves as they move towards the filter interface to form vaults. This occurs as a result of electric and adsorption forces between the organic anti-static agent on the geotextile fibers and soil particles.

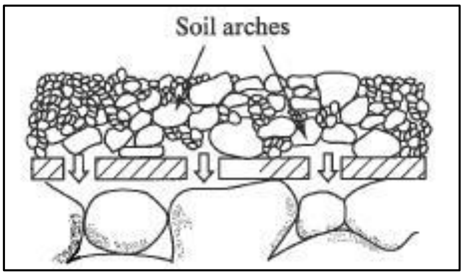


*Figure 2.22: Upstream soil particles forming vaults or arches over geotextile pores openings (after McGown, 1985)*

### 2.9.4. Types of clogging

Clogging can be classified as a form of incompatibility between a soil and a geotextile (fig 2.23). This may occur in response to physical, biological or chemical processes in soil (Fannin, 2010). According to Rollin and Lombard 1988, the term clogging does not only designate internal clogging but also blocking and blinding. The various types of clogging are discussed below (reference):

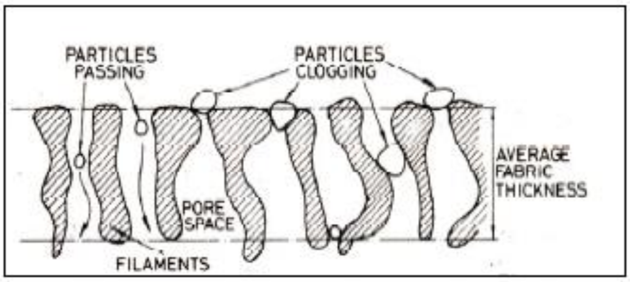


*Figure 2.23: Schematic representation of clogging of geotextile (Hoare, 1982)*

***Physical clogging***

The movement of base soil particles into the filter result in reduction of permeability of the filter which in some cases result in some of these particles being trapped in the filter causing complete blockage referred to as clogging (fig 2.23).

***Biological clogging***

This type of clogging occurs in solid waste landfills and it is associated with the flow of leachate through the geotextile filter under both aerobic and anaerobic conditions (Moraci, 2010). Two main mechanisms are responsible for the development of biological clogging (Giroud, 1996).

*First mechanism:* when a leachate moves through a geotextile filter it causes the development of a network of biofilms at various spots on the filter and as more bacteria continue to be supplied with nutrients, the network increases. This results in the reduction in permeability of the filter due to the decrease in pore spaces which causes clogging (Moraci, 2010).

*Second mechanism:* this mechanism involves the development of encrustations in two steps. In the first step, organic components of the leachate are transformed into fatty acids by fermentative, iron and manganese-reducing bacteria. This process lowers the pH of the leachate which results in the dissolution of metals such as iron, manganese and magnesium. During the second step, pH of the leachate increases due to the precipitation of carbonates and sulphides from the metals dissolved in the first step. This is caused by methane bacteria and sulphate reducing bacteria (Moraci, 2010). The processes occur in the network of biofilms and does not occur on the area of the filter not covered by the network.

### *Chemical clogging*

Chemical clogging when pH of the leachate becomes alkaline (pH>7) which results in the precipitation of salts such as calcium sulphate, calcium carbonate and magnesium carbonate.

#### *Biochemical clogging*

In contrast to biological clogging, biochemical clogging only occurs under aerobic conditions as a result of bacterial activity. The bacteria free iron from the leachate, the iron then oxidizes to form ferric oxide which precipitates resulting in a reddish brown mixture called *iron ochre.*

## 2.9.5. Additional factors affecting geotextiles in filtration

### *Stress level*

According to Moraci (2010), it is important to consider vertical effective stress in filtration since an increase in the stress causes a decrease in soil porosity. In addition, an increase in vertical effective stress causes a decrease in pore size distribution and porosity (n) that also causes a reduction in thickness ($t_{gt}$) and geotextile filtration opening size ($O_F$). The same effect was observed by Palmeira and Gardoni (2002) using the bubble point method relative to pore size distribution and filtration opening size $O_{95}$.

#### *Type of contact*

Soil-filter contact plays an important role in filter design (Moraci, 2010). The contact has to be continuous and the continuity depends on the building procedure used, the density of the base soil, and stiffness of the geotextile filter. For instance, in the case of river bank revetment, the impact energy due to placement of rip-rap blocks could cause deformations in the base soil, especially if the soil consist of loose granular material (fig 2.24). In these cases, the geotextile may follow the deformations depending on their stiffness characteristics and tensile modulus (Moraci, 2010).

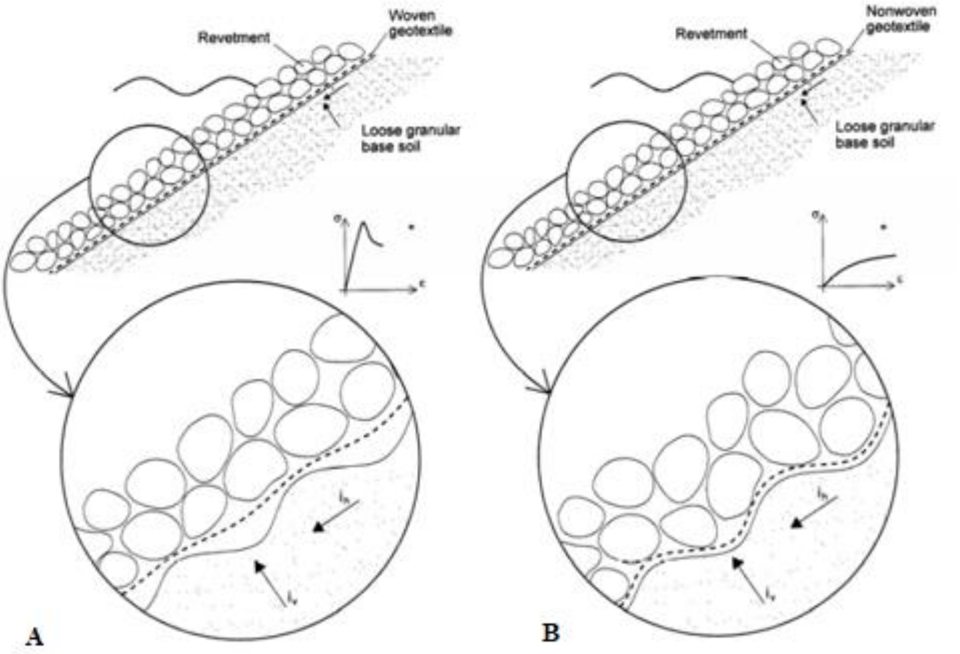


*Figure 2.24: Schematic representation of river bank revetments with loose granular soils; A. type of contact with a woven geotextile and B. type of contact with a non-woven geotextile (Moraci, 2010).*

Non-woven needle punched geotextiles have a low tensile modulus and are able to conform to surface irregularities or deformations (fig 2.24B). On the other hand, woven geotextiles have a high tensile modulus and are less conformable (fig 2.24A).

## 2.10. Subsoil Drainage System

Accumulation of excessive water in the underlying subgrade results in oversaturation and contributes to weakening and even failure of foundations. Solution to these problems is the installation of a subsurface/subsoil drain (Caleb, 2009). This type of drainage system drains away excess water from the subgrade that has accumulated due to high water table or exceptional high rain fall. However, draining away subsurface water or lowering the water table can have some consequences, especially in soils with high clay content. In these types of soils, decrease in water content causes shrinkage and damage to foundations/structures.

Groundwater sources may include (fig 2.25):

- Natural water table
- High rainfall
- Infiltration from dams, canals and during irrigation

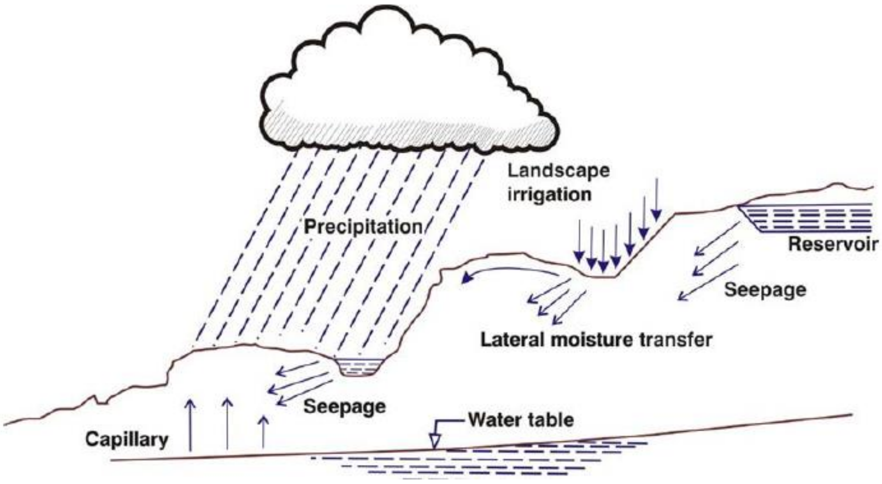


*Figure 2.25: Sources of groundwater (Adapted from ARRB 1987)*

### 2.10.1. Purpose/Importance of Subsoil Drainage

- To increase ground stability and building foundations by reducing moisture content variations
- To reduce waterlogging of soils and surface water ponding
- To reduce soil moisture content which increases soil strength
- To reduce pore water contained in the soil below foundations
- Reduction of uncontrolled movement of soil particles (piping)

### 2.10.2. Types of Subsoil Drains (SANRAL Drainage Manual, 2006)

This study will only focus on interception drainage which is further divided into two, namely, subsurface interception drain and subsurface interception geocomposite drain. These types of drains intercepts mainly subsurface water moving horizontally, lowering the water table *(SANRAL Drainage Manual, 2006).* They are used in a wide variety of applications which includes roadside drains, drains behind retaining walls, rail track edge drains, buildings, sports field, tennis courts, golf courses, bridges and agricultural applications. The different types of subsoil drains are discussed below:

### *Subsurface Interception Drain*

This is a convectional drainage system that incorporates coarse filter material (9.5 to 25 mm aggregate), a perforated geopipe, and a geotextile filter (fig 2.26).

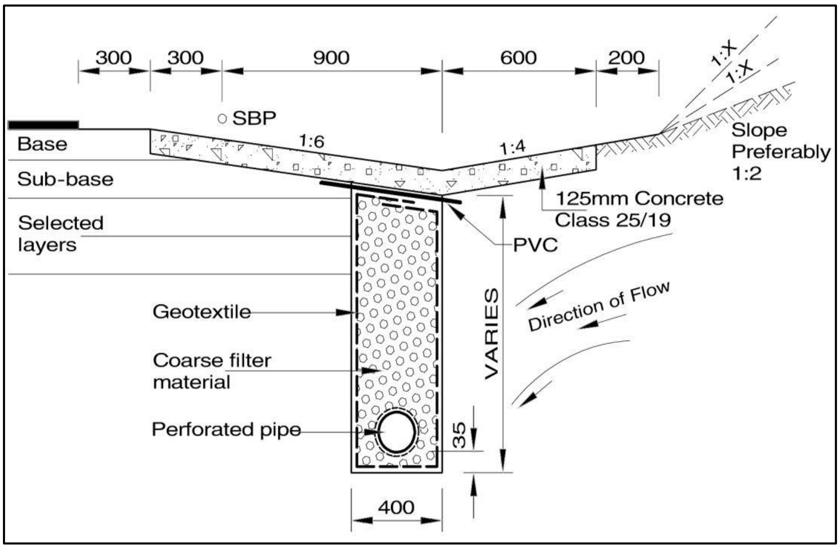


*Figure 2.26: Schematic representation of a subsurface interception drain (SANRAL Drainage Manual, 2006).*

### *Subsurface interception geocomposite drain.*

This is a thin drainage system consisting of a geonet drainage core wrapped in a geotextile filter and a perforated geopipe at the bottom (fig 2.27). Filter sand is usually placed on the side of the drain to prevent fine particles from washing into the filter. These drain types are much thinner (<25mm) than convectional granular drainage systems and are much more cost effective. The downside of geocomposite drains is that they are subjected to long term pressures and shear forces which might compromise the performance of the drainage system by reducing the thickness of the drain core (Müller, 2015).

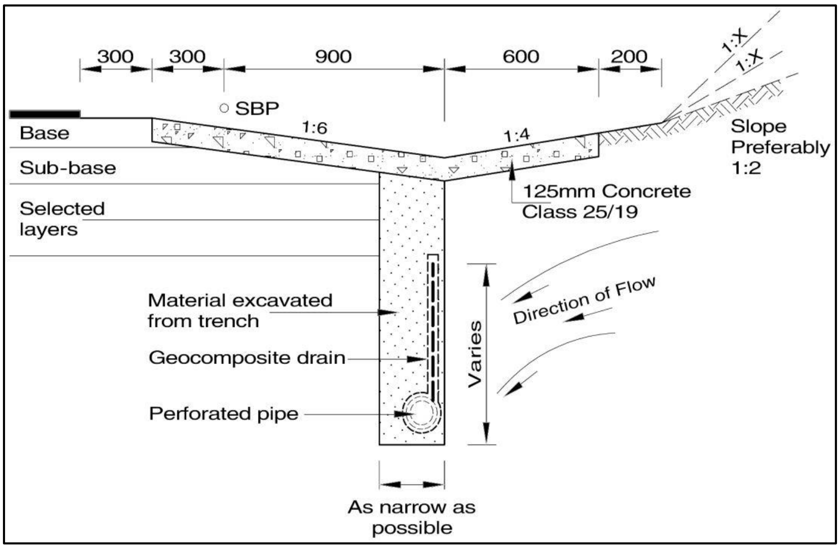


*Figure 2.27: Schematic representation of a subsurface interception geocomposite drain (SANRAL Drainage Manual, 2006).*

*Geopipe*

A pipe for subsurface drainage manufactured from Polyvinyl Chloride (PVC) or High Density Polyethylene (HDPE). As parts of the main components in both interception drainage systems, geopipes also have benefits in filtration. According to Koerner 1990, the use of a porous geopipe provide the following benefits:

- They have low flow resistance coupled with a large open area
- They provide a well-defined drainage path making connections with manholes and pits simple.
- Maximize cross-sectional drainage capacity.

## 2.11. Internal stability of soils

Internal stability of soil is defined as the ability of the coarse particles of the soil to prevent loss of the finer particles as a result of water/fluid seepage (Chang and Zhang, 2013). The coarse particles form a continuous skeleton that entraps particles that are smaller which entraps particles that are smaller and the network continues to the smallest diameter particles. It also depends on particle distribution of soils, a well-graded soil is regarded more stable than a gap-graded soil as a function of coefficient of uniformity (Giroud, 2010). Internal stability is one of the most important factors in the design of both granular and geotextile filters as some site failures are associated with soil internal instability (Chang, 2013). The failure is associated with loss of the fine particles in the soil structure resulting in internal erosion and possibly piping (Schuler, 1995). There is previous and ongoing research focused on geometric criterion to evaluate internal stability of soils (e.g. Kenney and Lau 1985, 1986; Li and Fannin 2008; Wan and Fell 2008).

There are some guidelines developed by Sherard (1984), for evaluating internal stability of soils based on coefficient of uniformity ($C_u = D_{60}/D_{10}$):

| | |
|---|---|
| If $C_u < 10$ | The soil is unlikely to be internally unstable |
| If $10 < C_u < 20$ | Internal instability is likely only in gap graded soils or soils with grading curves having sharp changes |
| If $20 < C_u < 75$ | The soil is generally stable if it is not gap graded or no sharp changes in direction of grading curve. |

# CHAPTER 3: METHODOLOGY

## 3.1. Introduction

The purpose of the laboratory testing is to evaluate and report on the performance three non-woven needle punched polyester geotextiles and two woven tapes and behaviour of 3 soil types that fall under 3 zones on the particle size distribution curve. The tests will assist in determining the following:

- Soil-geotextile compatibility
- Clogging potential, mechanisms and soil particle sizes that are most problematic in subsurface drainage systems.
- The effect of time on the performance of geotextile filers.
- The influence of coefficient of uniformity *(Cu)* of soils on the selection of geotextile filters.

In this chapter, the methodology of the research will be discussed in detail as well as the engineering properties of the materials being studied.

A desktop study was also carried out in support of the laboratory results (discussed in detail in Chapter 4).

**Testing Facilities**

Most of the geotextile testing was carried out at Kaytech's Geosynthetic Laboratory in Pinetown, Durban (Kwazulu-Natal Province). The Long Term Gradient Ratio and all the soil tests were carried out at Soillab, a SANAS accredited engineering material laboratory which is located at 230 Albertus Street, La Montagne, Pretoria east (Gauteng Province).

## 3.2. Materials and Methods

### 3.2.1. Test Methods and Procedures

Different testing procedures have been applied to evaluate the index, mechanical, and hydraulic properties of the geotextile samples produced. All the test except for the Long Term Gradient Ratio test, were performed in accordance with South African National Standards (SANS). Similarly, different SANS standards were applied to determine index properties of the soil samples used for the purpose of the study.

Sampling and preparation of geotextile test specimens were carried out according to ISO 9862:2005. After sampling, specimens were conditioned according to ISO 554 for a period of 24 hours before testing.

### 3.2.1.1. Geotextile Tests

#### *(a) Mass*

This is an index test method to determine mass per unit area ($P_A$) of geotextiles and it was carried out according to SANS 9864-2013. Ten specimens were cut to 100 $cm^2$ each using a cutting die. The specimens were weighed with a calibrated Mettler balance to an accuracy of 10 mg. The results were calculated from the formula below and expressed in grams per square meter ($g/m^2$).

$$P_A = \frac{m\ x\ 10\ 000}{A} \qquad (3.1)$$

*m – is the mass of the specimen, in g*

*A – is the area of the specimen, in* $cm^2$

#### *(b) Thickness*

Thickness of geotextiles is defined as the distance between the reference plate on which the specimen rests and the face of the parallel presser footer with an area of 25 $cm^2$ applying a given pressure (2 kPa for geotextiles) to the specimen for 5 seconds before a reading is taken. This test was carried out in accordance with SANS 9863-1-2013 using an AGP 511 analogue dial type thickness tester. The ten specimens used to determine mass per unit area were used to determine thickness under a 2 kPa foot pressure and the results reported in millimetres (mm).

#### *(c) Permeability (Through-Flow)*

Determination of water permeability characteristics normal to the plane, without load, was tested in accordance with SANS 11058-2013. Ten specimens of diameter 50 mm each were tested. Before testing, the specimens were initially placed in an alkyl sodium sulfonate wetting agent for 24 hours to remove air bubbles and to break surface tension.

Each specimen was tested under two constant water heads (50 mm and 100 mm) by running water through and perpendicular to the specimen’s plain. The rate of flow was determined by collecting the volume of water passing through each specimen for 30 seconds and measuring the quantity. Flow velocity, $V_{20}$, is calculated using the equation below:

$$V_{20} = \frac{VRT}{At} \qquad (3.2)$$

*Where:*

*V – is the volume of water measured in cubic meter (cm$^3$)*

*$R_T$ – is the correction factor to a water temperature of 20$^o$C*

*T – is the water temperature ($^o$C)*

*A – is the specimen area (m$^2$)*

*t - is the time measured to achieve the volume, V, in seconds.*

### *(d) Pore Size (Wet Sieving)*

Determination of characteristics opening size of geotextiles was carried out in accordance with SANS 12956:13. The particle size of a graded soil is determined after washing through a single layer of geotextile used as a sieve. The characteristic opening size corresponds to a specified size of the soil passed. Five specimens of 270 mm diameter each were cut, oven dried (at 70$^o$C) and weighed (to the nearest 0.1g). The specimens were then placed in water containing an alkyl sodium sulfonate wetting agent for 24 hours prior to testing. Each specimen was tested by placing it flat on a clamping device. The clamping device was then placed on an Octagon 200 sieve shaker. Soil of known particle size was places on the geotextile specimen and spread evenly on the surface. A supply device was placed on top of the clamping device. The sieve shaker was turned on and adjusted to a 3 mm swing height, water supply was then turned on and material passing through the specimen collected.

The results are expressed by plotting the cumulative percentage of the passed granular material against the corresponding sieve size on a semi-log scale graph. The characteristic opening size, $O_{90,}$ of geotextiles equal to $d_{90}$ of the particle size distribution curve.

### *(e) Puncture Resistance*

This is one of the most important parameter in geotextiles, especially when used in separation. This test evaluates the resistance to puncture of geotextiles by sharp rocks in separation, filtration and drainage applications. The test was performed in accordance with SANS 13433-2013 (Dynamic perforation test). Ten specimens of 250 x 250 mm were tested by clamping each specimen horizontally between two steel rings. A stainless steel cone with an angle of 45$^o$ and a mass of 1000 grams is used in the test. The cone is dropped, point facing down, from a height of 500 mm on to the centre of the specimen and the degree of penetration is measured by inserting a narrow graduated cone into the hole. The degree of penetration is an indication of the behavior of geotextiles when sharp rocks are dropped on its surface. The hole diameter is expressed in millimeters (mm).

### *(f) Tensile Strength*

Tensile strength test is used to check robustness of geotextiles. The tests were performed according to SANS 1525-2013. In order to get a good average, twenty specimens of 250 x 200 mm were tested in machine and cross directions. The test was conducted at a cross head speed of 20 mm/min (with a pre-load of 20 N) using an MTS Criterion 3 Tensile Tester with wave padded jaws grip type (complying with ISO 7500-1). The method covers measurement of load elongation characteristics, which allows for the calculation of maximum load per unit area. During the test, a specimen is held across its entire width in a set of clamps or jaws of the tensile machine operated at a constant speed of 20 mm/min, and a longitudinal force is applied to the test specimen until the specimen ruptures.

The tensile strength $T_{\max}$ is calculated from data obtained directly from the tensile machine and it is expressed in kilonewtons per meter (kN/m). The following equation is used to obtain $T_{\max}$:

$$T_{\max} = F_{\max}\, c$$

*Where:*

$F_{\max}$ *- is the recorded maximum force in kilonewtons (kN)*

*c – is obtained from the equation below*

$$c = \frac{1}{B} \qquad (3.3)$$

*Where:*

*B is the nominal width of the specimen in meters (m).*

### *(g) California Bearing Ratio (CBR)*

This test was performed in accordance with SANS 12236-2013. Ten specimens of 250 x 250 mm were tested. Each specimen was clamped between two steel rings and a 50 mm diameter probe was driven at a constant rate of 50 ±5 mm /min to the centre of the specimen and perpendicular to it. The result of the *push-through* force is expressed in kilonewtons (kN). This parameter is used to check for survivability of geotextiles in different applications.

#### 3.2.1.2. Soil tests

**(a) Constant Head Permeability (ASTM D2434)**

Standard test method for permeability of granular soils was carried out in accordance with ASTM D2434. A representative sample of air-dried granular soil containing less than 10% of particles passing 0.075 mm sieve was selected by a method of quartering. All particles larger than 19 mm were removed and not used for the test. The placement of the soil sample into the permeameter was done through a funnel and no compaction applied. The upper porous stone is placed on the soil sample, followed by a spring on top which is lightly pressed to seat on the porous stone. The rest of the permeability setup completed with a top plate on top of the spring. The system is de-aired using a vacuum followed by slow saturation of the soil specimen from the bottom. The vacuum is detached and the top inlet of the permeameter connected to the constant header tank. The inlet valve is opened to start the test then the quantity of flow, Q, and water temperature were measured.

**(b) Index Soil Tests**

***(i) Grading Analysis (SANS 3001:GR1)***

Particle size analysis of material retained on 0.075 mm sieve, carried out in accordance with SANS 3001:GR1. The sample was oven dried to a constant mass, weighed and the total mass recorded to the nearest 1g. The material was riffled until the required quantity was obtained then sieved through 14 mm, 5 mm, 2 mm, 0.425 mm and 0.075 mm diameter sieves. Percentage passing is determined and recorded then a particle size distribution curve is plotted. All material passing 0.075 mm sieve are analysed by the use of hydrometer analysis method.

***(ii) Hydrometer Analysis (SANS 3001:GR3)***

Particle size analysis for all particles with grain sizes less than 0.075 mm. A required quantity of the material was weighed (to the nearest 0.1g), placed in a 400 mL glass jar and covered with sodium hexametaphosphate solution. The solution was stirred and allowed to soak for 16 hours before testing. After the soaking period the contents of the jar were stirred and distilled water added to make up the solution to 400 mL. The contents was then transferred to a 1000 mL sedimentation cylinder, stoppered and shaken to agitate the solution. The cylinder was then placed on a flat surface, a hydrometer was inserted and measurements were r as sedimentation started in intervals of 40s, 2 min, 12 min etc.

Equation 3.4 below was used to calculate the percentage passing from the hydrometer readings:

$$P_{H\ 75\mu m} = 100 \text{ x } \frac{(M_{d1} - M_{d2} - M_{d3})}{M_{d1}} \qquad (3.4)$$

*Where:*

$P_{H\ 75\mu m}$ – is the percentage of the sample passing the 0.075 mm sieve;

$M_{d2}$ - is the mass retained on the 0.0425 mm sieve, in grams (g);

$M_{d3}$ - is the mass retained on the 0.075 mm sieve, in grams (g)

### *(iii) Atterberg Limits (SANS 3001:GR10)*

One of the most important tests in soil mechanics used to define ranges in moisture content that a soil will behave as plastic, liquid or solid. This test was performed according to SANS 3001:GR10, determination of one-point liquid limit, plastic limit, plasticity index and linear shrinkage (collectively called atterberg limits). It is normally carried out on material passing 0.0425 mm or 0.075 mm.

- **Liquid Limit**

A required quantity of the test sample was weighed and a small quantity of water was added while mixing until the material became stiff such that after grooving on the liquid limit device (casagrande apparatus) the mixtures flow to the centre at between 22 and 28 taps.

- **Linear Shrinkage**

A portion of the material from the liquid limit was taken, added on a trough and oven dried until no more shrinkage occurs.

- **Plastic Limit**

The remaining material in the casagrande apparatus after the test for liquid limit was used to determine plastic limit. The material was moulded into a ball which was then rolled with hands into threads of 3 mm diameter. The threads were immediately placed into moisture containers and sealed to lock in the moisture. Two specimens were tested and the results was the average between the two.

### Significance of atterberg limits

*1. Indicator of soil sensitivity*

Atterberg limits are used to compute liquidity index which can be a good indicator of sensitivity.

$$\boldsymbol{LI} = \frac{\boldsymbol{Ws-PL}}{\boldsymbol{PI}} \qquad (3.5)$$

*Where:*

*$W_S$ – is the natural water content of the soil*

*PL – plastic limit*

*PI – plastic index*

A sensitive soil is one that losses more than 8 times its undisturbed shear strength when strained. If the liquidity index is greater than 1, it is an indicator that the soil is sensitive.

*2. Indicator of clay activity and type*

Atterberg limits can also be used with hydrometer test to compute clay activity which can be a good indicator of clay type: Clay activity is calculated from equation 3.6 below.

$$\textbf{Activity} = A = \frac{PI}{\%\, clay\, fraction} \qquad (3.6)$$

*3. Indicator of swell potential*

If a soil has a PI of more than 20, it is prone to shrink/swell.

*4. Indication of stress history*

If liquidity index of the soil is greater or equal to 1($LI \geq 1$), then the soil is probably normally consolidated (i.e. the soil is currently experiencing its maximum load).

If liquidity index of the soil is less than 1 ($LI < 1$), then the soil is probably over consolidated (i.e. the soil experienced its greatest load in the past)

### 3.2.2. Material Properties

### 3.2.2.1. Soils

Three soil types were used for the purpose of this study. These soils fall under three zones in the particle size distribution curve and they are described in detail below:

*Zone 1 soils*

Zone 1 soils consist of more than 85% of particles smaller than 0.075 mm (i.e. clay and silt fractions). They usually have plasticity index of more than 15 or percentage clay to silt ratio of more than 0.5 (% Clay/% Silt > 0.5) and very low permeability. Due to the difficulty in finding the suitable material/soil that falls under zone 1 of the PSD graph, a clayey material was sampled and sieved on 0.075mm sieve to achieve the desired grading curve in order to satisfy the above criteria for zone 1 soils. Only the material passing the 0.075mm was used. The material is dark grey in colour, clayey silt with a PI of 13. The soil classified as "*ML*" according to the Unified Soils Classification System (USCS) which represents inorganic silts and very fine sands or clayey silts with slight plasticity. Only a small portion of the soil falls under zone 1 in the particle size distribution graph and the rest fall under zone 2.

*Zone 2 soils*

Most South African soils are derived from Karoo sediments and majority of these soils will fall into Zone 2. The soil was sampled from Wesselsbron, Free State and the site is underlain by mudstones, siltones and shales of the Beaufort Group which forms part of the Karoo Supergroup. The soil is of alluvium origin and typically transported by flowing water. It is dark grey to black in colour, clayey sand with a grading modulus of 0.54, a plasticity index of 19 and low heave potential. The soil classified as "*CL*" according to the Unified Soils Classification System (USCS) which represents inorganic silts of low to medium plasticity, gravelly, sandy, silty and lean clays.

*Zone 3 soils*

Zone 3 soil was sampled from Polokwane at the Vector Logitics Plant. Polokwane is predominantly underlain by grey and pink hornblende-biotite gneiss, grey biotite gneiss, and minor muscovite bearing granites, pegmatites in places. All these rocks form part of the Trnasvaal Sequence. The sampled soil is a yellowish brown speckled black weakly cemented sandy ferricrete gravel with a grading modulus of 2.18, a plasticity index of 8 and a low heave potential. The soil classified as "*GC*" according to the Unified Soils Classification System (USCS) which represents clayey gravels and gravel, sand, clay mixtures.

The table 3.1 is a summary of the sampling locations of the different soil samples. Detailed profiles attached in the Appendix Q.

*Table 3.1: Locations of the 3 different soil types used for the study.*

| **Soil Zone** | **Soil type/ Description** | **Position** | **Depth (m)** | **Origin** | **Location** | **GPS Coordinates** | |
|---|---|---|---|---|---|---|---|
| 1 | Silty Clay | - | - | Transported | Klerksdorp (Palmiet Farm) | S26°49'53.93" | E26°42'8.82"E |
| 2 | Clayey Sand | TP12 | 1.1 – 1.9 | Alluvium | Wesselsbron, Free State | S27° 49.165' | E26° 22.861' |
| 3 | Sandy Gravel | TP04 | 0.8 –1.23 | Residual | Polokwane (Vector Logistics) | S23° 52.411' | E29°26.876' |

#### 3.2.2.2. Geotextiles

The five geotextiles used in the column experiments were three non-woven, needle-punched, and four is commonly used for drainage and particle filtration. The average characteristics of the geotextile are presented in Table 1. All the geotextiles were washed with deionized water and dried before use to eliminate the manufacturing additives. These chemical additives can impact their hydraulic conductivity during the experiments (Lassabatere et al., 2004).

Three different nonwoven needle punched polyester geotextiles with identification A2, A4, A6 and averages masses of 2.7g, 3.6g, and 5.5g respectively. In addition to this, two woven polypropylene tapes identified as S120 and S270 with averages masses of 3.6 and 4.0g respectively.

##### *(a) Filtration Compatibility Test*

This test forms the basis of the research. It was originally developed by ASTM (American Society for Testing and Materials) with a designation ASTM D 5101. The method used for the purpose of this study is a modified version of the ASTM D 5101 and it is called the Long Term Gradient Ratio Test (LTGR). The method covers the determination of the compatibility of soil-geotextiles systems, soil fines retention and piping mechanisms under unidirectional flow conditions. It requires setting up a cylindrical clear plastic permeameter (see figures 3.1 and 3.2) with a geotextile and soil. Water is passed through this system by applying a constant differential head. The measurements of the differential head, head losses through the soil - geotextile system and flow rates are taken at regular intervals. Hydraulic gradient, gradient ratio and flow rate values obtained from the test were used as an indication of the soil-geotextile clogging potential and permeability.

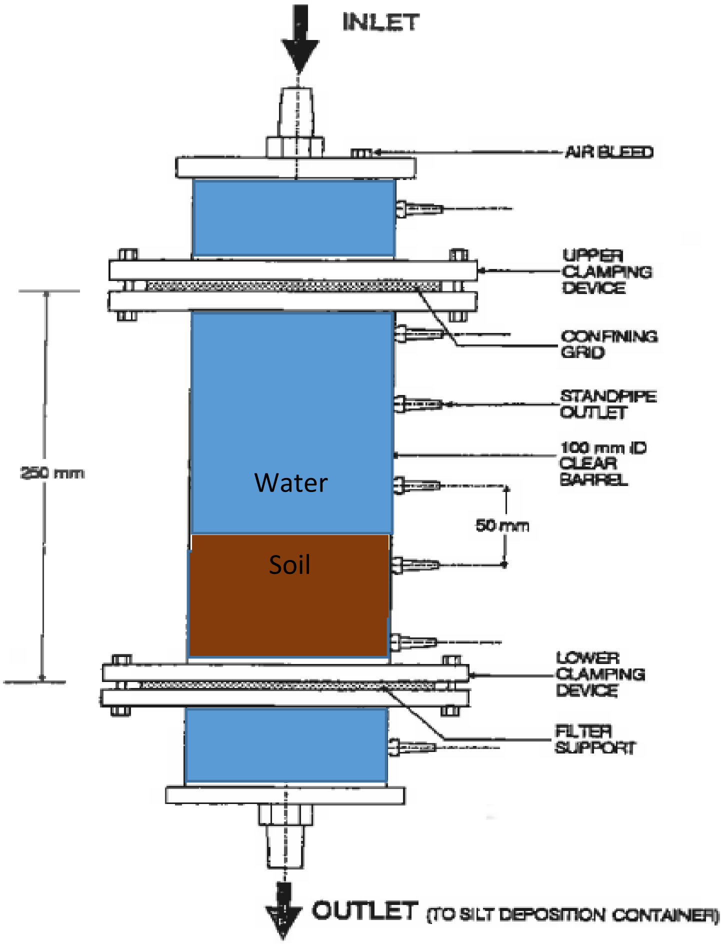


Figure 3.1: A typical permeameter set-up (Kaytech)

Figure 3.1 shows a schematic representation of a permeameter setup showing the positions of the different manometer ports, water inlet and outlet points, and direction of flow, positions of the geotextile specimen and soil sample. Figure 3.2 shows a complete setup with four LTGR tests in progress.

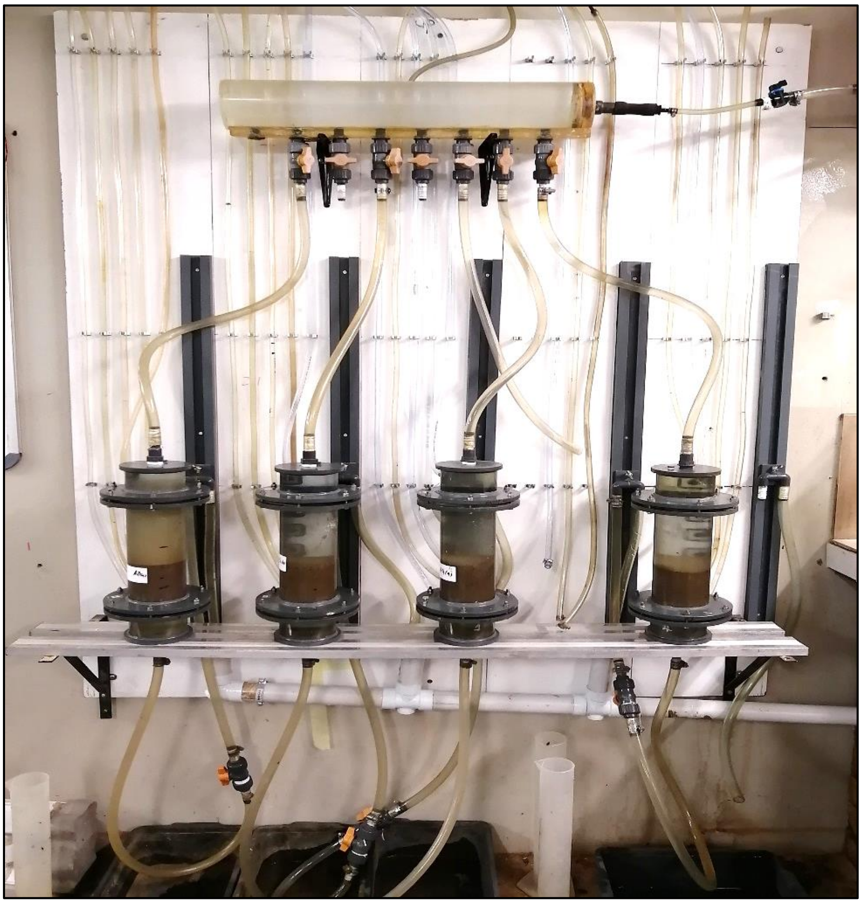


Figure 3.2: A typical LTGR Test Setup

The following test procedure describes equipment required, the sampling and testing procedures, calculations and suggested analysis of the results.

### *Sample and test equipment preparation*

#### *Geotextile specimen sampling and preparation*

A circular specimen with a diameter of 135mm was cut out of a full width geotextile roll using a cutting template. The specimens were obtained from positions equally spaced across the geotextile sample width and not closer than 150mm from either edge. Before testing, all specimens were oven dried at 60$^{o}$C until a constant mass was achieved.

#### *Soil sample preparation*

For each soil type, 40kg material was air dried for a day then quartered and rifled as required until a representative sample was achieved. A portion of the air-dried sample selected for the purpose of the test was sieved with a 2 mm sieve. The fraction retained on the 2 mm sieve was pulverized in a mortar with a rubber covered pestle until the aggregations of soil particles are broken up into separate grains. All particles larger than 5.6 mm should be removed.

Representative specimens for testing were placed in pans and oven dried at 100$^{o}$C until a constant mass was achieved and recorded on the work sheet.

Figure 3.3: Sample preparation: A: Soil sampling splitting; B: Sieving with 2 mm sieve

Figure 3.4: C: soil samples after splitting; D: Oven-drying soil samples

*Test Apparatus*

The test apparatus of the LTGR has many components and these are listed below:

- 3 piece permeameters with an internal diameter of 100mm;
- Continuous water supply to feed a constant header tank;
- Graduated measuring cylinders (1000ml and 2000 ml capacity);
- Electronic measuring scale with a 4 kg capacity and with an accuracy of 0.01 grams.
- Soil sample splitter or riffler.
- A thermostatically controlled thermal oven, for drying of soil and geotextile samples.
- Mortar and pestle for pulverizing the soil samples.

The permeameters and support apparatus were designed by Kaytech Engineered Fabrics based on internationally recognized state of the art testing.

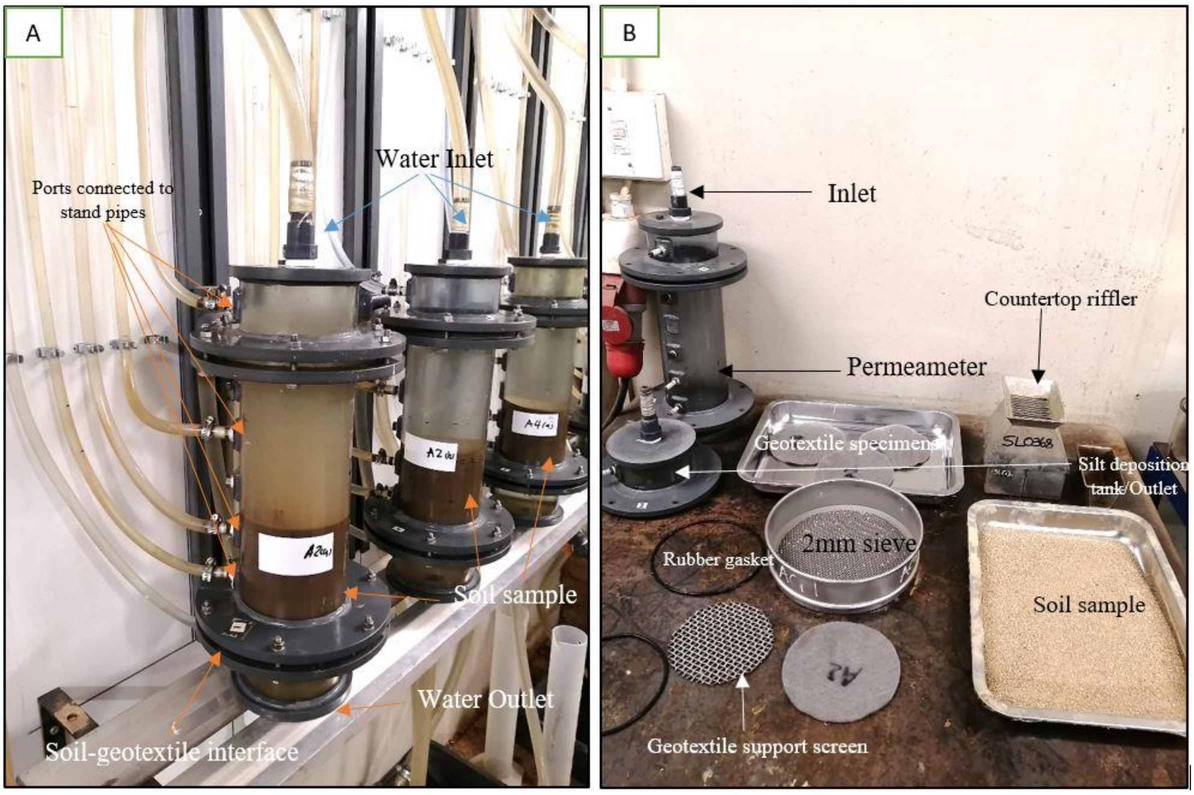


*Figure 3.5 A: LTGR Setup during testing; B: LTGR components, riffler, soil and geotextiles samples.*

*Test Water*

Test water was maintained between 16°C and 27°C throughout the test.

*Permeameter Setup*

The permeameter is the main component of the LTGR test apparatus. It was assembled through the following steps:

- The support screen was inserted on the lower section of the permeameter, then a geotextile specimen was placed on top and a circular rubber gasket.
- The middle permeameter section was placed, centralized on the lower section and radially fasten the bolts until there are no air bubbles evident on the face of the O-ring.
- The prepared oven-dried soil sample was then deposited in the permeameter through a funnel. All the soil samples were tested at 0% relative density, no compaction applied.
- A rubber gasket was placed on the top of the middle section and silicon grease was applied. The upper permeameter section was placed on top of the middle permeameter section and radially fastened with bolts until there were no air bubbles evident on the face of the O-ring.
- All manometer tubes were connected to their corresponding permeameter manometer ports.
- After all connections and leak checks have been completed, the wetting process starts. Wetting can either be done from the bottom or top of the permeameter and the rate of wetting from the underside at a rate not exceeding the anticipated permeability of the soil. Wetting was done from the bottom for the purpose of this study.
- Once the permeameter is fully saturated, the water inlet pipe from the bottom is disconnected and an outlet pipe is connected. The water is opened from the top inlet and the test starts.

Figure 3.6: A: Silt deposition tank, support screen and geotextile. B: Silt deposition tank with support screen on top

Figure 3.7: C: support screen in position prior to geotextile placement. D: Geotextile on top of support screen

*Running the test*

- The apparatus is checked for leaks
- The outflow level was adjusted to the desired hydraulic gradient.
- The outlet ball valve was opened slowly until it is fully open, and the initial starting time recorded.
- The flow rate from the system (outflow); quantity (q) milliliters for a time (t) in seconds were measured and recorded.
- The flow rate were recorded at 0, 24, and 48 hours, and continued in further increments of 24 hours from the starting time.
- The temperature (t) in degrees Celsius ($^{o}$C) of the water system in the system was noted.
- The water level readings from the individual manometers were measured with a measuring tape and recorded on the test sheet.

*Calculation*

After the test, the following important parameters were calculated using the results:

(a) *Hydraulic gradient* - the hydraulic gradients for the system i, was calculated using equation 7.

$$i = h/L \qquad (3.7)$$

h = Difference in manometer readings for soil analyzed, manometer 1 minus manometer 7, in mm, and L = Length of thickness of soil between manometers being analyzed, in mm).

(b) *System permeability* - calculate the system permeability at the temperature of the test using equation 2, and corrected to 20 degrees C using equation 3.8. A temperature of 20°C was assumed for all the test and a correction factor of 1 used.

$$K = Q/iAt \qquad (3.8)$$

K = permeability of the system in m/sec

Q = quantity of water collected in cubic m

A = cross sectional area of the soil in m²

T = time to collect water discharge in sec

$$Q=VRt \qquad (3.9)$$

(c) *Gradient Ratio* - the gradient ratio of the system was calculated using equation 3.10 below.

$$GR = \frac{i_{0-25}}{i_{25-75}} = \frac{(h_{25} - h_0)}{25} \times \frac{50}{(h_{75} - h_{25})} \qquad (3.10)$$

***Interpretation of Gradient Ratio***

A gradient ratio of 1 indicates that the geotextile has no effect on the hydraulic flow through the soil - geotextile system and that the soil is internally stable.

A gradient ratio of less than 1 indicates internal instability of the soil with some of the particles adjacent to the geotextile moving out of the system.

A gradient ratio of greater than 1 indicates system restriction at or near the surface of the geotextile or even within the geotextiles structure. Some of the possible mechanisms that could create the restriction are namely caking, blocking, blinding or clogging. The maximum permissible gradient ratio should not be greater than 3, which could indicate an excessive restriction at the geotextile interface.

***Determination of the soil particles lost during the LTGR test***

During the filtration test there is movement of soil particles in and on the geotextile. The movement leads to the development of mechanisms such as clogging, blocking and blinding. Some of the particles end up being washed off through the geotextile and lost in the process.

The soil particles lost through the system are calculated by weighing the remainder of the soil and the filter paper after the filtration test. Only the mass of the particles lost is determined. For the particles entrapped in the geotextile, the evaluation is done through microscopic evaluation (discussed later in this chapter). However, the geotextiles is weighed after the test to determine the mass of the entrapped particles. Entrapped particles refers to those causing clogging or partial clogging in the geotextile.

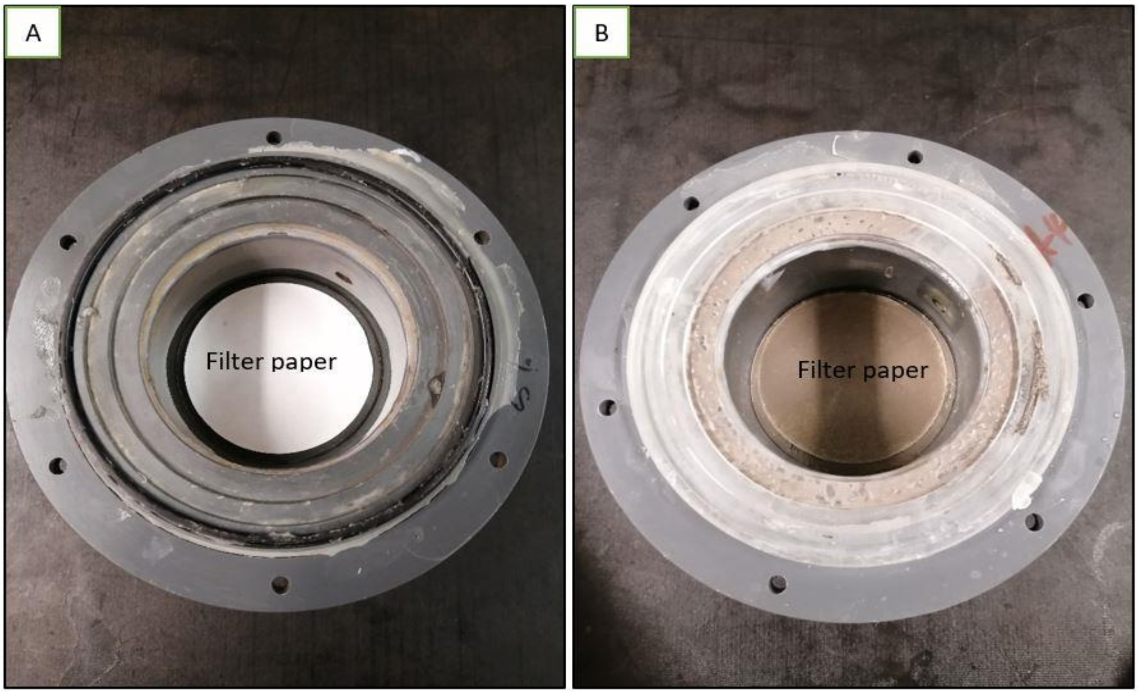


Figure 3.8: **A** - Silt deposition/outlet tank before test with a filter paper to catch fine particles that watched through the geotextile. **B** - Filter paper after test with fine silt and clay sized particles.

Figure 3.9: A - Soil sample and geotextile specimen after test (before drying). B - Geotextile specimens and filter papers after testing.

Furthermore, a full grading and hydrometer analysis is carried out on each soil sample tested to determine the size fraction lost during the filtration test.

## 3.3. Desktop Study

A Geotextile Filter Design Guide (2001), developed by Kaytech Engineered Fabrics is used in the selection of geotextiles for filtration or drainage applications. The desktop study in conjunction with the filter guide are only used for non-critical applications where the Long Term Gradient test is deemed unnecessary. In critical applications such dams, large embankments, mine tailings etc. a desktop study cannot be used and a long term gradient ratio test should be carried out. The spreadsheet gives a generic specification of how certain soils would behave with filter geotextiles. However, full grading and hydrometer results are required to plot the soil in the particle analysis graph. A desktop top study of the 3 soils is discussed in Chapter 4.

## 3.4. Microscopic Evaluation

All Non-woven polyester geotextiles (A2, A4 and A6) were analysed through the microscope after the filtration test to determine the size of the soil particles entrapped (i.e. particles clogging the geotextile). The results are discussed in detail in chapter 4.

## 3.5. Limitations

During the proposal stage of this research, it was suggested that five geotextiles and one monofilament mesh of a standard size be tested as a control sample but due to time constraints the monofilament mesh was disregarded. The amount of testing carried out, however, was enough to give sufficient information to deduce meaningful conclusions.

- *Applied Pressure*

A total head of 1.5 meters was applied on the system and no extra pressure was applied.

- *Air Bubbles*

Effort was made to remove all entrapped oxygen/air in the system before the test was started

- *Temperature*

All tests were carried out in temperatures of between 20$^{o}$C – 24$^{o}$C.

## 3.6. Conclusion

This chapter presented a summary of the laboratory methodology followed for the purpose of the study. Descriptions of tests and materials used is also given. Five geotextiles were tested against three soil types for the purpose of determining the range of problematic soils on the particle size distribution curve and to evaluate performance of geotextile filters in filtration and drainage applications. The following chapter summaries the results obtained from the Long Term Gradient Ratio test.

# CHAPTER 4: RESULTS AND ANALYSIS

## 4.1. Introduction

A total of 15 long term gradient ratio tests were carried out for the purpose of this study. Five different geotextiles were tested against 3 soil types that fall under three different zones in the gradation curve. The soils were selected to cover a wide range of the particle size distribution curve in order to get a broad understanding of the different soil types in filtration and drainage environments. Each test was run for a minimum of 400 hours or until the permeability graph has reached equilibrium. Equilibrium is reached when 3 consecutive readings of the flow rate are similar or less than 5% apart of each other. During the testing, the system was subjected to a total water head of 1 500 mm. Table 4.1 shows the number of tests carried out as well as the soil-geotextile combinations.

***Table 4.1: A Summary of all soil-geotextile tests carried out during the study.***

| Test Reference | Soil Zone | Soil Type | Geotextile | Geotextile type | Test duration (Hours) |
|---|---|---|---|---|---|
| A2–Zone 1 | 1 | Clayey Silt | A2 | Non-woven continuous filament polyester | 384 |
| A4–Zone 1 | 1 | Clayey Silt | A4 | | 384 |
| A6–Zone 1 | 1 | Clayey Silt | A6 | | 384 |
| S120–Zone 1 | 1 | Clayey Silt | S120 | Woven polypropylene tape | 912 |
| S270–Zone 1 | 1 | Clayey Silt | S270 | | 912 |
| A2–Zone 2 | 2 | Clayey Sand | A2 | Non-woven continuous filament polyester | 432 |
| A4–Zone 2 | 2 | Clayey Sand | A4 | | 432 |
| A6–Zone 2 | 2 | Clayey Sand | A6 | | 432 |
| S120–Zone 2 | 2 | Clayey Sand | S120 | Woven polypropylene tape | 552 |
| S270–Zone 2 | 2 | Clayey Sand | S270 | | 552 |
| A2–Zone 3 | 3 | Sandy Gravel | A2 | Non-woven continuous filament polyester | 1008 |
| A2–Zone 3 | 3 | Sandy Gravel | A4 | | 1008 |
| A2–Zone 3 | 3 | Sandy Gravel | A6 | | 840 |
| S120-Zone 3 | 3 | Sandy Gravel | S120 | Woven polypropylene tape | 432 |
| S270-Zone 3 | 3 | Sandy Gravel | S270 | | 432 |

Figure 4.1 shows a schematic diagram of the long-term gradient ratio test with standpipes 1 to 5. The standpipes were placed to measure the following:

- standpipe 1 measured the water head at the inlet;

- standpipe 2 measured head inside the permeameter;
- standpipe 3 measured head in the soil sample;
- standpipe 4 measured head at the soil-geotextile interface; and
- standpipe 5 measured head at the outlet.

The standpipes are located at the following distances above the outlet (standpipe 5): standpipe 4 is at 50 mm above the outlet, standpipe 3 is at 100 mm, standpipe 2 is 200 mm and lastly, standpipe 1 is 300 mm above the outlet.

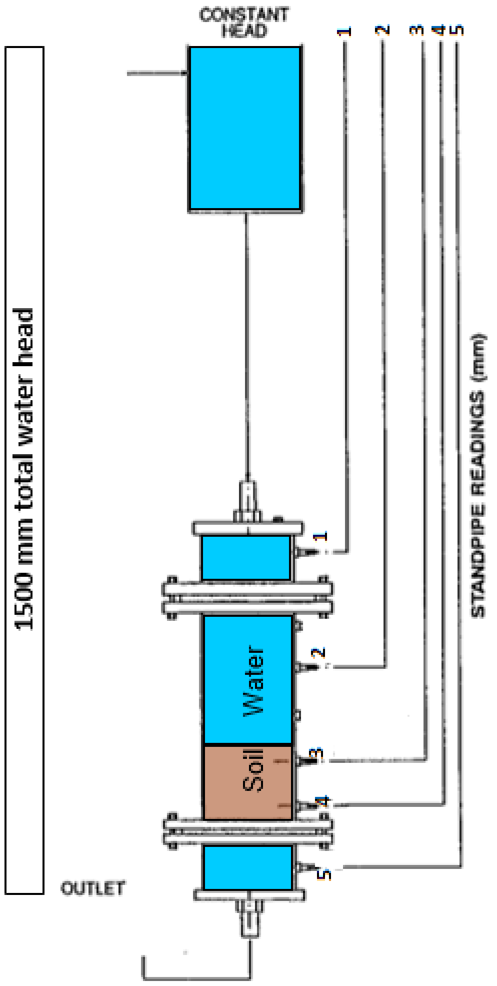


Figure 4.1: Schematic representation of the Long Term Gradient Ratio test (Source: Kaytech)

## 4.2. Results and Discussion

The Figure 4.2 present full grading results of the three types of soils used for the purpose of this study. The soils fall under three zones, as shown in Figure 4.2.

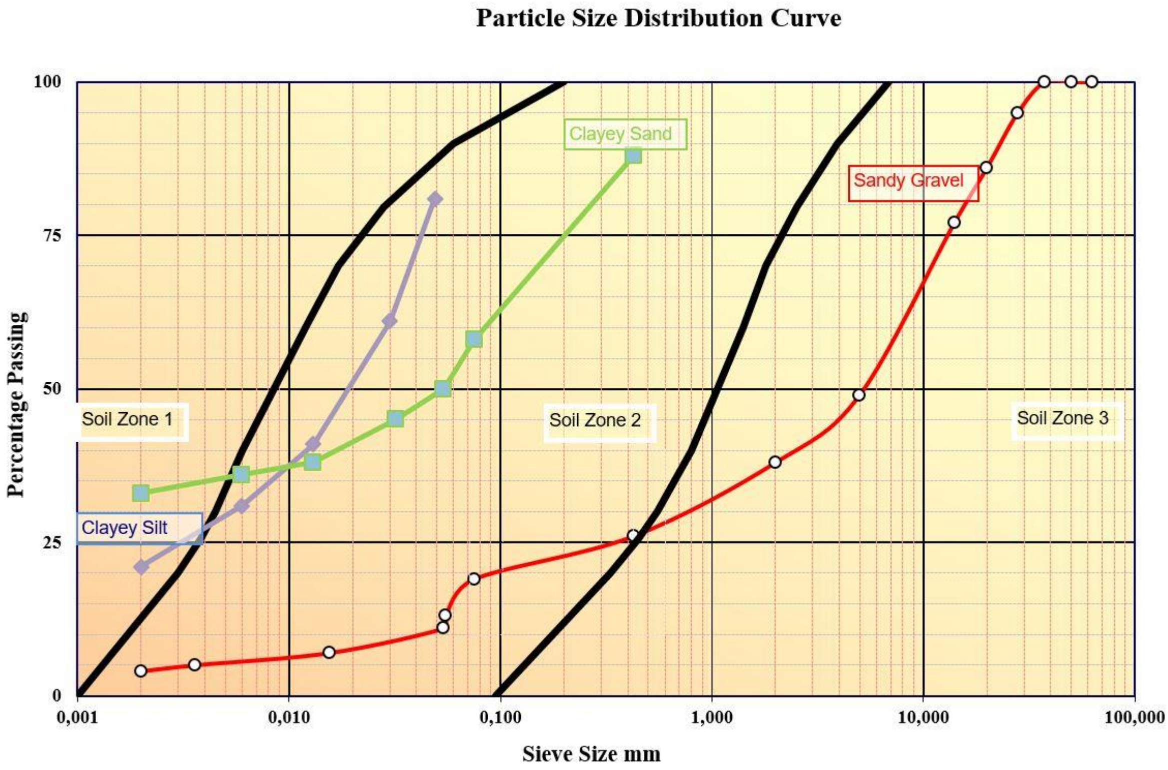


Figure 4.2: Particle size distribution curve showing the different soil zones and the graphs of the soils being studied

From the particle size distribution in figure 4.2, the purple curve is clayey silt, the green curve clayey sand and the red is sandy gravel soil. The thick black lines are the boundaries between the zones. The specific properties of the three soils used in this experimental study are listed in Table 4.2.

*Table 4.2: Properties of the 3 soil types*

| | **Zone 1** | **Zone 2** | **Zone 3** |
|---|---|---|---|
| **Description** | Clayey Silt | Clayey Sand | Sandy Gravel |
| **Clay (%)** | 31 | 36 | 5 |
| **Silt (%)** | 50 | 14 | 8 |
| **Sand (%)** | 19 | 50 | 25 |
| **Gravel (%)** | 0 | 0 | 62 |
| **Liquid Limit** | 39 | 45 | 27 |
| **Plastic Index (%)** | 13 | 19 | 8 |
| **Linear Shrinkage** | 6.0 | 8.0 | 3.0 |
| **Permeability (cm/s)** | $9.81 \times 10^{-8}$ | $4.47 \times 10^{-7}$ | $4.54 \times 10^{-6}$ |
| **USCS Classification** | ML | CL | GC |

Properties of the five geotextiles used for the purpose of this study are summarized in Table 4.3. Results for A2, A4 and A6 are from the actual tests carried out on the geotextiles, whereas, results for S120 and S270 are from the manufacturer’s data sheet.

***Table 4.3: Properties of geotextiles***

| Geotextile | Tensile Strength (kN/m) | Grab Tensile (N) | Trap Tear Strength (N) | Static Puncture (kN) | Pore Size - $O_{95w}$ (μm) | Permeability (m/s) |
|---|---|---|---|---|---|---|
| **Bidim A2** | 9.7 | 560 | 340 | 1.69 | 175 | $4.7x10^{-3}$ |
| **Bidim A4** | 13.5 | 918 | 507 | 2.49 | 136 | $4.2x10^{-3}$ |
| **Bidim A6** | 29.6 | 1797 | 914 | 4.66 | 128 | $3.9x10^{-3}$ |
| **Kaytape S120** | 19.9 | 565 | 408 | 30.9 | - | $2.0x10^{-4}$ |
| **Kaytape S270** | 50 | 1683 | 763 | 6.9 | - | $4.25x10^{-4}$ |

Gradient Ratio (GR) is the main parameter in determining the performance of soil-geotextile systems and it can be defined as *"the ratio of the hydraulic gradient across a soil-geotextile interface to the hydraulic gradient through the soil alone"* (ASTM D5101).

The results from the long-term gradient ratio tests for each soil type are discussed below:

### 4.2.1. Zone 1 Soil

Zone 1 soil is classified as clayey silt (fig 4.2) and the results of the long-term Gradient Ratio test with different geotextiles are summarized in the following subsections.

*(i) Clayey Silt Vs. Bidim A2*

The test was run for 384 hours and terminated after equilibrium was reached. It was observed that the water head at standpipe 1, 2 and 5 remained constant for the duration of the test (Table 4.4). There was a significant fluctuation of water head in standpipe 3 and 4 which is usually caused by the "activity" at the soil-geotextile interface. Activity refers to blinding, clogging and piping mechanisms that cause changes in pressure in the soil-geotextile interface. Water head loss is usually caused by the reduction in pressure in the system due to an open filter allowing ease of flow of water. Increase in water head is usually caused by clogging and blinding which increases pressure in the system.

***Table 4.4: Long term gradient ratio results for clayey silt vs. bidim A2***

| Test Accumulative (Hours) | Quantity (ml) | Duration (Min) | Permeability, k (m/s) | Sample Height (mm) | Gradient Ratio | Standpipe Readings – mm (Water head) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| *0* | *23* | *10* | *8,249E-07* | *120* | 2,3 | *1140* | | *1300* | | *880* | *670* | *430* |
| *1* | *24* | *10* | *8,608E-07* | *120* | 2,1 | *1140* | | *1300* | | *1060* | *750* | *430* |
| *24* | *26* | *10* | *9,325E-07* | *120* | 1,8 | *1140* | | *1300* | | *1130* | *760* | *430* |
| *48* | *24* | *10* | *8,608E-07* | *120* | 1,5 | *1140* | | *1300* | | *1120* | *720* | *430* |

| Test Accumulative (Hours) | Quantity (ml) | Duration (Min) | Permeability, k (m/s) | Sample Height (mm) | Gradient Ratio | Standpipe Readings – mm (Water head) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| *72* | *29* | *10* | *1,040E-06* | *120* | 2,4 | *1140* | | *1300* | | *1170* | *830* | *430* |
| *96* | *27* | *10* | *9,684E-07* | *120* | 1,5 | *1140* | | *1300* | | *1120* | *720* | *430* |
| *120* | *27* | *10* | *9,684E-07* | *120* | 1,8 | *1140* | | *1300* | | *1100* | *750* | *430* |
| *144* | *28* | *10* | *1,004E-06* | *120* | 1,7 | *1140* | | *1300* | | *1090* | *730* | *430* |
| *168* | *26* | *10* | *9,325E-07* | *120* | 1,4 | *1140* | | *1300* | | *1100* | *710* | *430* |
| *192* | *26* | *10* | *9,325E-07* | *120* | 1,4 | *1140* | | *1300* | | *1080* | *700* | *430* |
| *216* | *27* | *10* | *9,684E-07* | *120* | 1,6 | *1140* | | *1300* | | *1000* | *680* | *430* |
| *240* | *25* | *10* | *8,966E-07* | *120* | 1,6 | *1140* | | *1300* | | *1020* | *690* | *430* |
| *264* | *24* | *10* | *8,608E-07* | *120* | 1,7 | *1140* | | *1300* | | *980* | *680* | *430* |
| *288* | *25* | *10* | *8,966E-07* | *120* | 1,7 | *1140* | | *1300* | | *950* | *670* | *430* |
| *312* | *24* | *10* | *8,608E-07* | *120* | 2,0 | *1140* | | *1300* | | *910* | *670* | *430* |
| *336* | *24* | *10* | *8,608E-07* | *120* | 2,1 | *1140* | | *1300* | | *900* | *670* | *430* |
| *360* | *24* | *10* | *8,608E-07* | *120* | 1,9 | *1140* | | *1300* | | *900* | *660* | *430* |
| *384* | *24* | *10* | *8,608E-07* | *120* | 1,5 | *1140* | | *1300* | | *1010* | *680* | *430* |

The permeability of the system remained fairly constant ranging between 8 x $10^{-7}$ m/s and 1 x $10^{-6}$ m/s throughout the test and this suggests minimal particle migration into the filter (fig 4.3).

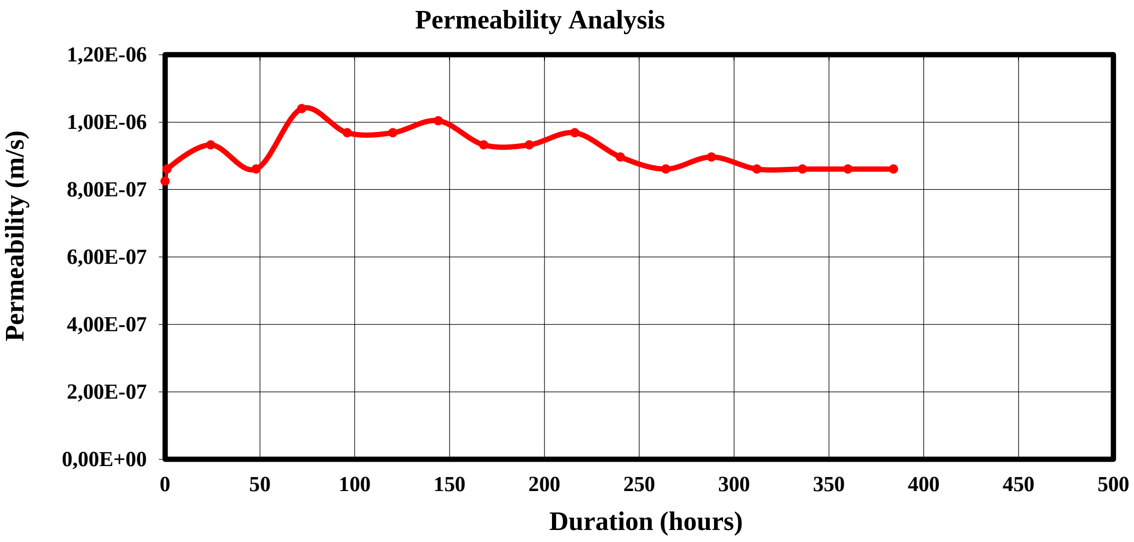


Figure 4.3: Permeability of the system (clayey silt vs. bidim A2)

The gradient ratio of the system was recorded for the duration of the test and was observed to vary between 1.4 and 2.3 which indicates that the system was either partially clogged or blinded (fig 4.4). The maximum gradient ratio was observed at 72 hours and the rest of the test duration the GR varied between 1.4 and 1.7 up to 312 hours where it increased to 2.0. The GR gradually decreased to 1.5 at 384 hours.

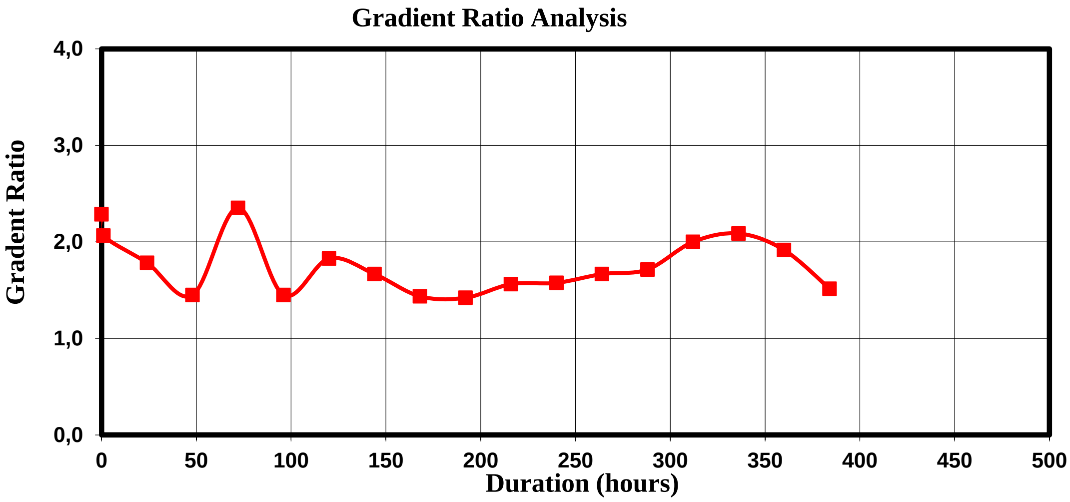


Figure 4.4: Gradient ratio of the system (clayey silt vs bidim A2)

*(ii) Clayey Silt Vs. Bidim A4*

This test was run for 384 hours and was terminated after equilibrium was reached. It was observed that standpipe 1, 2 and 5 remained constant for the duration of the test. At standpipe 3 and 4 there was a significant fluctuation of head caused by either partial clogging, blinding or piping of fine particles through the filter (Table 4.5). These water head fluctuations are caused by increase and decrease in pressure in the system.

***Table 4.5: Long term gradient ratio results for clayey silt vs. bidim A4***

| Test Accumulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Gradient Ratio | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| *0* | *31* | *10* | *1,112E-06* | *120* | 1,0 | *1140* | | *1300* | | *1000* | *620* | *430* |
| *1* | *32* | *10* | *1,148E-06* | *120* | 1,0 | *1140* | | *1300* | | *1050* | *630* | *430* |
| *24* | *30* | *10* | *1,076E-06* | *120* | 0,7 | *1140* | | *1300* | | *1100* | *610* | *430* |
| *48* | *26* | *10* | *9,325E-07* | *120* | 1,4 | *1140* | | *1300* | | *1060* | *690* | *430* |
| *72* | *37* | *10* | *1,327E-06* | *120* | 0,8 | *1140* | | *1300* | | *1040* | *610* | *430* |
| *96* | *30* | *10* | *1,076E-06* | *120* | 1,4 | *1140* | | *1300* | | *1000* | *660* | *430* |
| *120* | *27* | *10* | *9,684E-07* | *120* | 1,1 | *1140* | | *1300* | | *960* | *620* | *430* |

| Test Accumulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Gradient Ratio | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| *144* | *28* | *10* | *1,004E-06* | *120* | 1,2 | *1140* | | *1300* | | *970* | *630* | *430* |
| *168* | *25* | *10* | *8,966E-07* | *120* | 1,2 | *1140* | | *1300* | | *980* | *640* | *430* |
| *192* | *24* | *10* | *8,608E-07* | *120* | 1,2 | *1140* | | *1300* | | *960* | *630* | *430* |
| *216* | *26* | *10* | *9,325E-07* | *120* | 1,4 | *1140* | | *1300* | | *950* | *640* | *430* |
| *240* | *23* | *10* | *8,249E-07* | *120* | 1,5 | *1140* | | *1300* | | *940* | *650* | *430* |
| *264* | *22* | *10* | *7,890E-07* | *120* | 1,6 | *1140* | | *1300* | | *950* | *660* | *430* |
| *288* | *21* | *10* | *7,532E-07* | *120* | 1,5 | *1140* | | *1300* | | *960* | *660* | *430* |
| *312* | *20* | *10* | *7,173E-07* | *120* | 1,7 | *1140* | | *1300* | | *960* | *670* | *430* |
| *336* | *20* | *10* | *7,173E-07* | *120* | 1,4 | *1140* | | *1300* | | *980* | *660* | *430* |
| *360* | *19* | *10* | *6,815E-07* | *120* | 1,6 | *1140* | | *1300* | | *990* | *680* | *430* |
| *384* | *18* | *10* | *6,456E-07* | *120* | 1,5 | *1140* | | *1300* | | *1010* | *680* | *430* |

The permeability of the system remained constant throughout the test and this suggests that there was minimal particle migration through the soil-filter interface (fig 4.5).

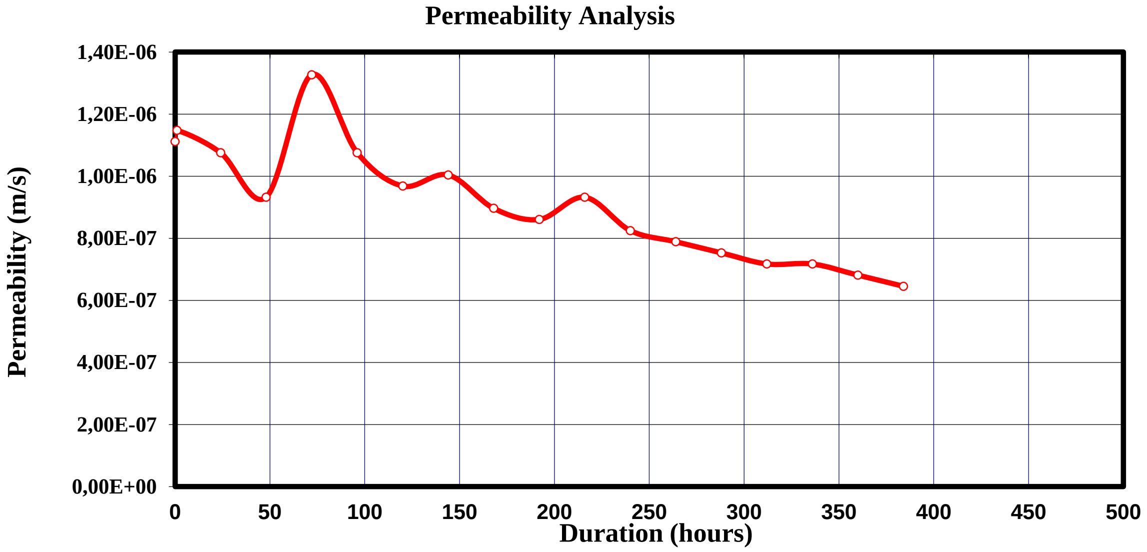


Figure 4.5: Permeability of the system (clayey silt vs. bidim A4)

The gradient ratio of the system was steady at the beginning between 0.8 and 1.0 which suggest a more open filter. From 96 hours the GR started increasing suggesting partial clogging of the system until it reached equilibrium at 384 hours (fig 4.6). The maximum gradient ratio was observed at 312 hours.

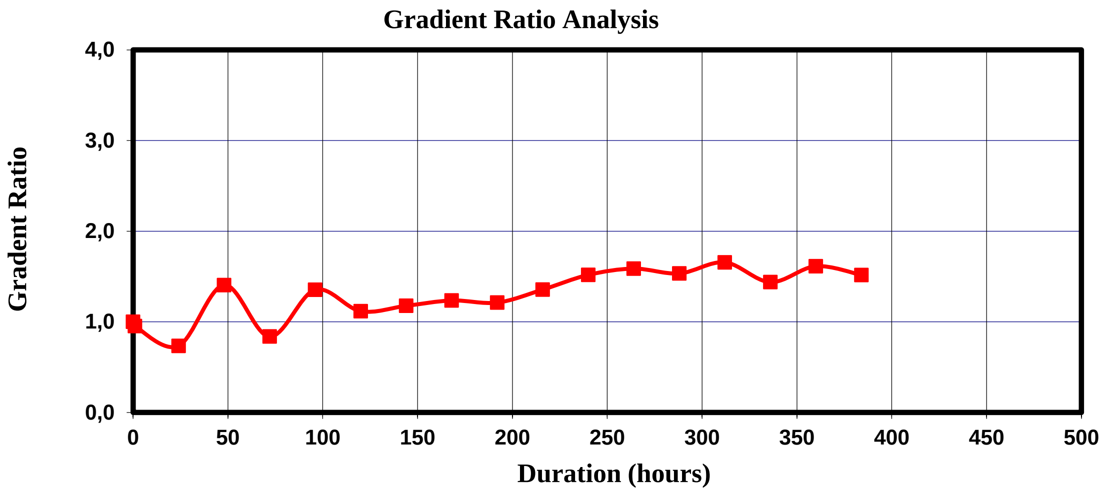


Figure 4.6: Gradient ratio of the system (clayey silt vs bidim A4)

### *(iii) Clayey Silt Vs. Bidim A6*

This test was run for a maximum of 384 hours and results of the test are presented in Table 4.6. It was observed that standpipe 1, 2 and 5 remained constant for the duration of the test. At standpipe 3 and 4 there was a significant fluctuation of head caused by either partial clogging, blinding or piping of fine particles through the filter. These water head fluctuations are caused by increase and decrease in pressure in the system. Standpipe 3 fluctuated between 880 and 1190 mm whilst standpipe 4 fluctuated between 600 and 930 mm.

***Table 4.6: Long term gradient ratio results for clayey silt vs. bidim A6***

| Test Accumulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Gradient Ratio | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| *0* | *25* | *10* | *8,966E-07* | *120* | 4,0 | *1140* | | *1300* | | *1180* | *930* | *430* |
| *1* | *25* | *10* | *8,966E-07* | *120* | 3,6 | *1140* | | *1300* | | *1190* | *920* | *430* |
| *24* | *26* | *10* | *9,325E-07* | *120* | 3,4 | *1140* | | *1300* | | *1220* | *930* | *430* |
| *48* | *24* | *10* | *8,608E-07* | *120* | 3,5 | *1140* | | *1300* | | *1230* | *940* | *430* |
| *72* | *36* | *10* | *1,291E-06* | *120* | 1,1 | *1140* | | *1300* | | *1130* | *680* | *430* |
| *96* | *35* | *10* | *1,255E-06* | *120* | 3,4 | *1140* | | *1300* | | *1080* | *840* | *430* |
| *120* | *36* | *10* | *1,291E-06* | *120* | 2,9 | *1140* | | *1300* | | *1020* | *780* | *430* |
| *144* | *34* | *10* | *1,219E-06* | *120* | 3,0 | *1140* | | *1300* | | *1000* | *770* | *430* |
| *168* | *30* | *10* | *1,076E-06* | *120* | 1,9 | *1140* | | *1300* | | *1010* | *710* | *430* |
| *192* | *31* | *10* | *1,112E-06* | *120* | 1,3 | *1140* | | *1300* | | *1000* | *650* | *430* |
| *216* | *31* | *10* | *1,112E-06* | *120* | 1,3 | *1140* | | *1300* | | *1020* | *660* | *430* |

| Test Accumulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Gradient Ratio | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| *240* | *33* | *10* | *1,184E-06* | *120* | 1.2 | *1140* | | *1300* | | *1030* | *650* | *430* |
| *264* | *28* | *10* | *1,004E-06* | *120* | 1.1 | *1140* | | *1300* | | *1000* | *630* | *430* |
| *288* | *29* | *10* | *1,040E-06* | *120* | 1.0 | *1140* | | *1300* | | *1010* | *620* | *430* |
| *312* | *26* | *10* | *9,325E-07* | *120* | 0,9 | *1140* | | *1300* | | *1030* | *620* | *430* |
| *336* | *25* | *10* | *8,966E-07* | *120* | 0,9 | *1140* | | *1300* | | *1000* | *600* | *430* |
| *360* | *25* | *10* | *8,966E-07* | *120* | 0,9 | *1140* | | *1300* | | *990* | *600* | *430* |
| *384* | *20* | *10* | *7,173E-07* | *120* | 1,2 | *1140* | | *1300* | | *880* | *600* | *430* |

The permeability of the system remained constant throughout the test and this suggests that there was minimal to no particle migration through the system (fig 4.7). Bidim A6 has very small pore openings as compared to A2 and A4 which reduces the possibility of soil particles moving into or through the filter *(retention criterion).*

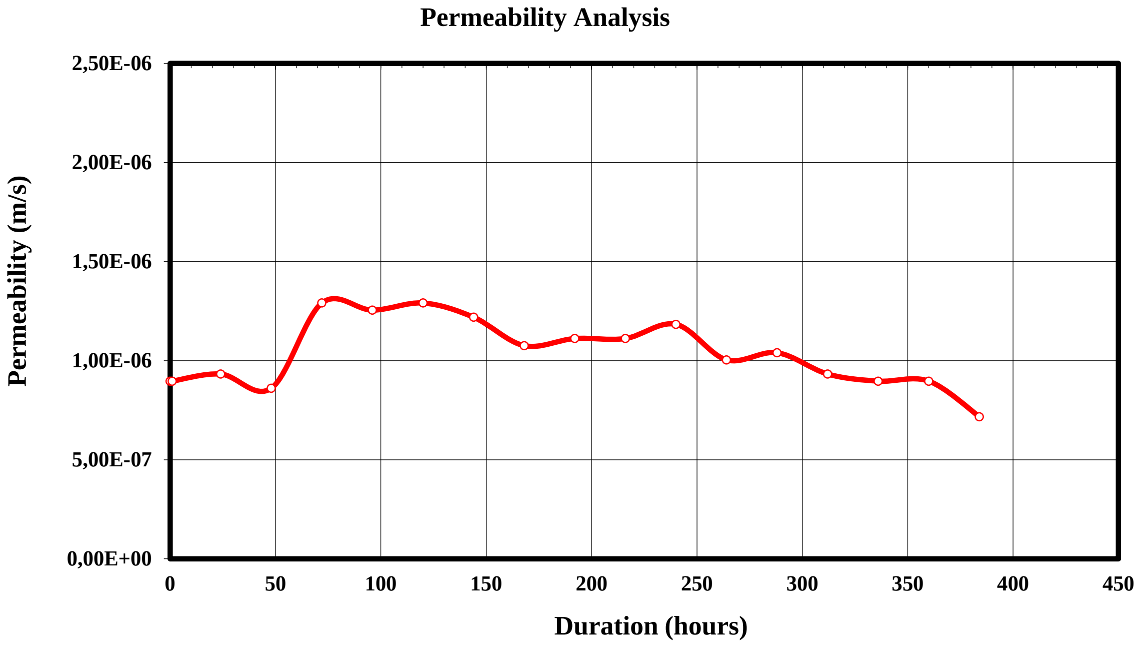


Figure 4.7: Permeability of the system (clayey silt vs. bidim A6)

The gradient ratio of the system was high and steady at the beginning ranging between 3.4 and 4.0 which indicates partial clogging. From 96 hours the GR started increasing suggesting partial clogging of the system until it reached equilibrium at 384 hours (fig 4.8). A low gradient ratio of 0.9 was observed between 312 and 360 hours when the system was also reaching equilibrium.

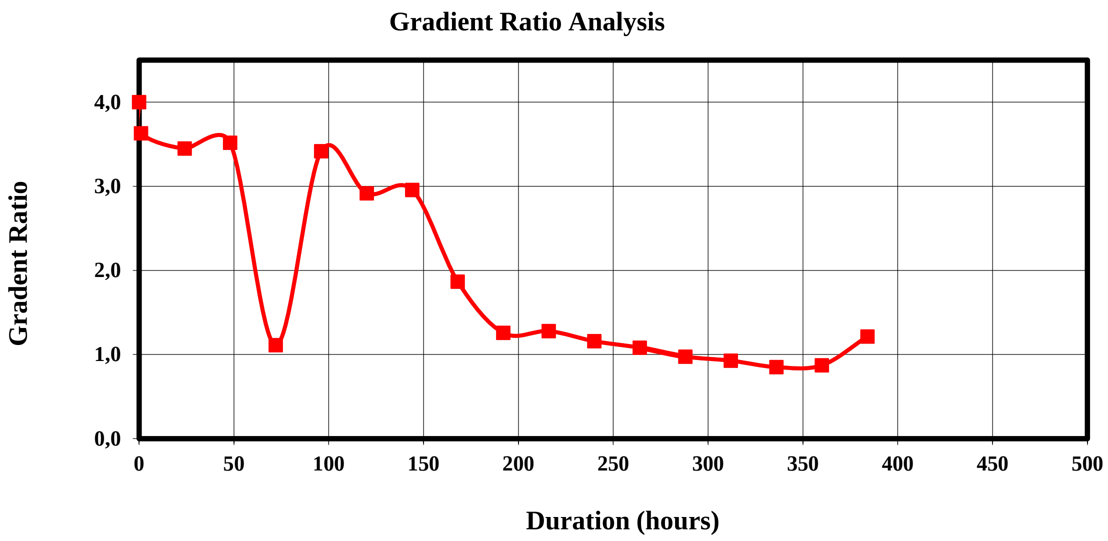


*Figure 4.8: Gradient ratio of the system (clayey silt vs bidim A6)(iv) Clayey Silt Vs. Kaytape S120*

The test was run for a total of 912 hours and the results of the test are summarized in Table 4.7. Standpipes 1, 2 and 5 remained constant for the duration of the test. Standpipe 3 fluctuated between 700 and 960 mm whilst standpipe 4 fluctuated between 560 and 750 mm.

***Table 4.7: Long term gradient ratio results for clayey silt vs Kaytape S120***

| Test Accumulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Gradient Ratio | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| 0 | 0 | 20 | 0,000E+00 | 130 | 1,9 | 1160 | | 1240 | | 700 | 560 | 430 |
| 1 | 0 | 20 | 0,000E+00 | 130 | 3,4 | 1160 | | 1240 | | 700 | 600 | 430 |
| 24 | 26 | 20 | 4,913E-07 | 130 | 2,5 | 1160 | | 1240 | | 700 | 580 | 430 |
| 48 | 26 | 20 | 4,913E-07 | 130 | 3,3 | 1160 | | 1240 | | 750 | 630 | 430 |
| 72 | 28 | 20 | 5,291E-07 | 130 | 3,7 | 1160 | | 1240 | | 770 | 650 | 430 |
| 96 | 30 | 20 | 5,669E-07 | 130 | 2,5 | 1160 | | 1240 | | 770 | 620 | 430 |
| 120 | 31 | 20 | 5,857E-07 | 130 | 2,8 | 1160 | | 1240 | | 790 | 640 | 430 |
| 144 | 33 | 20 | 6,235E-07 | 130 | 2,7 | 1160 | | 1240 | | 850 | 670 | 430 |
| 168 | 33 | 20 | 6,235E-07 | 130 | 2,8 | 1160 | | 1240 | | 860 | 680 | 430 |
| 192 | 35 | 20 | 6,613E-07 | 130 | 2,4 | 1160 | | 1240 | | 960 | 720 | 430 |
| 216 | 34 | 20 | 6,424E-07 | 130 | 2,9 | 1160 | | 1240 | | 870 | 690 | 430 |
| 240 | 31 | 20 | 5,857E-07 | 130 | 3,6 | 1160 | | 1240 | | 850 | 700 | 430 |
| 264 | 29 | 20 | 5,480E-07 | 130 | 3,7 | 1160 | | 1240 | | 860 | 710 | 430 |
| 288 | 26 | 20 | 4,913E-07 | 130 | 3,3 | 1160 | | 1240 | | 830 | 680 | 430 |

| Test Accumulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Gradient | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| 312 | 28 | 20 | 5,291E-07 | 130 | 3,9 | 1160 | | 1240 | | 840 | 700 | 430 |
| 336 | 27 | 20 | 5,102E-07 | 130 | 3,6 | 1160 | | 1240 | | 880 | 720 | 430 |
| 360 | 25 | 20 | 4,724E-07 | 130 | 3,8 | 1160 | | 1240 | | 920 | 750 | 430 |
| 384 | 26 | 20 | 4,913E-07 | 130 | 3,3 | 1160 | | 1240 | | 910 | 730 | 430 |
| 408 | 24 | 20 | 4,535E-07 | 130 | 3,6 | 1160 | | 1240 | | 880 | 720 | 430 |
| 432 | 27 | 20 | 5,102E-07 | 130 | 3,3 | 1160 | | 1240 | | 880 | 710 | 430 |
| 456 | 26 | 20 | 4,913E-07 | 130 | 3,0 | 1160 | | 1240 | | 880 | 700 | 430 |
| 480 | 29 | 20 | 5,480E-07 | 130 | 2,5 | 1160 | | 1240 | | 880 | 680 | 430 |
| 504 | 31 | 20 | 5,857E-07 | 130 | 2,7 | 1160 | | 1240 | | 880 | 690 | 430 |
| 528 | 28 | 20 | 5,291E-07 | 130 | 3,0 | 1160 | | 1240 | | 880 | 700 | 430 |
| 552 | 27 | 20 | 5,102E-07 | 130 | 3,3 | 1160 | | 1240 | | 880 | 710 | 430 |
| 572 | 25 | 20 | 4,724E-07 | 130 | 3,0 | 1160 | | 1240 | | 880 | 700 | 430 |
| 600 | 24 | 20 | 4,535E-07 | 130 | 3,3 | 1160 | | 1240 | | 880 | 710 | 430 |
| 624 | 26 | 20 | 4,913E-07 | 130 | 3,0 | 1160 | | 1240 | | 880 | 700 | 430 |
| 648 | 24 | 20 | 4,535E-07 | 130 | 2,5 | 1160 | | 1240 | | 880 | 680 | 430 |
| 672 | 24 | 20 | 4,535E-07 | 130 | 2,7 | 1160 | | 1240 | | 880 | 690 | 430 |
| 696 | 27 | 20 | 5,102E-07 | 130 | 3,0 | 1160 | | 1240 | | 880 | 700 | 430 |
| 720 | 25 | 20 | 4,724E-07 | 130 | 3,3 | 1160 | | 1240 | | 880 | 710 | 430 |
| 744 | 25 | 20 | 4,724E-07 | 130 | 3,0 | 1160 | | 1240 | | 880 | 700 | 430 |
| 768 | 24 | 20 | 4,535E-07 | 130 | 2,7 | 1160 | | 1240 | | 880 | 690 | 430 |
| 792 | 25 | 20 | 4,724E-07 | 130 | 2,5 | 1160 | | 1240 | | 880 | 680 | 430 |
| 816 | 23 | 20 | 4,346E-07 | 130 | 3,0 | 1160 | | 1240 | | 880 | 700 | 430 |
| 840 | 24 | 20 | 4,535E-07 | 130 | 2,7 | 1160 | | 1240 | | 880 | 690 | 430 |
| 864 | 23 | 20 | 4,346E-07 | 130 | 2,1 | 1160 | | 1240 | | 880 | 660 | 430 |
| 888 | 24 | 20 | 4,535E-07 | 130 | 2,7 | 1160 | | 1240 | | 850 | 670 | 430 |
| 912 | 25 | 20 | 4,724E-07 | 130 | 3,1 | 1160 | | 1240 | | 840 | 680 | 430 |

Permeability of the system was zero for the first 1 hour and started increasing from 24 hours reaching peak at 192 hours. The system started stabilizing at around 360 hours and reached equilibrium at 912 hours. The permeability varied between 4.3 x $10^{-7}$ m/s and 6.6 x $10^{-7}$ m/s throughout the duration of the test.

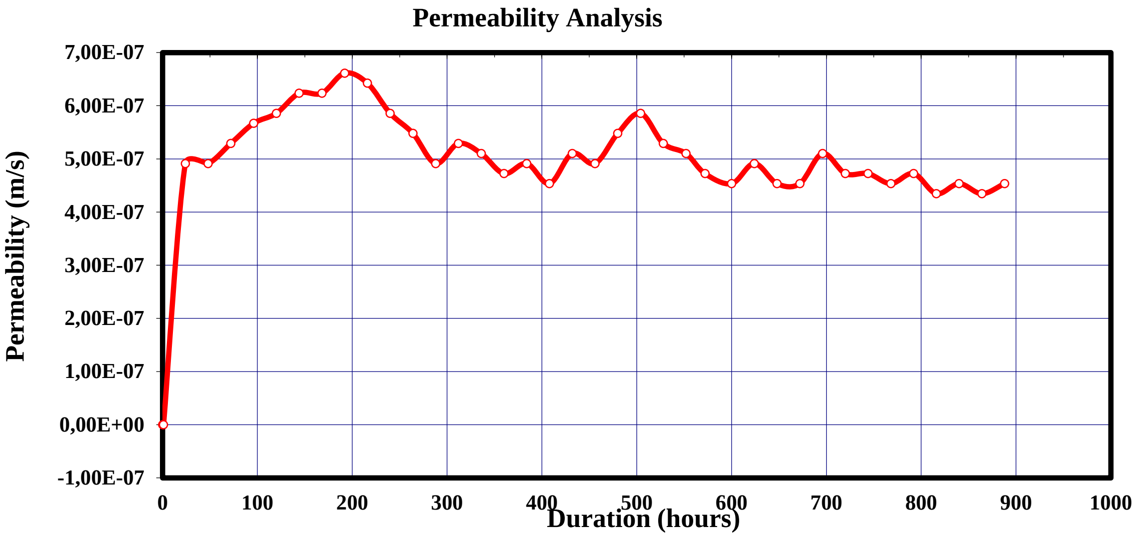


Figure 4.9: Permeability of the system (clayey silt vs Kaytape S120)

Gradient ratio of the system was fairly high throughout the test, varying between 1.9 and 3.7. The high gradient ratio values are evidence of fine soil particles migrating into the soil-geotextile interface and some into the geotextile causing partial clogging.

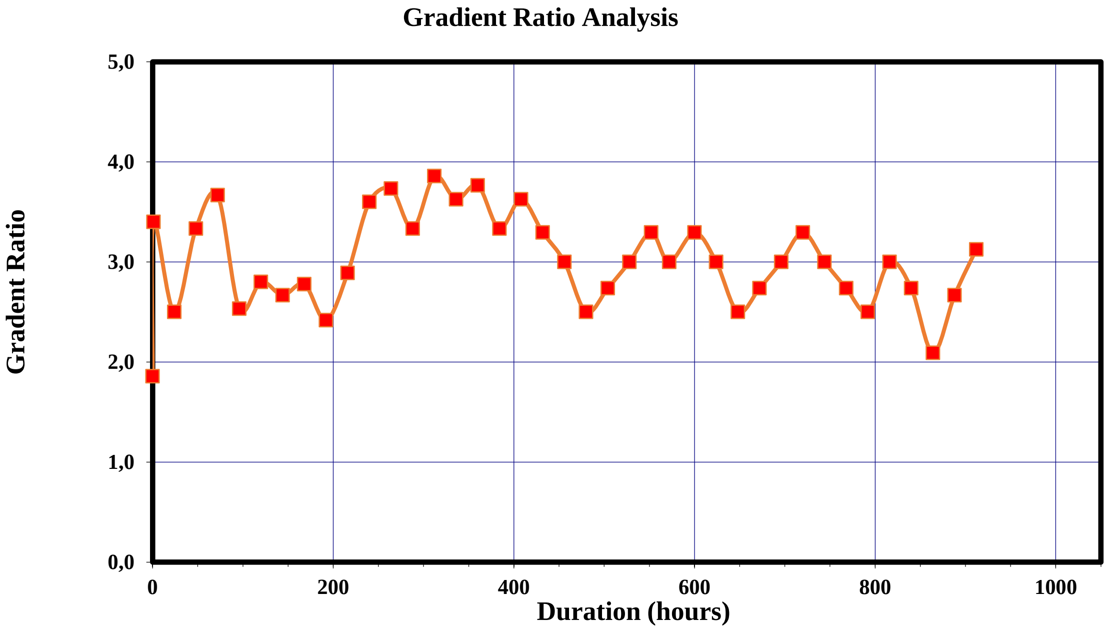


Figure 4.10: Gradient ratio of the system (clayey silt vs Kaytape S120)

*(v) Clayey Silt Vs. Kaytape S270*

The test was run for a total of 912 hours and the results are summarized in Table 4.8. Standpipe 1 and 2 remained constant at 1160 and 1240 respectively for the duration of the test.

*Table 4.8: Long term gradient ratio results for clayey silt vs Kaytape S270*

| Test Accumulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Gradient Ratio | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| *0* | *0* | *20* | *0,000E+00* | *100* | **3,0** | *1160* | | *1240* | | *730* | *610* | *430* |
| *1* | *0* | *20* | *0,000E+00* | *100* | **2,8** | *1160* | | *1240* | | *810* | *650* | *430* |
| *24* | *26* | *20* | *3,779E-07* | *100* | **2,4** | *1160* | | *1240* | | *850* | *660* | *430* |
| *48* | *46* | *20* | *6,686E-07* | *100* | **3,2** | *1160* | | *1240* | | *1000* | *780* | *430* |
| *72* | *44* | *20* | *6,395E-07* | *100* | **2,4** | *1160* | | *1240* | | *1110* | *800* | *430* |
| *96* | *45* | *20* | *6,541E-07* | *100* | **2,2** | *1160* | | *1240* | | *1120* | *790* | *430* |
| *120* | *43* | *20* | *6,250E-07* | *100* | **1,9** | *1160* | | *1240* | | *1100* | *760* | *430* |
| *144* | *36* | *20* | *5,232E-07* | *100* | **3,7** | *1160* | | *1240* | | *970* | *780* | *430* |
| *168* | *33* | *20* | *4,796E-07* | *100* | **3,9** | *1160* | | *1240* | | *990* | *800* | *430* |
| *192* | *30* | *20* | *4,360E-07* | *100* | **2,8** | *1160* | | *1240* | | *1100* | *820* | *430* |
| *216* | *29* | *20* | *4,215E-07* | *100* | **3,4** | *1160* | | *1240* | | *1000* | *790* | *430* |
| *240* | *27* | *20* | *3,924E-07* | *100* | **3,8** | *1160* | | *1240* | | *1010* | *810* | *430* |
| *264* | *30* | *20* | *4,360E-07* | *100* | **3,7** | *1160* | | *1240* | | *1000* | *800* | *430* |
| *288* | *26* | *20* | *3,779E-07* | *100* | **2,7** | *1160* | | *1240* | | *990* | *750* | *430* |
| *312* | *28* | *20* | *4,070E-07* | *100* | **3,2** | *1160* | | *1240* | | *980* | *770* | *430* |
| *336* | *25* | *20* | *3,634E-07* | *100* | **2,7** | *1160* | | *1240* | | *970* | *740* | *430* |
| *360* | *24* | *20* | *3,488E-07* | *100* | **4,3** | *1160* | | *1240* | | *900* | *750* | *430* |
| *384* | *25* | *20* | *3,634E-07* | *100* | **3,5** | *1160* | | *1240* | | *900* | *730* | *430* |
| *408* | *24* | *20* | *3,488E-07* | *100* | **3,5** | *1160* | | *1240* | | *900* | *730* | *430* |
| *432* | *25* | *20* | *3,634E-07* | *100* | **3,9** | *1160* | | *1240* | | *900* | *740* | *430* |
| *456* | *25* | *20* | *3,634E-07* | *100* | **3,5** | *1160* | | *1240* | | *900* | *730* | *430* |
| *480* | *26* | *20* | *3,779E-07* | *100* | **2,9** | *1160* | | *1240* | | *900* | *710* | *430* |
| *504* | *25* | *20* | *3,634E-07* | *100* | **3,0** | *1160* | | *1240* | | *960* | *750* | *430* |
| *528* | *24* | *20* | *3,488E-07* | *100* | **3,9** | *1160* | | *1240* | | *900* | *740* | *430* |
| *552* | *21* | *20* | *3,052E-07* | *100* | **2,7** | *1160* | | *1240* | | *900* | *700* | *430* |
| *572* | *20* | *20* | *2,907E-07* | *100* | **2,9** | *1160* | | *1240* | | *900* | *710* | *430* |
| *600* | *21* | *20* | *3,052E-07* | *100* | **2,6** | *1160* | | *1240* | | *910* | *700* | *430* |
| *624* | *22* | *20* | *3,198E-07* | *100* | **2,9** | *1160* | | *1240* | | *920* | *720* | *430* |
| *648* | *20* | *20* | *2,907E-07* | *100* | **2,7** | *1160* | | *1240* | | *900* | *700* | *430* |
| *672* | *22* | *20* | *3,198E-07* | *100* | **3,1** | *1160* | | *1240* | | *910* | *720* | *430* |
| *696* | *23* | *20* | *3,343E-07* | *100* | **3,9** | *1160* | | *1240* | | *900* | *740* | *430* |
| *720* | *21* | *20* | *3,052E-07* | *100* | **3,1** | *1160* | | *1240* | | *910* | *720* | *430* |
| *744* | *20* | *20* | *2,907E-07* | *100* | **2,9** | *1160* | | *1240* | | *900* | *710* | *430* |
| *768* | *22* | *20* | *3,198E-07* | *100* | **2,7** | *1160* | | *1240* | | *900* | *700* | *430* |

| Test Accumulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Gradient Ratio | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| *792* | *19* | *20* | *2,762E-07* | *100* | 3,0 | *1160* | | *1240* | | *960* | *750* | *430* |
| *816* | *20* | *20* | *2,907E-07* | *100* | 3,0 | *1160* | | *1240* | | *980* | *760* | *430* |
| *840* | *21* | *20* | *3,052E-07* | *100* | 3,6 | *1160* | | *1240* | | *910* | *740* | *430* |
| *864* | *20* | *20* | *2,907E-07* | *100* | 3,3 | *1160* | | *1240* | | *880* | *710* | *430* |
| *888* | *20* | *20* | *2,907E-07* | *100* | 3,4 | *1160* | | *1240* | | *890* | *720* | *430* |
| *912* | *20* | *20* | *2,907E-07* | *100* | 2,9 | *1160* | | *1240* | | *900* | *710* | *430* |

The permeability of the system started at zero for the first 1 hour and this is due to the very low permeability of the sandy clay. Permeability started increasing after 24 hours and reached peak at 48 hours. The system started reaching equilibrium at 336 hours and by 912 hours it had completely stabilized at a low permeability of 2.907 x $10^{-7}$ m/s.

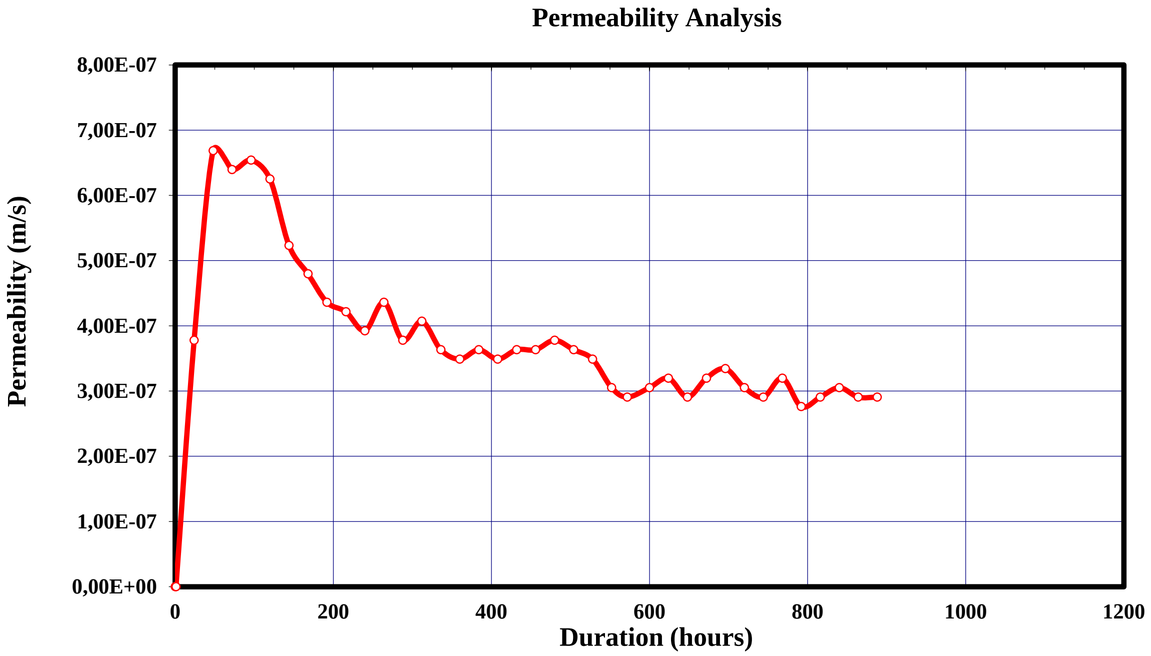


Figure 4.11: Permeability of the system (clayey silt vs Kaytape S270)

Gradient ratio of the system was very high from the beginning and peaked at 360 hours reaching a maximum value of 4.3 which indicates a severe case of clogging. The high gradient ratio values are indicative of fine clay sized particles migrating into the filter and reducing permeability of the system.

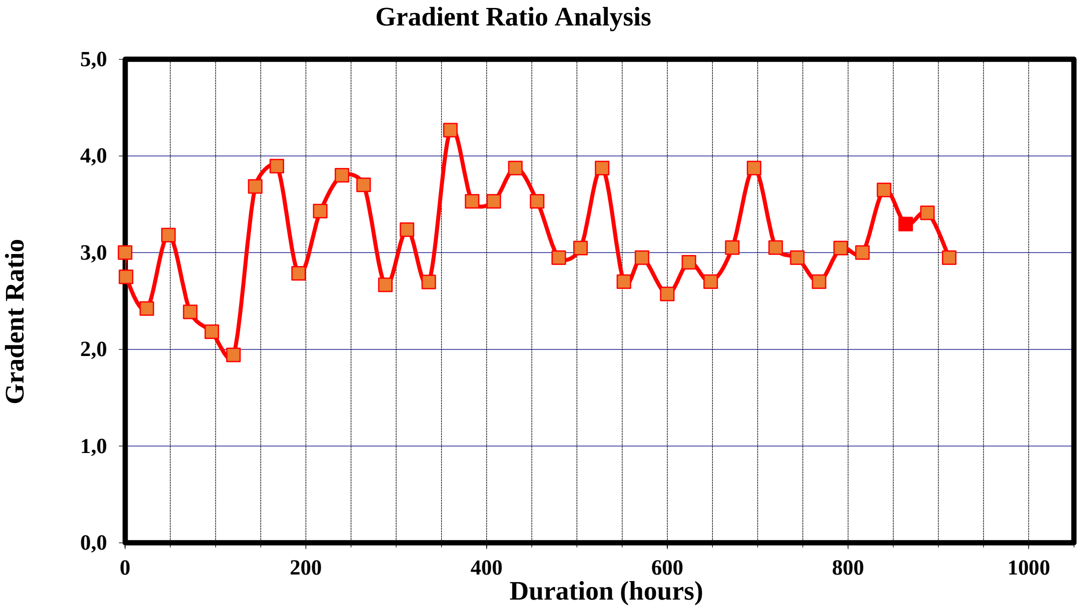


Figure 4.12: Gradient ratio of the system (clayey silt vs Kaytape S270)

### 4.2.2. Zone 2 Soil

Zone 2 soil was classified as Clayey Sand (fig 4.2) and the results of the long-term Gradient Ratio test of this soil with different geotextiles are summarized in the following subsections.

*(i) Clayey Sand Vs. Bidim A2*

The test between clayey sand and Bidim A2 was run for a maximum of 432 hours and the results are summarized in Table 4.9. There was a significant fluctuation in water head in all the standpipes with the exception of standpipe 5. Water head in standpipe 1 varied between 1030 and 1120 mm throughout the duration of the test. There were very small pressure fluctuations in the inlet and therefore the water head remained fairly constant. Water head at standpipe 2 fluctuated between 1290 and 1300 mm which also suggest minimal pressure changes in that zone. Standpipes 3 and 4 had fluctuations in head and this is usually caused by the “activity” in the soil-geotextile interface. Readings in Standpipe 3 varied between 1390 and 1430 whilst in standpipe 4 it varied between 460 and 880.

***Table 4.9: Long term gradient ratio results for clayey sand vs. bidim A2***

| Test Accumulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Gradient Ratio | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| *0* | *183* | *10* | *1,036E-05* | *160* | **0,1** | *1030* | | *1290* | | *1390* | *460* | *430* |
| *1* | *136* | *10* | *7,696E-06* | *160* | **0,4** | *1030* | | *1310* | | *1410* | *590* | *430* |

| Test Accumulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Gradient Ratio | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| *24* | *50* | *10* | *2,391E-06* | *160* | **1,6** | *1140* | | *1340* | | *1430* | *880* | *430* |
| *48* | *35* | *10* | *1,735E-06* | *160* | **1,8** | *1115* | | *1290* | | *1390* | *890* | *430* |
| *72* | *29* | *10* | *1,437E-06* | *160* | **1,7** | *1115* | | *1290* | | *1400* | *875* | *430* |
| *96* | *33* | *10* | *1,636E-06* | *160* | **1,6** | *1115* | | *1290* | | *1390* | *850* | *430* |
| *120* | *24* | *10* | *1,190E-06* | *160* | **1,7** | *1115* | | *1290* | | *1400* | *880* | *430* |
| *144* | *20* | *10* | *1,014E-06* | *160* | **1,6** | *1100* | | *1290* | | *1400* | *880* | *430* |
| *168* | *23* | *10* | *1,157E-06* | *160* | **1,7** | *1105* | | *1300* | | *1390* | *880* | *430* |
| *192* | *23* | *10* | *1,132E-06* | *160* | **1,6** | *1120* | | *1300* | | *1390* | *880* | *430* |
| *216* | *21* | *10* | *1,033E-06* | *160* | **1,6** | *1120* | | *1300* | | *1390* | *880* | *430* |
| *240* | *20* | *10* | *9,841E-07* | *160* | **1,8** | *1120* | | *1300* | | *1390* | *880* | *430* |
| *264* | *21* | *10* | *1,033E-06* | *160* | **1,7** | *1120* | | *1300* | | *1390* | *880* | *430* |
| *288* | *22* | *10* | *1,083E-06* | *160* | **1,8** | *1120* | | *1300* | | *1390* | *880* | *430* |
| *312* | *21* | *10* | *1,033E-06* | *160* | **1,8** | *1120* | | *1300* | | *1390* | *880* | *430* |
| *336* | *21* | *10* | *1,033E-06* | *160* | **1,6** | *1120* | | *1300* | | *1390* | *880* | *430* |
| *360* | *23* | *10* | *1,132E-06* | *160* | **1,7** | *1120* | | *1300* | | *1390* | *880* | *430* |
| *384* | *20* | *10* | *9,841E-07* | *160* | **1,8** | *1120* | | *1300* | | *1390* | *880* | *430* |
| *408* | *22* | *10* | *1,083E-06* | *160* | **1,8** | *1120* | | *1300* | | *1390* | *880* | *430* |
| *432* | *22* | *10* | *1,083E-06* | *160* | **1,8** | *1120* | | *1300* | | *1390* | *880* | *430* |

The permeability of the system started very high for the first 24 hours which suggest that there was no particle migration into the soil-geotextile interface. After the first 24 hours system permeability decreased and remained fairly constant between 1.0 x $10^{-6}$ m/s and 9.8 x $10^{-7}$ m/s. This is evidence of migration of silt and clay sized particles into and through the filter causing partial clogging.

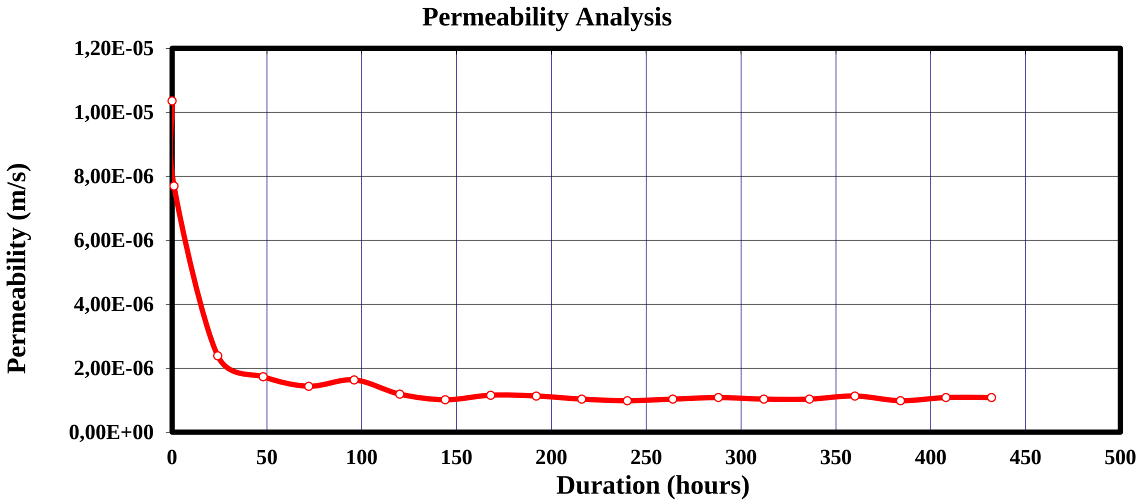


Figure 4.13: Permeability of the system (clayey sand vs. bidim A2)

The gradient ratio of the system was recorded for the duration of the test and was observed to vary between 0.1 and 1.8 which indicates that the system was very permeable at the start but got slightly clogged from around 24 hours until equilibrium was reached (fig 4.14). The maximum gradient ratio of 1.8 was observed towards the end of the test and it indicates silt and clay sized particles moving into the filter causing reduction in system permeability.

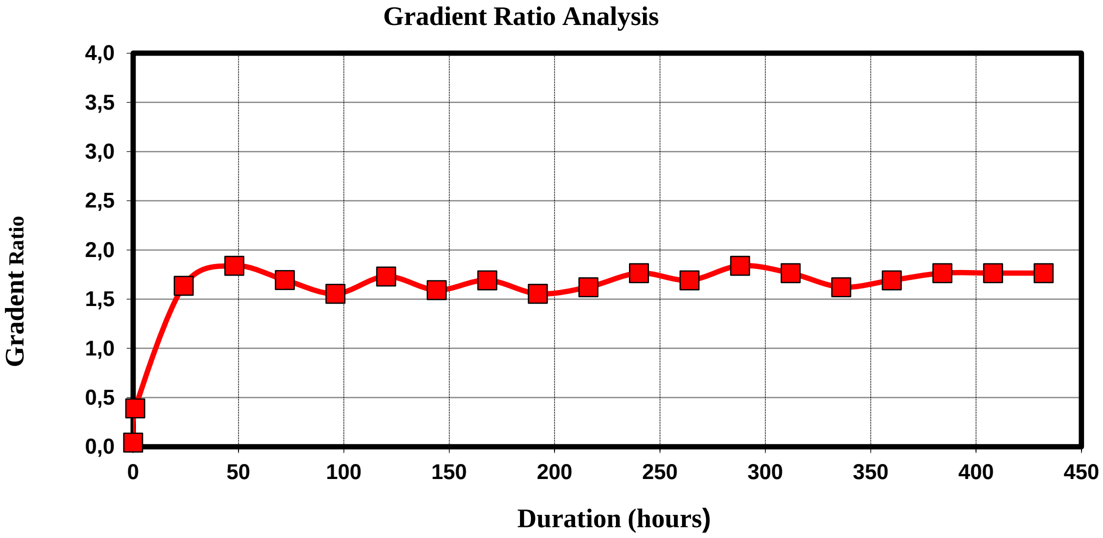


Figure 4.14: Gradient Ratio of the system (clayey sand vs. bidim A2)

*(ii) Clayey Sand Vs. Bidim A4*

The test was run for a maximum of 432 hours and results are summarized in Table 4.10. Water head fluctuation was observed in all the standpipes with the exception of the outlet (standpipe 5). Standpipe 1 readings fluctuated in the first 48 hours and became constant at 1140 mm throughout the rest of the test duration. There was no pressure fluctuation in the inlet and therefore the water head remains constant for the duration of the test. Standpipe 2 was also constant at 1300 mm throughout. Standpipe 3 and 4 had fluctuations in head. At standpipe 3 water head varied between 500 and 1260 whilst standpipe 4 readings varied between 440 and 750.

***Table 4.10: Long term gradient ratio results for clayey sand vs. bidim A4***

| Test Accumulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Gradient Ratio | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | Silica Sand | | | Soil Sample | | Outlet |
| *0* | *182* | *10* | *9,269E-06* | *120* | **0,3** | *930* | | *1300* | | *500* | *440* | *430* |
| *1* | *131* | *10* | *4,906E-06* | *120* | **0,4** | *1110* | | *1310* | | *550* | *450* | *430* |
| *24* | *78* | *10* | *2,580E-06* | *120* | **0,9** | *1200* | | *1340* | | *1170* | *660* | *430* |
| *48* | *48* | *10* | *1,722E-06* | *120* | **1,0** | *1140* | | *1290* | | *1320* | *720* | *430* |
| *72* | *38* | *10* | *1,363E-06* | *120* | **0,9** | *1140* | | *1290* | | *1330* | *710* | *430* |
| *96* | *40* | *10* | *1,435E-06* | *120* | **0,8** | *1140* | | *1290* | | *1330* | *690* | *430* |
| *120* | *33* | *10* | *1,184E-06* | *120* | **0,9** | *1140* | | *1290* | | *1340* | *720* | *430* |
| *144* | *31* | *10* | *1,112E-06* | *120* | **1,0** | *1140* | | *1290* | | *1360* | *730* | *430* |
| *168* | *83* | *10* | *2,977E-06* | *120* | **1,0** | *1140* | | *1300* | | *1290* | *710* | *430* |
| *192* | *65* | *10* | *2,331E-06* | *120* | **1,1** | *1140* | | *1300* | | *1280* | *730* | *430* |
| *216* | *60* | *10* | *2,152E-06* | *120* | **1,1** | *1140* | | *1300* | | *1225* | *720* | *430* |
| *240* | *53* | *10* | *1,901E-06* | *120* | **1,1** | *1140* | | *1300* | | *1260* | *720* | *430* |
| *264* | *41* | *10* | *1,470E-06* | *120* | **1,2** | *1140* | | *1300* | | *1260* | *740* | *430* |
| *288* | *45* | *10* | *1,614E-06* | *120* | **1,3** | *1140* | | *1300* | | *1230* | *750* | *430* |
| *312* | *47* | *10* | *1,686E-06* | *120* | **1,2** | *1140* | | *1300* | | *1260* | *735* | *430* |
| *336* | *42* | *10* | *1,506E-06* | *120* | **1,0** | *1140* | | *1300* | | *1260* | *710* | *430* |
| *360* | *49* | *10* | *1,757E-06* | *120* | **1,0** | *1140* | | *1300* | | *1280* | *720* | *430* |
| *384* | *51* | *10* | *1,829E-06* | *120* | **1,0** | *1140* | | *1300* | | *1260* | *700* | *430* |
| *408* | *48* | *10* | *1,722E-06* | *120* | **1,1** | *1140* | | *1300* | | *1260* | *720* | *430* |
| *432* | *49* | *10* | *1,757E-06* | *120* | **1,1** | *1140* | | *1300* | | *1230* | *720* | *430* |

The permeability of the system started very high for the first 24 hours which suggests that there was no particle migration into the soil-geotextile interface. After the first 48 hours system permeability decreased and remained fairly constant between 1.1 x $10^{-6}$ m/s and 2.9 x $10^{-6}$ m/s. This is evidence of migration of silt and clay sized particles into and through the filter causing partial clogging.

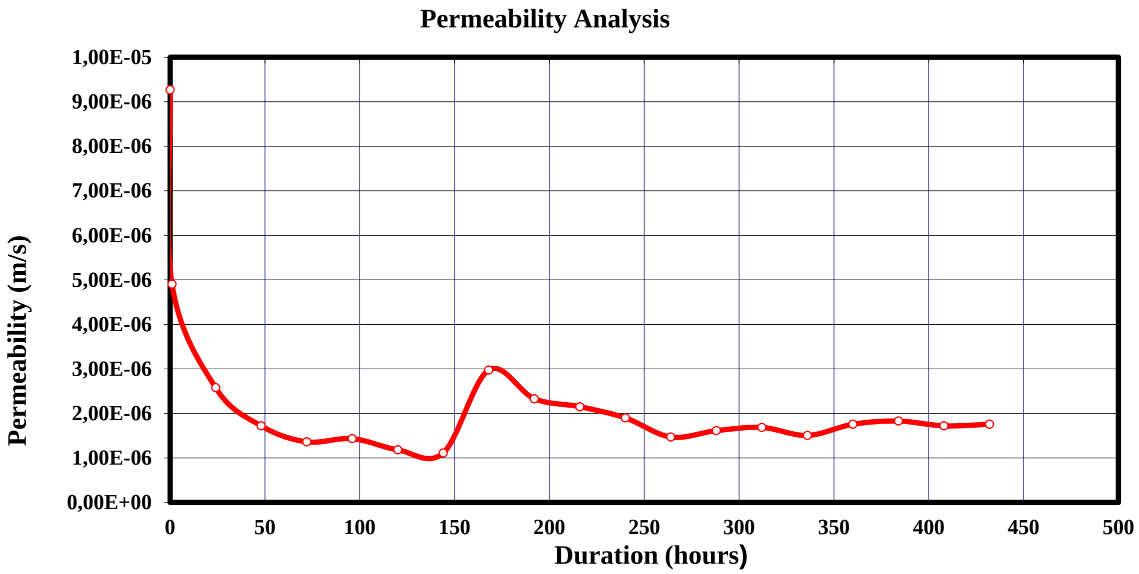


Figure 4.15: Permeability of the system (clayey sand vs. bidim A4)

The gradient ratio of the system was recorded for the duration of the test and was observed to vary between 0.3 and 1.3 which indicates that the system was fairly permeable throughout with very minimal soil particles moving into or through the filter (fig 4.16).

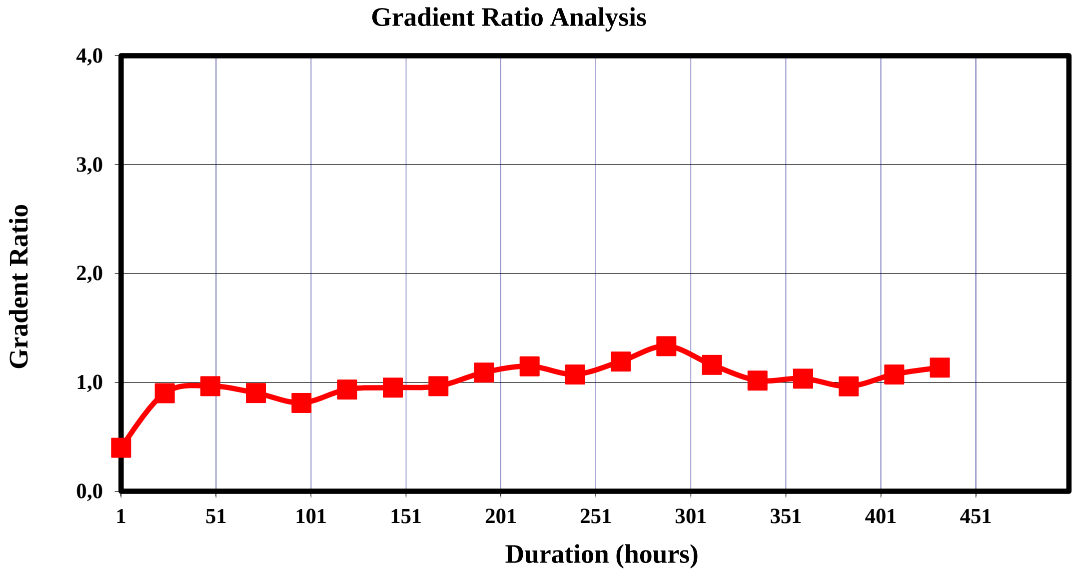


Figure 4.16: Gradient Ratio of the system (clayey sand vs. bidim A4)

*(iii) Clayey Sand Vs. Bidim A6*

The test was run for a maximum of 504 hours and results are summarized in Table 4.11. It was observed that the inlet (standpipe 1) and outlet (standpipe 5) water heads were constant at 1140 and 1300 mm respectively. The rest of the standpipes experienced some fluctuations. Standpipe

2 had some head fluctuations in the first 24 hours and remained constant thereafter. Standpipe 3 varied between 1060 and 1290 whilst standpipe 4 varied between 700 and 920.

***Table 4.11: Long term gradient ratio results for clayey sand vs. bidim A6***

| Test Accumulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Gradient Ratio | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| 0 | 130 | 10 | 3,885E-06 | 100 | **1,5** | 1140 | | 1250 | | 1060 | 700 | 430 |
| 1 | 101 | 10 | 3,019E-06 | 100 | **1,7** | 1140 | | 1270 | | 1210 | 790 | 430 |
| 24 | 64 | 10 | 1,913E-06 | 100 | **2,3** | 1140 | | 1290 | | 1280 | 880 | 430 |
| 48 | 35 | 10 | 1,046E-06 | 100 | **2,7** | 1140 | | 1290 | | 1280 | 920 | 430 |
| 72 | 31 | 10 | 9,265E-07 | 100 | **2,6** | 1140 | | 1290 | | 1290 | 920 | 430 |
| 96 | 26 | 10 | 7,771E-07 | 100 | **2,5** | 1140 | | 1290 | | 1310 | 920 | 430 |
| 120 | 45 | 10 | 1,345E-06 | 100 | **3,2** | 1140 | | 1300 | | 1230 | 920 | 430 |
| 144 | 58 | 10 | 1,734E-06 | 100 | **3,9** | 1140 | | 1300 | | 1110 | 880 | 430 |
| 168 | 55 | 10 | 1,644E-06 | 100 | **3,5** | 1140 | | 1300 | | 1060 | 830 | 430 |
| 192 | 45 | 10 | 1,345E-06 | 100 | **3,4** | 1140 | | 1300 | | 1020 | 800 | 430 |
| 216 | 42 | 10 | 1,255E-06 | 100 | **4,4** | 1140 | | 1300 | | 1040 | 850 | 430 |
| 240 | 41 | 10 | 1,225E-06 | 100 | **3,3** | 1140 | | 1300 | | 1060 | 820 | 430 |
| 264 | 43 | 10 | 1,285E-06 | 100 | **3,0** | 1140 | | 1300 | | 1100 | 830 | 430 |
| 288 | 50 | 10 | 1,494E-06 | 100 | **3,1** | 1140 | | 1300 | | 1120 | 850 | 430 |
| 312 | 47 | 10 | 1,405E-06 | 100 | **3,4** | 1140 | | 1300 | | 1080 | 840 | 430 |
| 336 | 45 | 10 | 1,345E-06 | 100 | **4,3** | 1140 | | 1300 | | 1060 | 860 | 430 |
| 360 | 49 | 10 | 1,465E-06 | 100 | **3,7** | 1140 | | 1300 | | 1060 | 840 | 430 |
| 384 | 48 | 10 | 1,435E-06 | 100 | **4,2** | 1140 | | 1300 | | 1080 | 870 | 430 |
| 408 | 48 | 10 | 1,435E-06 | 100 | **3,6** | 1140 | | 1300 | | 1100 | 860 | 430 |
| 432 | 50 | 10 | 1,494E-06 | 100 | **3,0** | 1140 | | 1300 | | 1100 | 830 | 430 |
| 456 | 50 | 10 | 1,494E-06 | 100 | **3,3** | 1140 | | 1300 | | 1090 | 840 | 430 |
| 480 | 50 | 10 | 1,494E-06 | 100 | **3,0** | 1140 | | 1300 | | 1100 | 830 | 430 |
| 504 | 51 | 10 | 1,524E-06 | 100 | **3,2** | 1140 | | 1300 | | 1080 | 830 | 430 |

The permeability of the system started very high for the first 24 hours which suggest that there was no particle migration into the soil-geotextile interface. After the first 48 hours system permeability reduced and remained fairly constant between 1.4 x $10^{-6}$ and 9 x $10^{-7}$ m/s. Some silt and clay sized particles migrated into the filter causing partial clogging. Bidim A6 is the least permeable of the three polyester geotextiles and tends to have a high retention of fine particles.

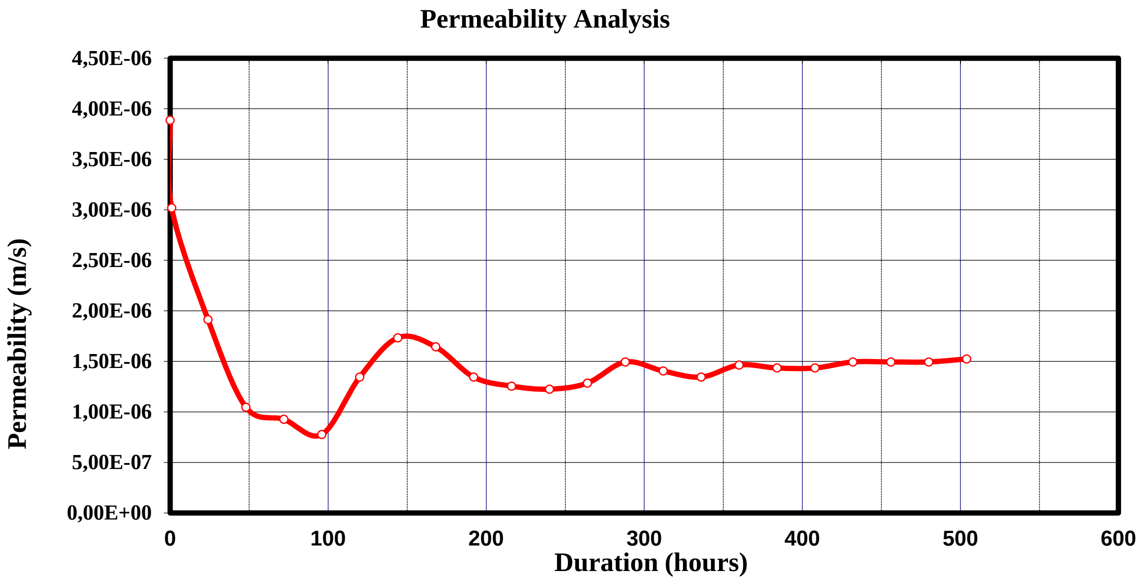


Figure 4.17: Permeability of the system (clayey sand vs. bidim A6)

The gradient ratio of the system started at 1.5 which indicates fine particles moving into the filter and it increased to a maximum of 4.4 at 216 hours which suggest partial clogging or blinding of the filter. Figure 4.18 shows the gradient ratios of the test from 0 hours until equilibrium at 504 hours.

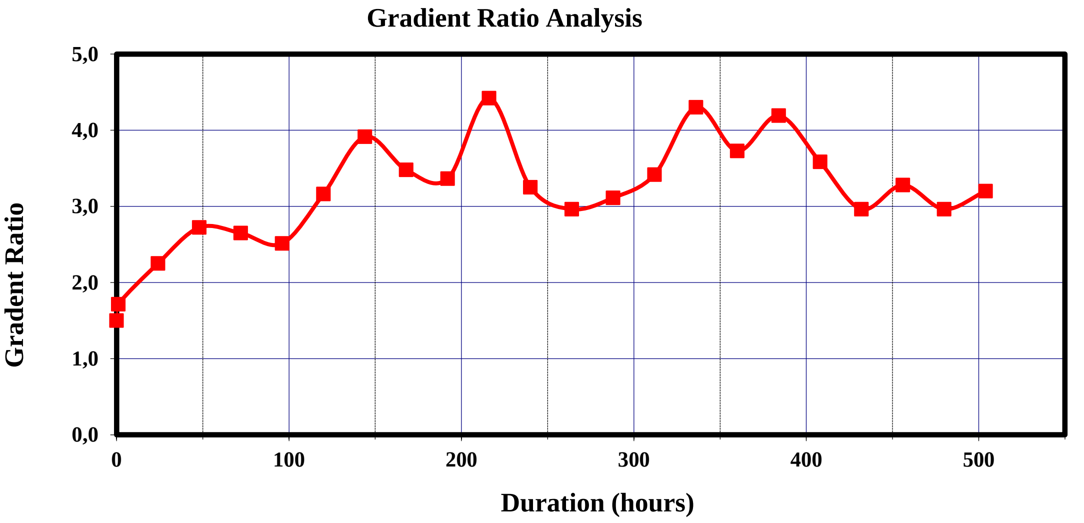


Figure 4.18: Gradient Ratio of the system (clayey sand vs. bidim A6)

*(iv) Clayey Sand Vs. Kaytape S120*

This test was run for 696 hours and the results are summarized in Table 4.12. Changes in water heads were observed in standpipes 3 and 4 which is usually caused by the "activity" in the soil-geotextile interface. The other standpipes remained constant for the duration of the test.

*Table 4.12: Long term gradient ratio results for clayey sand vs. Kaytape S120*

| Test Accumulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Gradient Ratio | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| *0* | *35* | *10* | *1,255E-06* | *120* | **3,7** | *1140* | | *1300* | | *1200* | *930* | *430* |
| *1* | *33* | *10* | *1,184E-06* | *120* | **3,5** | *1140* | | *1300* | | *1200* | *920* | *430* |
| *24* | *22* | *10* | *7,890E-07* | *120* | **3,9** | *1140* | | *1300* | | *1280* | *990* | *430* |
| *48* | *29* | *10* | *1,040E-06* | *120* | **3,8** | *1140* | | *1300* | | *1300* | *1000* | *430* |
| *72* | *56* | *10* | *2,008E-06* | *120* | **3,3** | *1140* | | *1300* | | *1280* | *960* | *430* |
| *96* | *78* | *10* | *2,798E-06* | *120* | **3,3** | *1140* | | *1300* | | *1220* | *920* | *430* |
| *120* | *99* | *10* | *3,551E-06* | *120* | **2,2** | *1140* | | *1300* | | *1170* | *820* | *430* |
| *144* | *105* | *10* | *3,766E-06* | *120* | **2,5** | *1140* | | *1300* | | *1100* | *800* | *430* |
| *168* | *104* | *10* | *3,730E-06* | *120* | **2,7** | *1140* | | *1300* | | *1140* | *840* | *430* |
| *192* | *98* | *10* | *3,515E-06* | *120* | **2,5** | *1140* | | *1300* | | *1060* | *780* | *430* |
| *216* | *87* | *10* | *3,120E-06* | *120* | **3,0** | *1140* | | *1300* | | *960* | *750* | *430* |
| *240* | *78* | *10* | *2,798E-06* | *120* | **2,6** | *1140* | | *1300* | | *940* | *720* | *430* |
| *264* | *78* | *10* | *2,798E-06* | *120* | **2,6** | *1140* | | *1300* | | *890* | *690* | *430* |
| *288* | *75* | *10* | *2,690E-06* | *120* | **2,4** | *1140* | | *1300* | | *910* | *690* | *430* |
| *312* | *70* | *10* | *2,511E-06* | *120* | **2,3** | *1140* | | *1300* | | *880* | *670* | *430* |
| *336* | *68* | *10* | *2,439E-06* | *120* | **3,1** | *1140* | | *1300* | | *890* | *710* | *430* |
| *360* | *73* | *10* | *2,618E-06* | *120* | **2,9** | *1140* | | *1300* | | *900* | *710* | *430* |
| *384* | *69* | *10* | *2,475E-06* | *120* | **2,2** | *1140* | | *1300* | | *910* | *680* | *430* |
| *408* | *64* | *10* | *2,295E-06* | *120* | **2,4** | *1140* | | *1300* | | *890* | *680* | *430* |
| *432* | *58* | *10* | *2,080E-06* | *120* | **2,2** | *1140* | | *1300* | | *910* | *680* | *430* |
| *456* | *56* | *10* | *2,008E-06* | *120* | **2,1** | *1140* | | *1300* | | *920* | *680* | *430* |
| *480* | *50* | *10* | *1,793E-06* | *120* | **2,3** | *1140* | | *1300* | | *900* | *680* | *430* |
| *504* | *53* | *10* | *1,901E-06* | *120* | **2,0** | *1140* | | *1300* | | *870* | *650* | *430* |
| *528* | *39* | *10* | *1,399E-06* | *120* | **3,2** | *1140* | | *1300* | | *690* | *590* | *430* |
| *552* | *31* | *10* | *1,112E-06* | *120* | **3,6** | *1140* | | *1300* | | *710* | *610* | *430* |
| *572* | *32* | *10* | *1,148E-06* | *120* | **3,4** | *1140* | | *1300* | | *700* | *600* | *430* |
| *600* | *30* | *10* | *1,076E-06* | *120* | **3,5** | *1140* | | *1300* | | *730* | *620* | *430* |
| *624* | *33* | *10* | *1,184E-06* | *120* | **3,8** | *1140* | | *1300* | | *720* | *620* | *430* |
| *648* | *35* | *10* | *1,255E-06* | *120* | **3,8** | *1140* | | *1300* | | *720* | *620* | *430* |
| *672* | *32* | *10* | *1,148E-06* | *120* | **3,6** | *1140* | | *1300* | | *710* | *610* | *430* |
| *696* | *33* | *10* | *1,184E-06* | *120* | **3,2** | *1140* | | *1300* | | *690* | *590* | *430* |

The permeability started low at 1.2 x $10^{-6}$ m/s at 0 to 72 hours and increased after 96 hours to 2.8 x $10^{-6}$ m/s. The system was significantly permeable between 96 and 360 hours. The increase in permeability is evident that some fine silt and clay sized particles have moved through the system resulting in the formation of a stable filter. The reduction in permeability observed around 408 hours is assumed to be a result of blinding of the geotextile pores by fine soil particles. Woven tapes have a very thin structure and therefore no fine particles can get entrapped.

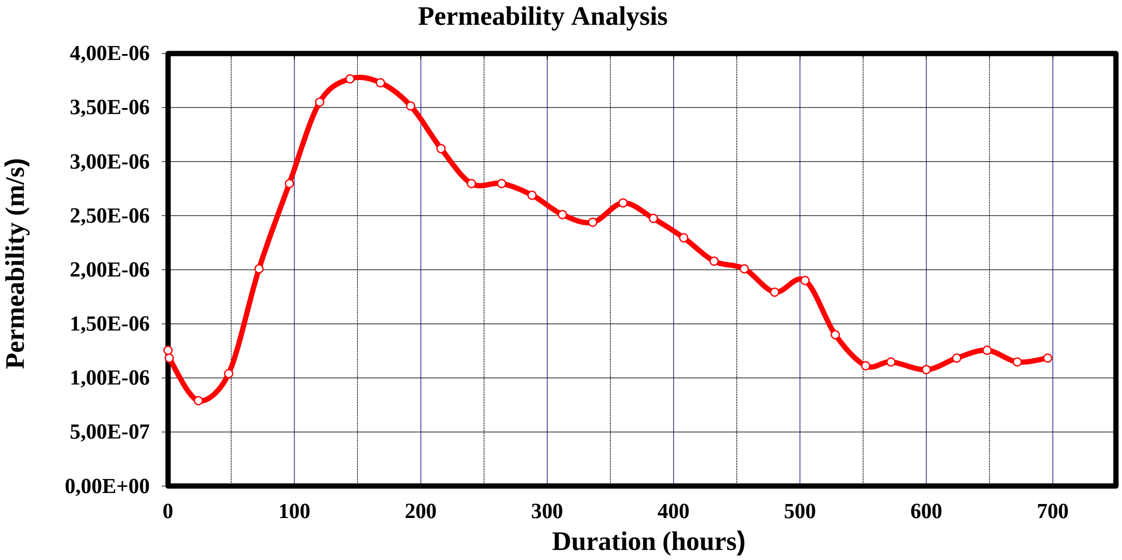


Figure 4.19: Permeability of the system (clayey sand vs. Kaytape S120)

*Gradient Ratio*

The gradient ratio of the system was observed to be high from the beginning of the test and it varied between 2.2 and 3.9 until equilibrium was reached at 696 hours. This high GR values are indicative of partial clogging of the system. Blinding of the geotextile pores by fine soil particles also causes high GR values. Although GR indicates system partially clogging or blinding, the system was quite permeable between 96 and 360 hours.

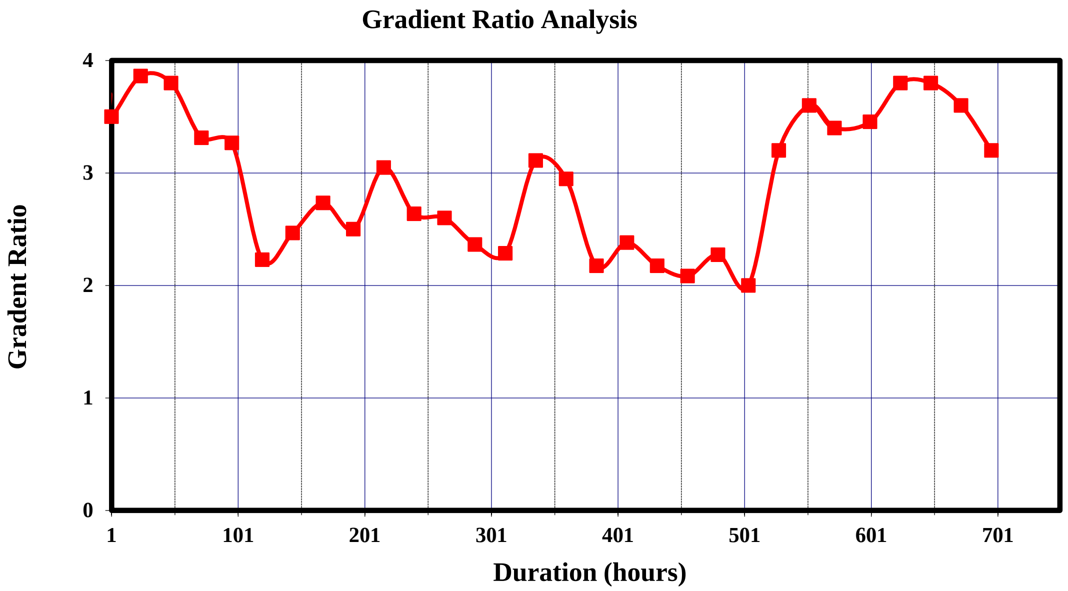


Figure 4.20: Gradient Ratio of the system (clayey sand vs. Kaytape S120)

### *(v) Clayey Sand Vs. Kaytape S270*

The test was run for a maximum of 624 hours and the results are summarized in Table 4.13. It was observed that the changes in water head was small and some standpipes remained constant throughout the test (Table 4.13). The following variation was noted during the test:

Standpipe 1 was constant at 1140 mm throughout. There was no pressure fluctuation in the inlet and therefore the water head remains constant for the duration of the test. Standpipe 2 was also constant at 1300 mm throughout. Standpipe 3 and 4 had fluctuations in head and this is usually caused by the "activity" in the soil-geotextile interface. Standpipe 3 water head varied between 850 and 1400 whilst standpipe 4 varied between 670 and 1050. Water head loss is usually caused by the reduction in pressure in the system due to an open filter allowing ease flow of water. Increase in water head is usually caused by clogging and blinding which increases pressure in the system. Standpipe 5 (outlet) remained constant at 430 mm throughout the test.

***Table 4.13: Long term gradient ratio results for clayey sand vs. Kaytape S270***

| Test Accumulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Gradient Ratio | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| *0* | *32* | *10* | *1,148E-06* | *120* | 2,8 | *1140* | | *1300* | | *1350* | *970* | *430* |

| Test Accumulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Gradient Ratio | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| *1* | *31* | *10* | *1,112E-06* | *120* | ***3,0*** | *1140* | | *1300* | | *1350* | *980* | *430* |
| *24* | *19* | *10* | *6,815E-07* | *120* | ***3,1*** | *1140* | | *1300* | | *1400* | *1020* | *430* |
| *48* | *8* | *10* | *2,869E-07* | *120* | ***3,5*** | *1140* | | *1300* | | *1400* | *1050* | *430* |
| *72* | *18* | *10* | *6,456E-07* | *120* | ***3,2*** | *1140* | | *1300* | | *1400* | *1030* | *430* |
| *96* | *24* | *10* | *8,608E-07* | *120* | ***3,1*** | *1140* | | *1300* | | *1400* | *1020* | *430* |
| *120* | *46* | *10* | *1,650E-06* | *120* | ***2,5*** | *1140* | | *1300* | | *1380* | *960* | *430* |
| *144* | *53* | *10* | *1,901E-06* | *120* | ***2,5*** | *1140* | | *1300* | | *1370* | *950* | *430* |
| *168* | *54* | *10* | *1,937E-06* | *120* | ***2,5*** | *1140* | | *1300* | | *1370* | *955* | *430* |
| *192* | *56* | *10* | *2,008E-06* | *120* | ***2,6*** | *1140* | | *1300* | | *1350* | *950* | *430* |
| *216* | *102* | *10* | *3,658E-06* | *120* | ***1,2*** | *1140* | | *1300* | | *1220* | *720* | *430* |
| *240* | *133* | *10* | *4,770E-06* | *120* | ***1,2*** | *1140* | | *1300* | | *1160* | *700* | *430* |
| *264* | *119* | *10* | *4,268E-06* | *120* | ***1,3*** | *1140* | | *1300* | | *1110* | *700* | *430* |
| *288* | *100* | *10* | *3,587E-06* | *120* | ***1,4*** | *1140* | | *1300* | | *1100* | *700* | *430* |
| *312* | *105* | *10* | *3,766E-06* | *120* | ***1,2*** | *1140* | | *1300* | | *1090* | *680* | *430* |
| *336* | *98* | *10* | *3,515E-06* | *120* | ***1,1*** | *1140* | | *1300* | | *1115* | *670* | *430* |
| *360* | *77* | *10* | *2,762E-06* | *120* | ***1,7*** | *1140* | | *1300* | | *1080* | *730* | *430* |
| *384* | *70* | *10* | *2,511E-06* | *120* | ***2,1*** | *1140* | | *1300* | | *1020* | *730* | *430* |
| *408* | *73* | *10* | *2,618E-06* | *120* | ***1,9*** | *1140* | | *1300* | | *990* | *700* | *430* |
| *432* | *65* | *10* | *2,331E-06* | *120* | ***2,8*** | *1140* | | *1300* | | *1000* | *760* | *430* |
| *456* | *63* | *10* | *2,260E-06* | *120* | ***2,2*** | *1140* | | *1300* | | *950* | *700* | *430* |
| *480* | *60* | *10* | *2,152E-06* | *120* | ***2,5*** | *1140* | | *1300* | | *900* | *690* | *430* |
| *504* | *53* | *10* | *1,901E-06* | *120* | ***2,7*** | *1140* | | *1300* | | *850* | *670* | *430* |
| *528* | *35* | *10* | *1,255E-06* | *120* | ***2,1*** | *1140* | | *1300* | | *900* | *670* | *430* |
| *552* | *31* | *10* | *1,112E-06* | *120* | ***2,3*** | *1140* | | *1300* | | *880* | *670* | *430* |
| *576* | *32* | *10* | *1,148E-06* | *120* | ***2,0*** | *1140* | | *1300* | | *890* | *660* | *430* |
| *600* | *32* | *10* | *1,148E-06* | *120* | ***2,3*** | *1140* | | *1300* | | *880* | *670* | *430* |
| *624* | *31* | *10* | *1,112E-06* | *120* | ***2,3*** | *1140* | | *1300* | | *900* | *680* | *430* |

The permeability of the system started low at 0 to 24 hours and continue to drop to a low of 2.9 x $10^{-7}$ m/s at 48 hours. Permeability started increasing at 72 hours until it reached a peak of 4.6 x $10^{-6}$ m/s at 240 hours. The increase and decrease in permeability between 0 and 240 hours is indicative of soil particle migration towards and into the filter causing blinding and partial clogging. Some particles were piped through the system which resulted in the sharp increase in permeability. After 360 hours the system started stabilizing until equilibrium was reached at 624 hours.

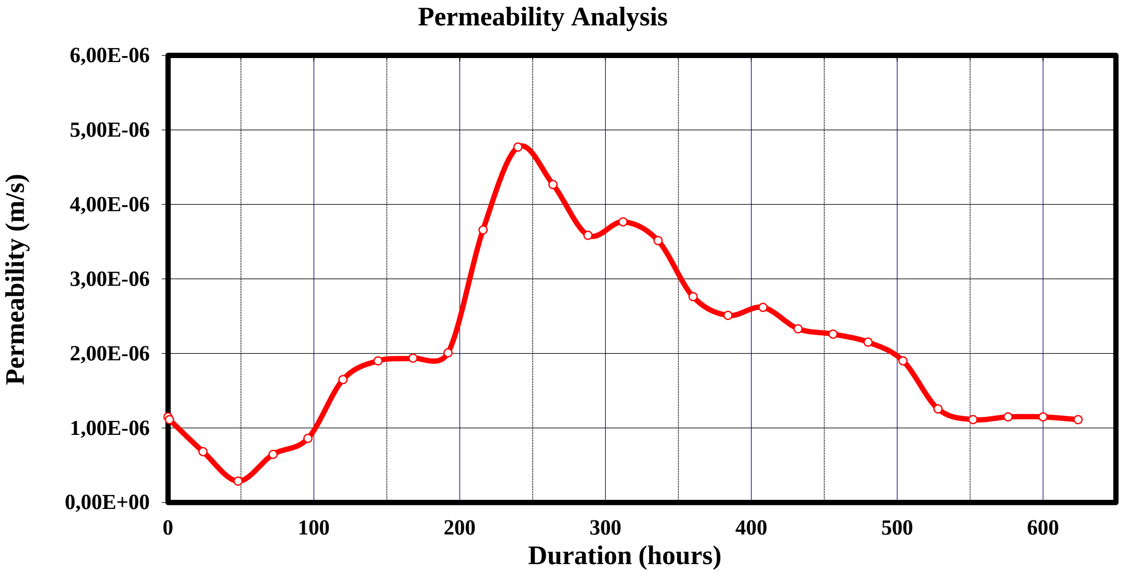


Figure 4.21: Permeability of the system (clayey sand vs. Kaytape S270)

The gradient ratio of the system was observed to be high at the beginning of the test, varying between 2.5 and 3.5 from 0 hours to 196 hours. The GR dropped at 216 hours to 1.2 which indicated formation of a stable filter system. At 384 hours GR increased to 2.1 and remained above 2 until the end of the test at 624 hours. This suggests that the system was moving towards clogging at the when equilibrium was reached.

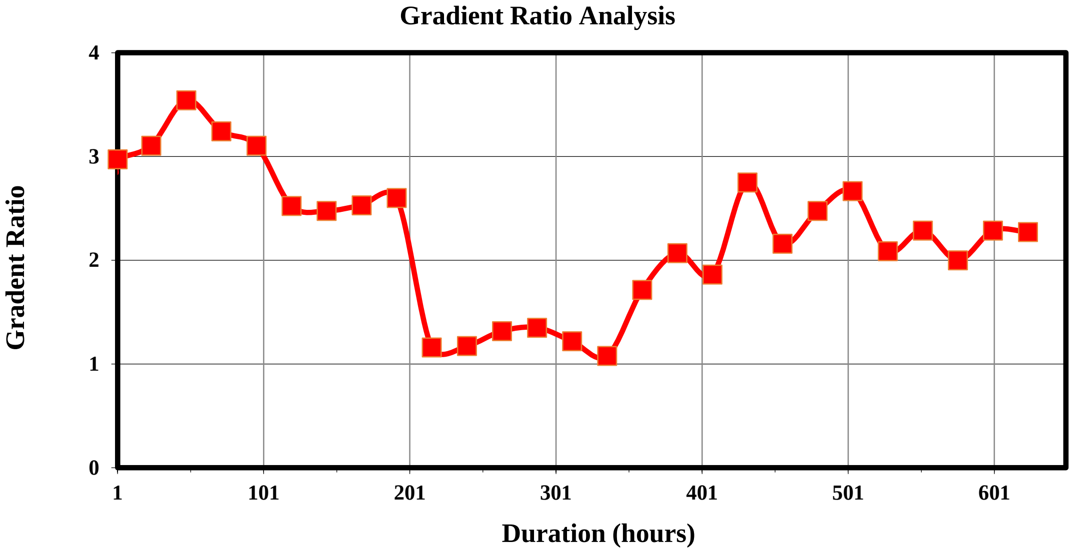


Figure 4.22: Gradient Ratio of the system (clayey sand vs. Kaytape S270)

### 4.2.3. Zone 3 Soil

Zone 3 soil was classified as Sandy Gravel (fig. 4.2) and the results of the Long Term Gradient Ratio test of this soil with different geotextiles are summarized in the following subsections.

*(i) Sandy Gravel Vs. Bidim A2*

This test was run for 1008 hours and the results are summarized in Table 4.14. It was noted that all the standpipes experienced some water head fluctuation with the exception of standpipe 5 (outlet) which remained constant at 430 throughout the duration of the test. Water head in standpipe 1, 2, 3 and 4 fluctuated as follows:

Water head at standpipe 1 fluctuated between 1060 and 1150 mm. Standpipe 2 was fairly constant at 1290, although there were some small fluctuations. Standpipe 3 water has varied between 1340 and 1420 whilst standpipe 4 varied between 615 and 800.

***Table 4.14: Long term gradient ratio results for sand gravel vs. bidim A2***

| **Test Accumulative Hours** | **Quantity ml** | **Duration min** | **Permeability k m/s** | **Sample Height mm** | **Gradient Ratio** | **Standpipe Readings - mm** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **1** | | **2** | | **3** | **4** | **5** |
| | | | | | | **300** | **250** | **200** | **150** | **100** | **50** | **0** |
| | | | | | | **Inlet** | | | | **Soil Sample** | | **Outlet** |
| *0* | *380* | *10* | *1,120E-05* | *100* | ***0,5*** | *1150* | | *1290* | | *1290* | *600* | *430* |
| *1* | *840* | *10* | *2,476E-05* | *100* | ***0,5*** | *1150* | | *1290* | | *1390* | *630* | *430* |
| *24* | *970* | *10* | *2,859E-05* | *100* | ***0,4*** | *1150* | | *1290* | | *1390* | *600* | *430* |
| *48* | *1030* | *10* | *3,036E-05* | *100* | ***0,3*** | *1150* | | *1290* | | *1390* | *570* | *430* |
| *72* | *1470* | *10* | *4,333E-05* | *100* | ***0,3*** | *1150* | | *1290* | | *1390* | *550* | *430* |
| *96* | *1350* | *10* | *3,979E-05* | *100* | ***0,4*** | *1150* | | *1290* | | *1390* | *590* | *430* |
| *120* | *890* | *10* | *2,623E-05* | *100* | ***0,4*** | *1150* | | *1290* | | *1390* | *600* | *430* |
| *144* | *725* | *10* | *2,137E-05* | *100* | ***0,5*** | *1150* | | *1290* | | *1390* | *610* | *430* |
| *168* | *545* | *10* | *1,606E-05* | *100* | ***0,7*** | *1150* | | *1290* | | *1390* | *680* | *430* |
| *192* | *430* | *10* | *1,362E-05* | *100* | ***0,9*** | *1100* | | *1240* | | *1340* | *720* | *430* |
| *216* | *410* | *10* | *1,299E-05* | *100* | ***0,8*** | *1100* | | *1240* | | *1340* | *680* | *430* |
| *240* | *440* | *10* | *1,482E-05* | *100* | ***0,5*** | *1060* | | *1240* | | *1340* | *615* | *430* |
| *264* | *260* | *10* | *8,488E-06* | *100* | ***0,4*** | *1080* | | *1220* | | *1360* | *600* | *430* |
| *288* | *285* | *10* | *9,027E-06* | *100* | ***0,5*** | *1100* | | *1240* | | *1360* | *620* | *430* |
| *312* | *565* | *10* | *1,689E-05* | *100* | ***0,4*** | *1140* | | *1270* | | *1360* | *600* | *430* |
| *336* | *480* | *10* | *1,435E-05* | *100* | ***0,4*** | *1140* | | *1270* | | *1360* | *600* | *430* |
| *360* | *450* | *10* | *1,345E-05* | *100* | ***0,6*** | *1140* | | *1250* | | *1360* | *650* | *430* |
| *384* | *430* | *10* | *1,285E-05* | *100* | ***0,7*** | *1140* | | *1270* | | *1350* | *660* | *430* |
| *408* | *410* | *10* | *1,225E-05* | *100* | ***0,6*** | *1140* | | *1260* | | *1360* | *650* | *430* |

| **Test Accumulative Hours** | **Quantity ml** | **Duration min** | **Permeability k m/s** | **Sample Height mm** | **Gradient Ratio** | **Standpipe Readings - mm** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **1** | | **2** | | **3** | **4** | **5** |
| | | | | | | **300** | **250** | **200** | **150** | **100** | **50** | **0** |
| | | | | | | **Inlet** | | | | **Soil Sample** | | **Outlet** |
| *432* | *320* | *10* | *9,841E-06* | *100* | ***0,7*** | *1120* | | *1260* | | *1380* | *675* | *430* |
| *456* | *430* | *10* | *1,322E-05* | *100* | ***0,7*** | *1120* | | *1260* | | *1380* | *680* | *430* |
| *480* | *271* | *10* | *8,713E-06* | *100* | ***0,8*** | *1090* | | *1230* | | *1350* | *700* | *430* |
| *504* | *275* | *10* | *8,582E-06* | *100* | ***0,8*** | *1110* | | *1260* | | *1360* | *690* | *430* |
| *528* | *277* | *10* | *8,644E-06* | *100* | ***0,6*** | *1110* | | *1260* | | *1360* | *650* | *430* |
| *552* | *233* | *10* | *7,380E-06* | *100* | ***0,7*** | *1100* | | *1260* | | *1330* | *675* | *430* |
| *572* | *374* | *10* | *1,102E-05* | *100* | ***0,6*** | *1150* | | *1290* | | *1400* | *650* | *430* |
| *600* | *283* | *10* | *8,518E-06* | *100* | ***0,6*** | *1135* | | *1290* | | *1390* | *660* | *430* |
| *624* | *277* | *10* | *8,338E-06* | *100* | ***0,6*** | *1135* | | *1290* | | *1400* | *650* | *430* |
| *648* | *280* | *10* | *8,428E-06* | *100* | ***0,6*** | *1135* | | *1290* | | *1390* | *640* | *430* |
| *672* | *260* | *10* | *7,826E-06* | *100* | ***0,5*** | *1135* | | *1290* | | *1380* | *620* | *430* |
| *696* | *256* | *10* | *7,706E-06* | *100* | ***0,5*** | *1135* | | *1290* | | *1400* | *630* | *430* |
| *720* | *246* | *10* | *7,405E-06* | *100* | ***0,6*** | *1135* | | *1290* | | *1400* | *650* | *430* |
| *744* | *218* | *10* | *6,337E-06* | *100* | ***0,7*** | *1160* | | *1320* | | *1420* | *680* | *430* |
| *768* | *235* | *10* | *6,831E-06* | *100* | ***0,7*** | *1160* | | *1320* | | *1410* | *690* | *430* |
| *792* | *227* | *10* | *6,599E-06* | *100* | ***0,9*** | *1160* | | *1320* | | *1400* | *730* | *430* |
| *816* | *240* | *10* | *7,224E-06* | *100* | ***0,8*** | *1135* | | *1295* | | *1400* | *700* | *430* |
| *840* | *235* | *10* | *6,926E-06* | *100* | ***1,2*** | *1150* | | *1290* | | *1400* | *800* | *430* |
| *864* | *243* | *10* | *7,212E-06* | *100* | ***1,0*** | *1145* | | *1290* | | *1400* | *750* | *430* |
| *888* | *237* | *10* | *6,985E-06* | *100* | ***0,9*** | *1150* | | *1295* | | *1390* | *720* | *430* |
| *912* | *240* | *10* | *7,074E-06* | *100* | ***0,7*** | *1150* | | *1290* | | *1390* | *690* | *430* |
| *936* | *243* | *10* | *7,212E-06* | *100* | ***0,6*** | *1145* | | *1295* | | *1400* | *650* | *430* |
| *960* | *238* | *10* | *7,015E-06* | *100* | ***0,7*** | *1150* | | *1290* | | *1390* | *680* | *430* |
| *984* | *235* | *10* | *6,926E-06* | *100* | ***0,7*** | *1150* | | *1295* | | *1390* | *670* | *430* |
| *1008* | *237* | *10* | *7,034E-06* | *100* | ***0,6*** | *1145* | | *1295* | | *1390* | *650* | *430* |

The permeability of the system was very high from the beginning of the test at 1.120 x $10^{-5}$ m/s and decreased slightly at 264 and 288 hours which indicative movement of soil particles into the filter. The highest permeabilities were observed at 72 and 96 hours, with permeability values of 4.333 x $10^{-5}$ m/s and 3.979 x $10^{-5}$ m/s respectively. The system was quite stable until the end of the test which suggest very minimal or no clogging at all. Bidim A2 has large pore as compared to the other polyester geotextiles and therefore has a low retention which means there might have been a significant amount of the base soil lost through the filter.

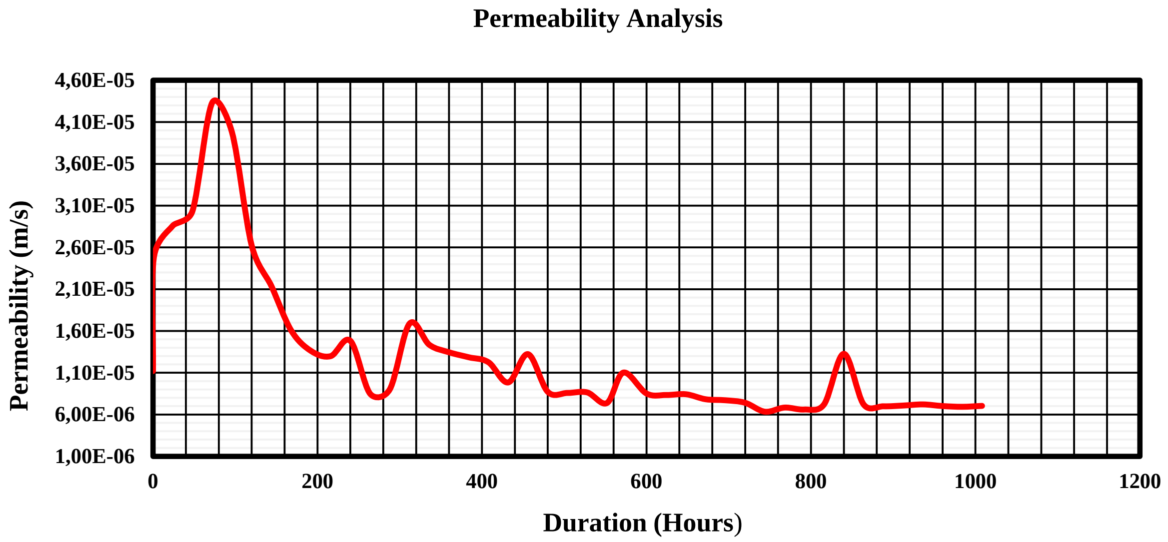


Figure 4.23: Permeability of the system (sandy gravel vs.bidim A2)

The gradient ratio of the system was less than 1.2 for the duration of the test which is indicative of a stable system. The lowest observed GR was 0.3 at 48 to 72 hours which indicates a more open filter system.

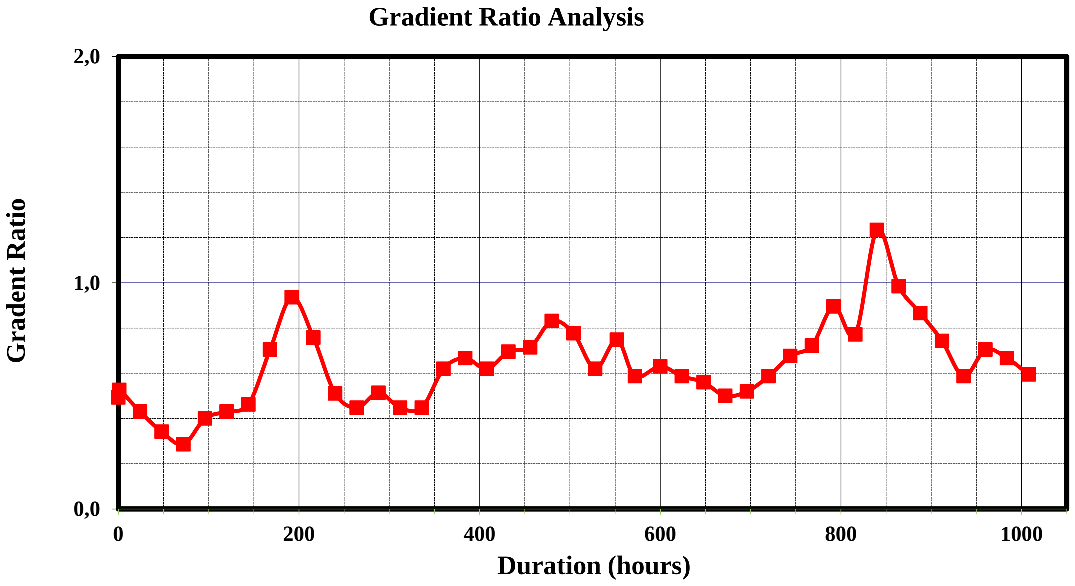


Figure 4.24: Gradient Ratio of the system (sandy gravel vs.bidim A2)

*(ii) Sandy Gravel Vs. Bidim A4*

This test was run for 1008 hours and the results are summarized in Table 4.15. It was observed that all standpipes experienced some water head changes with an exception of standpipe 5 which remained constant at 430 mm throughout. Water head at standpipe 1 fluctuated between

1090 and 1150 mm. At standpipe 2, water head fluctuated between 1200 and 1320 mm for the duration of the test. Standpipe 3 water has varied between 1200 and 1320 whilst standpipe 4 varied between 590 and 670. Water head loss is usually caused by the reduction in pressure in the system due to an open filter allowing ease flow of water. Increase in water head is usually caused by clogging and blinding which increases pressure in the system.

***Table 4.15: Long term gradient ratio results for sand gravel vs. bidim A4***

| **Test Accumulative Hours** | **Quantity ml** | **Duration min** | **Permeability k m/s** | **Sample Height mm** | **Gradient Ratio** | **Standpipe Readings - mm** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **1** | | **2** | | **3** | **4** | **5** |
| | | | | | | **300** | **250** | **200** | **150** | **100** | **50** | **0** |
| | | | | | | **Inlet** | | | | **Soil Sample** | | **Outlet** |
| *0* | *1050* | *10* | *3,095E-05* | *100* | ***0,5*** | *1150* | | *1290* | | *1200* | *590* | *430* |
| *1* | *1000* | *10* | *2,947E-05* | *100* | ***0,5*** | *1150* | | *1290* | | *1250* | *600* | *430* |
| *24* | *650* | *10* | *1,916E-05* | *100* | ***0,7*** | *1150* | | *1290* | | *1250* | *650* | *430* |
| *48* | *540* | *10* | *1,592E-05* | *100* | ***0,6*** | *1150* | | *1290* | | *1300* | *640* | *430* |
| *72* | *570* | *10* | *1,680E-05* | *100* | ***0,7*** | *1150* | | *1290* | | *1300* | *650* | *430* |
| *96* | *765* | *10* | *2,255E-05* | *100* | ***0,7*** | *1150* | | *1290* | | *1300* | *650* | *430* |
| *120* | *870* | *10* | *2,564E-05* | *100* | ***0,7*** | *1150* | | *1290* | | *1300* | *650* | *430* |
| *144* | *1340* | *10* | *3,949E-05* | *100* | ***0,4*** | *1150* | | *1290* | | *1300* | *580* | *430* |
| *168* | *800* | *10* | *2,358E-05* | *100* | ***0,7*** | *1150* | | *1290* | | *1300* | *650* | *430* |
| *192* | *450* | *10* | *1,425E-05* | *100* | ***0,6*** | *1100* | | *1240* | | *1300* | *640* | *430* |
| *216* | *420* | *10* | *1,330E-05* | *100* | ***0,7*** | *1100* | | *1240* | | *1290* | *660* | *430* |
| *240* | *450* | *10* | *1,516E-05* | *100* | ***0,7*** | *1060* | | *1200* | | *1240* | *650* | *430* |
| *264* | *290* | *10* | *9,468E-06* | *100* | ***0,8*** | *1080* | | *1230* | | *1260* | *670* | *430* |
| *288* | *525* | *10* | *1,663E-05* | *100* | ***0,6*** | *1100* | | *1260* | | *1300* | *630* | *430* |
| *312* | *765* | *10* | *2,286E-05* | *100* | ***0,5*** | *1140* | | *1270* | | *1320* | *620* | *430* |
| *336* | *695* | *10* | *2,137E-05* | *100* | ***0,7*** | *1120* | | *1250* | | *1280* | *640* | *430* |
| *360* | *730* | *10* | *2,245E-05* | *100* | ***0,7*** | *1120* | | *1250* | | *1280* | *650* | *430* |
| *384* | *595* | *10* | *1,830E-05* | *100* | ***0,8*** | *1120* | | *1250* | | *1240* | *660* | *430* |
| *408* | *580* | *10* | *1,734E-05* | *100* | ***0,7*** | *1140* | | *1270* | | *1240* | *650* | *430* |
| *432* | *570* | *10* | *1,753E-05* | *100* | ***0,6*** | *1120* | | *1260* | | *1280* | *630* | *430* |
| *456* | *320* | *10* | *9,841E-06* | *100* | ***0,5*** | *1120* | | *1260* | | *1280* | *610* | *430* |
| *480* | *325* | *10* | *1,045E-05* | *100* | ***0,7*** | *1090* | | *1230* | | *1260* | *640* | *430* |
| *504* | *343* | *10* | *1,086E-05* | *100* | ***0,7*** | *1100* | | *1260* | | *1260* | *650* | *430* |
| *528* | *338* | *10* | *1,071E-05* | *100* | ***0,8*** | *1100* | | *1250* | | *1260* | *660* | *430* |
| *552* | *365* | *10* | *1,156E-05* | *100* | ***0,8*** | *1100* | | *1250* | | *1260* | *670* | *430* |
| *572* | *355* | *10* | *1,092E-05* | *100* | ***0,7*** | *1120* | | *1280* | | *1290* | *650* | *430* |
| *600* | *398* | *10* | *1,207E-05* | *100* | ***0,5*** | *1130* | | *1270* | | *1290* | *610* | *430* |

| **Test Accumulative Hours** | **Quantity ml** | **Duration min** | **Permeability k m/s** | **Sample Height mm** | **Gradient Ratio** | **Standpipe Readings - mm** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **1** | | **2** | | **3** | **4** | **5** |
| | | | | | | **300** | **250** | **200** | **150** | **100** | **50** | **0** |
| | | | | | | **Inlet** | | | | **Soil Sample** | | **Outlet** |
| *624* | *415* | *10* | *1,258E-05* | *100* | ***0,7*** | *1130* | | *1270* | | *1290* | *650* | *430* |
| *648* | *487* | *10* | *1,476E-05* | *100* | ***0,7*** | *1130* | | *1270* | | *1290* | *650* | *430* |
| *672* | *520* | *10* | *1,576E-05* | *100* | ***0,7*** | *1130* | | *1270* | | *1290* | *660* | *430* |
| *696* | *505* | *10* | *1,531E-05* | *100* | ***0,6*** | *1130* | | *1270* | | *1290* | *640* | *430* |
| *720* | *472* | *10* | *1,431E-05* | *100* | ***0,7*** | *1130* | | *1270* | | *1300* | *650* | *430* |
| *744* | *527* | *10* | *1,532E-05* | *100* | ***0,8*** | *1160* | | *1320* | | *1300* | *670* | *430* |
| *768* | *500* | *10* | *1,453E-05* | *100* | ***0,7*** | *1160* | | *1320* | | *1330* | *660* | *430* |
| *792* | *490* | *10* | *1,424E-05* | *100* | ***0,6*** | *1160* | | *1320* | | *1320* | *640* | *430* |
| *816* | *450* | *10* | *1,336E-05* | *100* | ***0,7*** | *1145* | | *1310* | | *1300* | *650* | *430* |
| *840* | *475* | *10* | *1,400E-05* | *100* | ***0,7*** | *1150* | | *1310* | | *1300* | *650* | *430* |
| *864* | *507* | *10* | *1,494E-05* | *100* | ***0,6*** | *1150* | | *1320* | | *1320* | *630* | *430* |
| *888* | *488* | *10* | *1,438E-05* | *100* | ***0,6*** | *1150* | | *1320* | | *1320* | *640* | *430* |
| *912* | *477* | *10* | *1,406E-05* | *100* | ***0,7*** | *1150* | | *1320* | | *1320* | *650* | *430* |
| *936* | *482* | *10* | *1,431E-05* | *100* | ***0,7*** | *1145* | | *1310* | | *1320* | *660* | *430* |
| *960* | *478* | *10* | *1,419E-05* | *100* | ***0,7*** | *1145* | | *1320* | | *1320* | *650* | *430* |
| *984* | *475* | *10* | *1,400E-05* | *100* | ***0,6*** | *1150* | | *1320* | | *1320* | *640* | *430* |
| *1008* | *479* | *10* | *1,412E-05* | *100* | ***0,7*** | *1150* | | *1320* | | *1320* | *650* | *430* |

The permeability of the system started very high at 0 to 1 hour (3.1 x $10^{-5}$ m/s) and it dropped at 24 hours to 1.9 x $10^{-5}$ m/s. Between 120 and 144 hours there was a sharp increase in permeability which is indicative of an open filter system. It is evident from the system permeability values that there was no clogging or blinding of the filter throughout the test. At 888 hours the system started being fairly constant and reached eventually reached equilibrium at 1008 hours.

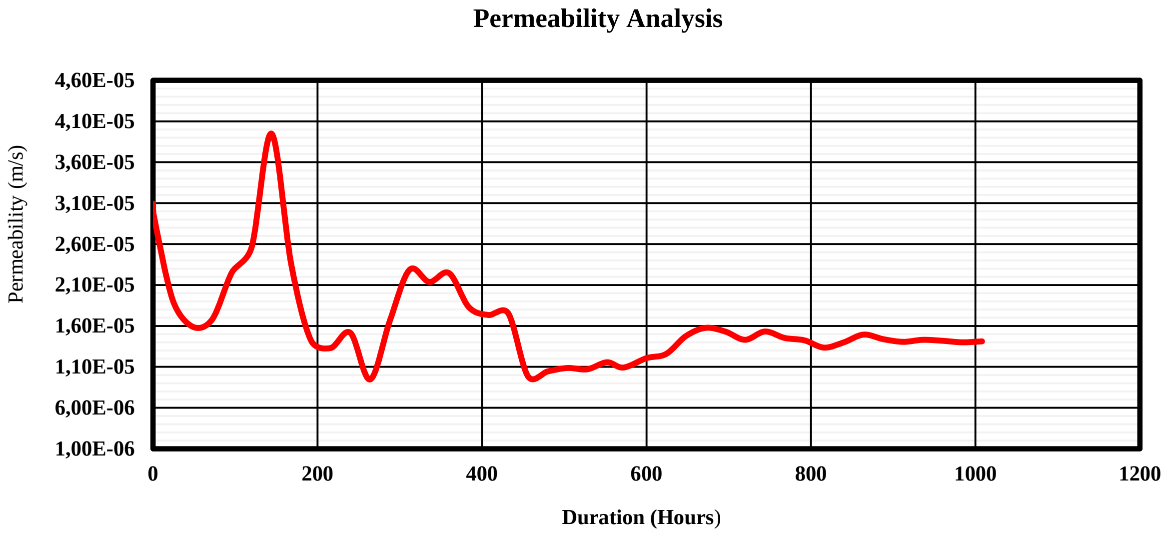


Figure 4.25: Permeability of the system (sandy gravel vs. bidim A4)

The gradient ratio of the system was recorded for the duration of the test and was observed to vary between 0.5 and 0.8 which indicates that the system was permeable throughout the duration of the test (fig 4.26). No partial clogging and blinding were observed in this test, however, piping of small soil particles through the filter cannot be ruled out.

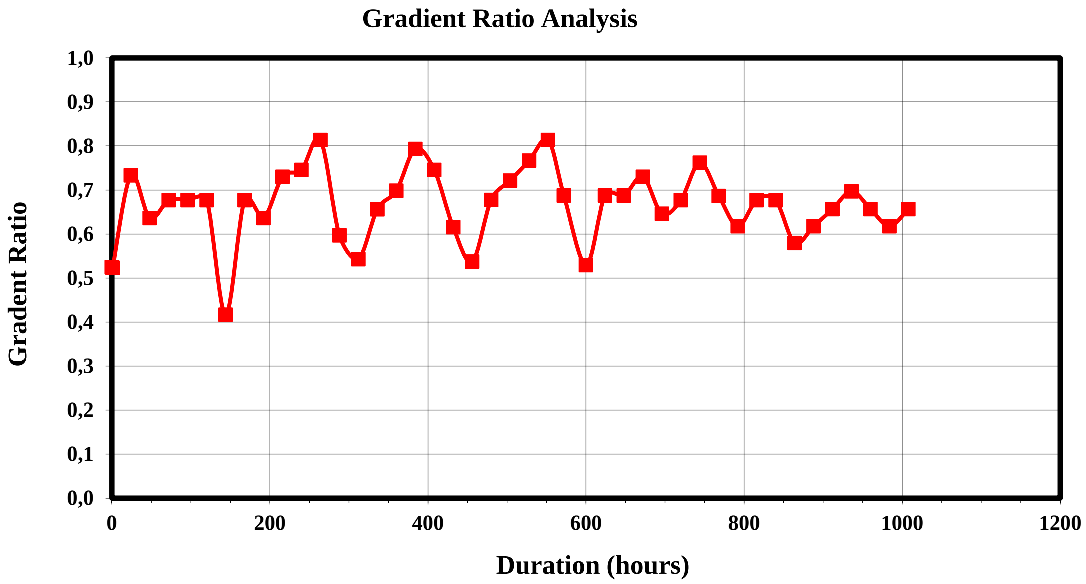


Figure 4.26: Gradient Ratio of the system (sandy gravel vs.bidim A4)

*(iii) Sandy Gravel Vs. Bidim A6*

This test was run for a maximum of 840 hours and the results are summarized in Table 4.16. There was a significant variation in different water heads throughout the test with an exception of standpipes 2 and 5 (Table 4.16). The following variation was noted during the test:

Water head at standpipe 1 fluctuated between 1060 and 1150 mm throughout the test duration. At standpipe 2, water head varied between 1200 and 1300 mm throughout. Standpipe 3 and 4 had fluctuations in head and this is usually caused by the "activity" in the soil-geotextile interface. Standpipe 3 water has varied between 600 and 1360 whilst standpipe 4 varied between 480 and 900. Water head loss is usually caused by the reduction in pressure in the system due to an open filter allowing ease flow of water. Increase in water head is usually caused by clogging and blinding which increases pressure in the system. Standpipe 5 (outlet) remained constant at 430 mm throughout the test.

***Table 4.16: Long term gradient ratio results for sand gravel vs. bidim A6***

| **Test Accumulative Hours** | **Quantity ml** | **Duration min** | **Permeability k m/s** | **Sample Height mm** | **Gradient Ratio** | **Standpipe Readings - mm** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **1** | | **2** | | **3** | **4** | **5** |
| | | | | | | **300** | **250** | **200** | **150** | **100** | **50** | **0** |
| | | | | | | **Inlet** | | | | **Soil Sample** | | **Outlet** |
| *0* | *500* | *10* | *1,584E-05* | *100* | **0,8** | *1100* | | *1290* | | *600* | *480* | *430* |
| *1* | *630* | *10* | *1,995E-05* | *100* | **1,1** | *1100* | | *1290* | | *800* | *560* | *430* |
| *24* | *360* | *10* | *1,140E-05* | *100* | **1,1** | *1100* | | *1290* | | *900* | *600* | *430* |
| *48* | *285* | *10* | *8,400E-06* | *100* | **1,3** | *1150* | | *1290* | | *1150* | *720* | *430* |
| *72* | *285* | *10* | *8,400E-06* | *100* | **1,3** | *1150* | | *1290* | | *1220* | *740* | *430* |
| *96* | *340* | *10* | *1,002E-05* | *100* | **1,3** | *1150* | | *1290* | | *1350* | *790* | *430* |
| *120* | *200* | *10* | *6,335E-06* | *100* | **1,3** | *1100* | | *1240* | | *1360* | *800* | *430* |
| *144* | *200* | *10* | *6,335E-06* | *100* | **1,4** | *1100* | | *1240* | | *1360* | *810* | *430* |
| *168* | *160* | *10* | *5,389E-06* | *100* | **1,5** | *1060* | | *1200* | | *1320* | *810* | *430* |
| *192* | *100* | *10* | *3,265E-06* | *100* | **1,5** | *1080* | | *1240* | | *1240* | *780* | *430* |
| *216* | *215* | *10* | *7,019E-06* | *100* | **1,4** | *1080* | | *1260* | | *1270* | *780* | *430* |
| *240* | *160* | *10* | *4,921E-06* | *100* | **1,5** | *1120* | | *1280* | | *1300* | *800* | *430* |
| *264* | *135* | *10* | *4,152E-06* | *100* | **1,7** | *1120* | | *1280* | | *1270* | *810* | *430* |
| *288* | *120* | *10* | *3,691E-06* | *100* | **1,6** | *1120* | | *1280* | | *1270* | *800* | *430* |
| *312* | *105* | *10* | *3,376E-06* | *100* | **0,9** | *1090* | | *1250* | | *1260* | *690* | *430* |
| *336* | *110* | *10* | *3,433E-06* | *100* | **1,4** | *1110* | | *1270* | | *1270* | *770* | *430* |
| *360* | *90* | *10* | *2,768E-06* | *100* | **1,6** | *1120* | | *1280* | | *1280* | *810* | *430* |
| *384* | *90* | *10* | *2,768E-06* | *100* | **1,5** | *1120* | | *1280* | | *1280* | *790* | *430* |
| *408* | *75* | *10* | *2,411E-06* | *100* | **1,8** | *1090* | | *1250* | | *1260* | *820* | *430* |
| *432* | *65* | *10* | *2,059E-06* | *100* | **2,0** | *1100* | | *1260* | | *1280* | *850* | *430* |
| *456* | *63* | *10* | *1,910E-06* | *100* | **1,9** | *1130* | | *1270* | | *1280* | *840* | *430* |
| *480* | *47* | *10* | *1,489E-06* | *100* | **2,0** | *1100* | | *1240* | | *1240* | *830* | *430* |
| *504* | *61* | *10* | *1,849E-06* | *100* | **2,0** | *1130* | | *1300* | | *1260* | *850* | *430* |
| *528* | *51* | *10* | *1,546E-06* | *100* | **1,8** | *1130* | | *1300* | | *1265* | *830* | *430* |

| Test Accumulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Gradient Ratio | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| 552 | 66 | 10 | 2,001E-06 | 100 | 1,8 | 1130 | | 1300 | | 1260 | 820 | 430 |
| 572 | 62 | 10 | 1,880E-06 | 100 | 1,7 | 1130 | | 1300 | | 1250 | 810 | 430 |
| 600 | 64 | 10 | 1,940E-06 | 100 | 1,5 | 1130 | | 1300 | | 1290 | 800 | 430 |
| 624 | 58 | 10 | 1,758E-06 | 100 | 1,6 | 1130 | | 1300 | | 1260 | 800 | 430 |
| 648 | 68 | 10 | 2,061E-06 | 100 | 2,0 | 1130 | | 1300 | | 1270 | 850 | 430 |
| 672 | 67 | 10 | 1,975E-06 | 100 | 1,8 | 1150 | | 1300 | | 1280 | 830 | 430 |
| 696 | 65 | 10 | 1,916E-06 | 100 | 1,8 | 1150 | | 1300 | | 1320 | 850 | 430 |
| 720 | 60 | 10 | 1,768E-06 | 100 | 1,7 | 1150 | | 1300 | | 1330 | 840 | 430 |
| 744 | 62 | 10 | 1,827E-06 | 100 | 2,1 | 1150 | | 1300 | | 1310 | 880 | 430 |
| 768 | 64 | 10 | 1,913E-06 | 100 | 2,0 | 1140 | | 1300 | | 1320 | 870 | 430 |
| 792 | 60 | 10 | 1,768E-06 | 100 | 1,8 | 1150 | | 1300 | | 1330 | 860 | 430 |
| 816 | 60 | 10 | 1,781E-06 | 100 | 2,1 | 1145 | | 1300 | | 1310 | 880 | 430 |
| 840 | 61 | 10 | 1,798E-06 | 100 | 2,2 | 1150 | | 1300 | | 1320 | 900 | 430 |

The permeability of the system started high for the first 144 hours, ranging between 6.3 x $10^{-6}$ m/s and 1.0 x $10^{-5}$ m/s. A sharp decrease in permeability was observed from 360 hours which suggest fine soil particles moving into the filter causing partial clogging (fig 4.27). The system started being fairly constant from 432 hours until 840 hours where the test was terminated.

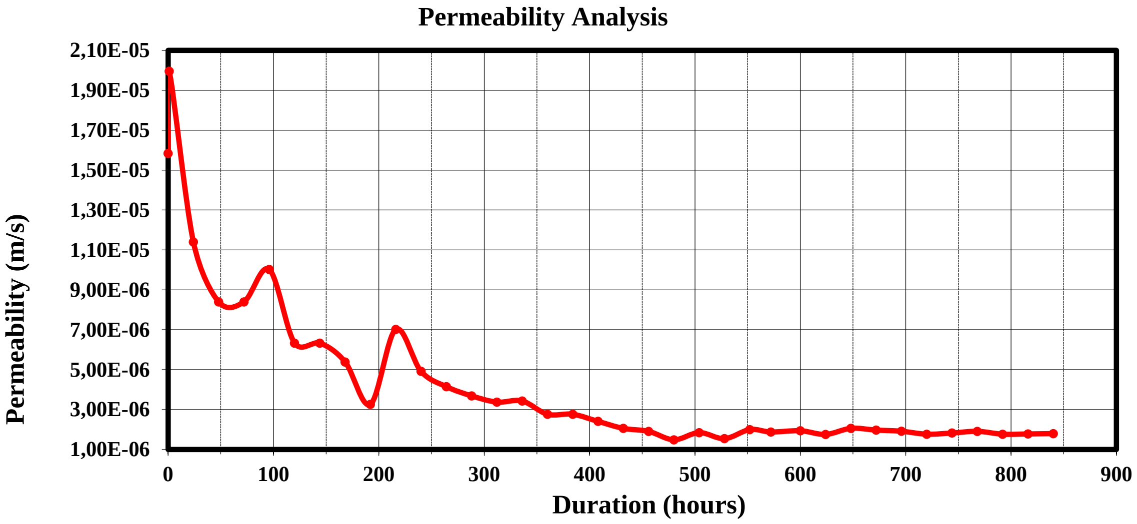


Figure 4.27: Permeability of the system (sandy gravel vs. bidim A6)

The gradient ratio of the system was recorded for the duration of the test and was observed to vary between 0.8 and 2.2 which indicates that the system was fairly permeable from the beginning but got slightly clogged towards the end of the test (fig 4.28). Bidim A6 has small pores and therefore, very little or no piping of fine particles was observed. This suggest that the reduction in permeability might have been caused by blinding.

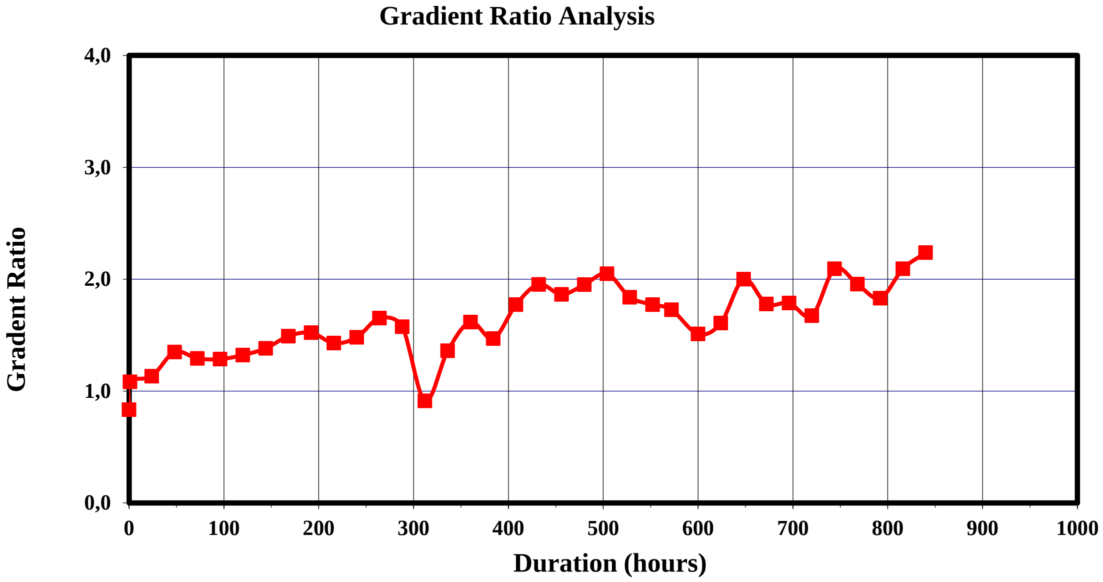


Figure 4.28: Gradient Ratio of the system (sandy gravel vs. bidim A6)

*(iv) Sandy Gravel Vs. Kaytape S120*

This test was run for a maximum of 480 hours and the results are summarized in Table 4.17. It was observed that there were significant fluctuations in water head in all the standpipes with the exception of standpipe 5 (outlet) that remained constant for the duration of the test (Table 4.17). The following variation was noted during the test:

Standpipe 1 fluctuated between 1140 and 1200 mm throughout. Standpipe 2 fluctuated between 1290 and 1340 mm. Standpipe 3 and 4 had fluctuations in head and this is usually caused by the “activity” in the soil-geotextile interface. Standpipe 3 water has varied between 770 and 1340 whilst standpipe 4 varied between 500 and 1000. Water head loss is usually caused by the reduction in pressure in the system due to an open filter allowing ease flow of water. Increase in water head is usually caused by clogging and blinding which increases pressure in the system. Standpipe 5 (outlet) remained constant at 430 mm throughout the test.

*Table 4.17: Long term gradient ratio results for sand gravel vs. Kaytape S120*

| Test Accumulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Gradient Ratio | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| 0 | 121 | 10 | 3,542E-06 | 100 | 0,5 | 1155 | | 1310 | | 770 | 500 | 430 |
| 1 | 98 | 10 | 2,829E-06 | 100 | 0,8 | 1165 | | 1320 | | 1260 | 660 | 430 |
| 24 | 72 | 10 | 1,984E-06 | 100 | 2,1 | 1200 | | 1340 | | 1330 | 890 | 430 |
| 48 | 72 | 10 | 1,984E-06 | 100 | 2,3 | 1200 | | 1340 | | 1330 | 910 | 430 |
| 72 | 60 | 10 | 1,654E-06 | 100 | 2,2 | 1200 | | 1340 | | 1330 | 900 | 430 |
| 96 | 68 | 10 | 1,874E-06 | 100 | 2,3 | 1200 | | 1340 | | 1320 | 910 | 430 |
| 120 | 119 | 10 | 3,280E-06 | 100 | 0,9 | 1200 | | 1340 | | 1330 | 700 | 430 |
| 144 | 53 | 10 | 1,520E-06 | 100 | 3,2 | 1170 | | 1310 | | 1320 | 980 | 430 |
| 168 | 51 | 10 | 1,406E-06 | 100 | 3,6 | 1200 | | 1340 | | 1320 | 1000 | 430 |
| 192 | 38 | 10 | 1,047E-06 | 100 | 2,9 | 1200 | | 1340 | | 1340 | 970 | 430 |
| 216 | 42 | 10 | 1,157E-06 | 100 | 3,6 | 1200 | | 1340 | | 1320 | 1000 | 430 |
| 240 | 22 | 10 | 6,575E-07 | 100 | 2,5 | 1140 | | 1290 | | 1330 | 930 | 430 |
| 264 | 14 | 10 | 4,184E-07 | 100 | 3,1 | 1140 | | 1290 | | 1330 | 980 | 430 |
| 288 | 16 | 10 | 4,782E-07 | 100 | 2,8 | 1140 | | 1290 | | 1340 | 960 | 430 |
| 312 | 45 | 10 | 1,345E-06 | 100 | 1,9 | 1140 | | 1290 | | 1320 | 860 | 430 |
| 336 | 44 | 10 | 1,315E-06 | 100 | 2,1 | 1140 | | 1300 | | 1250 | 850 | 430 |
| 360 | 42 | 10 | 1,255E-06 | 100 | 2,0 | 1140 | | 1300 | | 1240 | 830 | 430 |
| 384 | 41 | 10 | 1,225E-06 | 100 | 2,6 | 1140 | | 1300 | | 1220 | 880 | 430 |
| 408 | 36 | 10 | 1,076E-06 | 100 | 2,3 | 1140 | | 1300 | | 1210 | 850 | 430 |
| 432 | 31 | 10 | 9,265E-07 | 100 | 2,4 | 1140 | | 1300 | | 1200 | 850 | 430 |
| 456 | 32 | 10 | 9,564E-07 | 100 | 2,4 | 1140 | | 1300 | | 1200 | 850 | 430 |
| 480 | 31 | 10 | 9,265E-07 | 100 | 2,3 | 1140 | | 1300 | | 1220 | 850 | 430 |

The permeability of the system was fairly high in the first 24 hours, ranging between 2.829 x $10^{-6}$ m/s and 1.984 x $10^{-6}$ m/s. At 72 hours permeability decreased to 1.654 x $10^{-6}$ m/s. A sharp increase in permeability was observed at 120 hours which suggest that there might have been some fine particles piping through the filter (fig 4.29). Signs of filter blinding were observed between 264 and 288 hours where permeability was the lowest. The system started being constant at 432 hours and finally reached equilibrium at 480 hours.

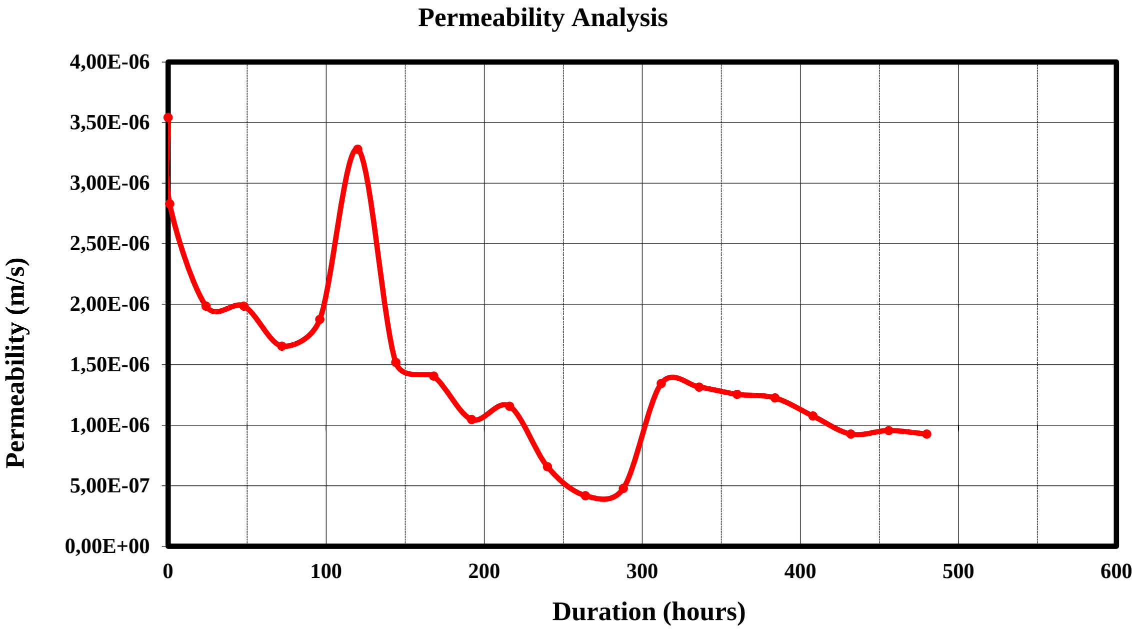


Figure 4.29: Permeability of the system (sand gravel vs. Kaytape S120)

The gradient ratio of the system was recorded for the duration of the test and was observed to vary between 0.5 and 3.6 which indicates that the system was partially blinded (fig 4.30).

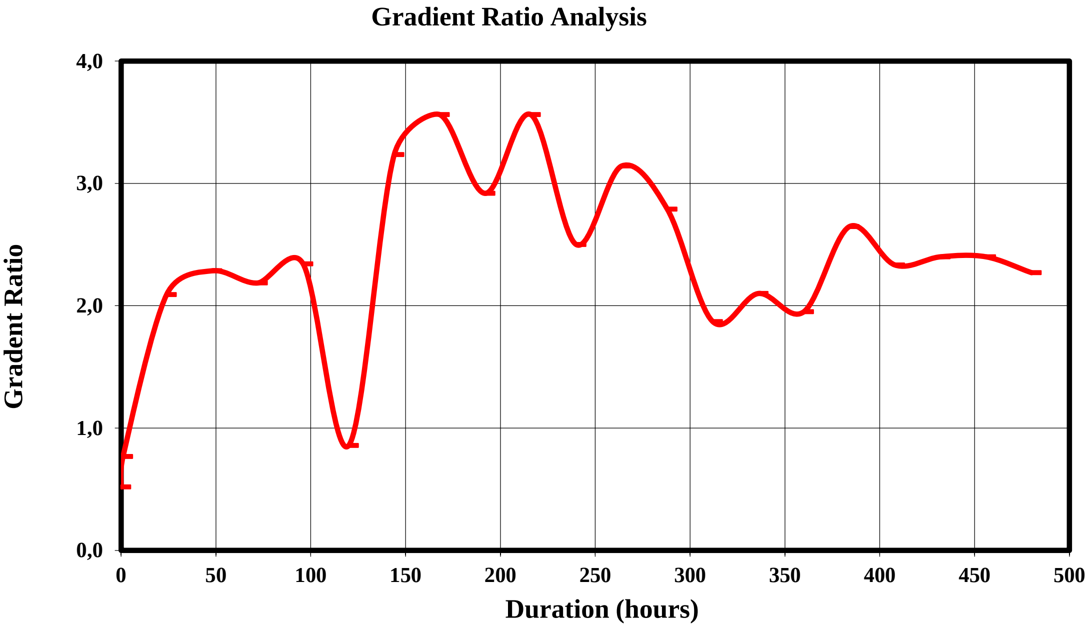


Figure 4.*30*: Gradient Ratio of the system (sand gravel vs. Kaytape S120)

*(v) Sandy Gravel Vs. Kaytape S270*

The test was run for 552 hours and the results are summarized in Table 4.18. Water head fluctuations were observed in all standpipes with an exception of standpipe 5 that remained constant at 430 mm throughout (Table 4.18). The following variation was noted during the test:

Water head at standpipe 1 fluctuated between 1140 and 1200 mm. Standpipe 2 was fairly constant between 1290 and 1340 mm. Standpipe 3 and 4 had fluctuations in head and this is usually caused by the “activity” in the soil-geotextile interface. Standpipe 3 water has varied between 600 and 1020 whilst standpipe 4 varied between 550 and 760. Water head loss is usually caused by the reduction in pressure in the system due to an open filter allowing ease flow of water. Increase in water head is usually caused by clogging and blinding which increases pressure in the system.

***Table 4.18: Long term gradient ratio results for sand gravel vs. Kaytape S270***

| **Test Accumulative Hours** | **Quantity ml** | **Duration min** | **Permeability k m/s** | **Sample Height mm** | **Gradient Ratio** | **Standpipe Readings - mm** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **1** | | **2** | | **3** | **4** | **5** |
| | | | | | | **300** | **250** | **200** | **150** | **100** | **50** | **0** |
| | | | | | | **Inlet** | | | | **Soil Sample** | | **Outlet** |
| *0* | *178* | *10* | *5,036E-06* | *100* | 0,8 | *1180* | | *320* | | *600* | *480* | *430* |
| *1* | *75* | *10* | *2,067E-06* | *100* | 1,4 | *1200* | | *650* | | *650* | *520* | *430* |
| *24* | *44* | *10* | *1,213E-06* | *100* | 2,0 | *1200* | | *1340* | | *670* | *550* | *430* |
| *48* | *40* | *10* | *1,102E-06* | *100* | 2,9 | *1200* | | *1340* | | *700* | *590* | *430* |
| *72* | *35* | *10* | *9,646E-07* | *100* | 3,3 | *1200* | | *1340* | | *720* | *610* | *430* |
| *96* | *38* | *10* | *1,047E-06* | *100* | 2,6 | *1200* | | *1340* | | *730* | *600* | *430* |
| *120* | *61* | *10* | *1,681E-06* | *100* | 3,3 | *1200* | | *1340* | | *750* | *630* | *430* |
| *144* | *60* | *10* | *1,721E-06* | *100* | 4,2 | *1170* | | *1310* | | *800* | *680* | *430* |
| *168* | *50* | *10* | *1,378E-06* | *100* | 3,8 | *1200* | | *1340* | | *780* | *660* | *430* |
| *192* | *40* | *10* | *1,102E-06* | *100* | 3,3 | *1200* | | *1340* | | *750* | *630* | *430* |
| *216* | *38* | *10* | *1,047E-06* | *100* | 2,9 | *1200* | | *1340* | | *800* | *650* | *430* |
| *240* | *34* | *10* | *1,016E-06* | *100* | 2,7 | *1140* | | *1290* | | *900* | *700* | *430* |
| *264* | *27* | *10* | *8,070E-07* | *100* | 2,8 | *1140* | | *1290* | | *1000* | *760* | *430* |
| *288* | *22* | *10* | *6,575E-07* | *100* | 2,5 | *1140* | | *1290* | | *1020* | *760* | *430* |
| *312* | *35* | *10* | *1,046E-06* | *100* | 2,6 | *1140* | | *1290* | | *1010* | *760* | *430* |
| *336* | *35* | *10* | *1,046E-06* | *100* | 2,9 | *1140* | | *1300* | | *990* | *760* | *430* |
| *360* | *26* | *10* | *7,771E-07* | *100* | 3,1 | *1140* | | *1300* | | *970* | *760* | *430* |
| *384* | *27* | *10* | *8,070E-07* | *100* | 3,4 | *1140* | | *1300* | | *955* | *760* | *430* |
| *408* | *25* | *10* | *7,472E-07* | *100* | 3,9 | *1140* | | *1300* | | *930* | *760* | *430* |
| *432* | *22* | *10* | *6,575E-07* | *100* | 3,7 | *1140* | | *1300* | | *940* | *760* | *430* |
| *456* | *23* | *10* | *6,874E-07* | *100* | 3,5 | *1140* | | *1300* | | *950* | *760* | *430* |
| *480* | *22* | *10* | *6,575E-07* | *100* | 3,9 | *1140* | | *1300* | | *930* | *760* | *430* |
| *504* | *21* | *10* | *6,277E-07* | *100* | 3,7 | *1140* | | *1300* | | *940* | *760* | *430* |
| *528* | *20* | *10* | *5,978E-07* | *100* | 3,5 | *1140* | | *1300* | | *950* | *760* | *430* |
| *552* | *21* | *10* | *6,277E-07* | *100* | 3,7 | *1140* | | *1300* | | *940* | *760* | *430* |

Permeability of the system started high in the first 24 hours, ranging between 5.036 x $10^{-6}$ m/s and 1.213 x $10^{-6}$ m/s before fine particles were washed into the filter interface. After 24 hours a decreased in permeability was observed as fine soil particles started to cause blinding in the soil-filter interface. The permeability of the system was fairly constant from 360 hours at 7.771 x 10-7 m/s until it reached equilibrium at 552 hours (fig 4.31).

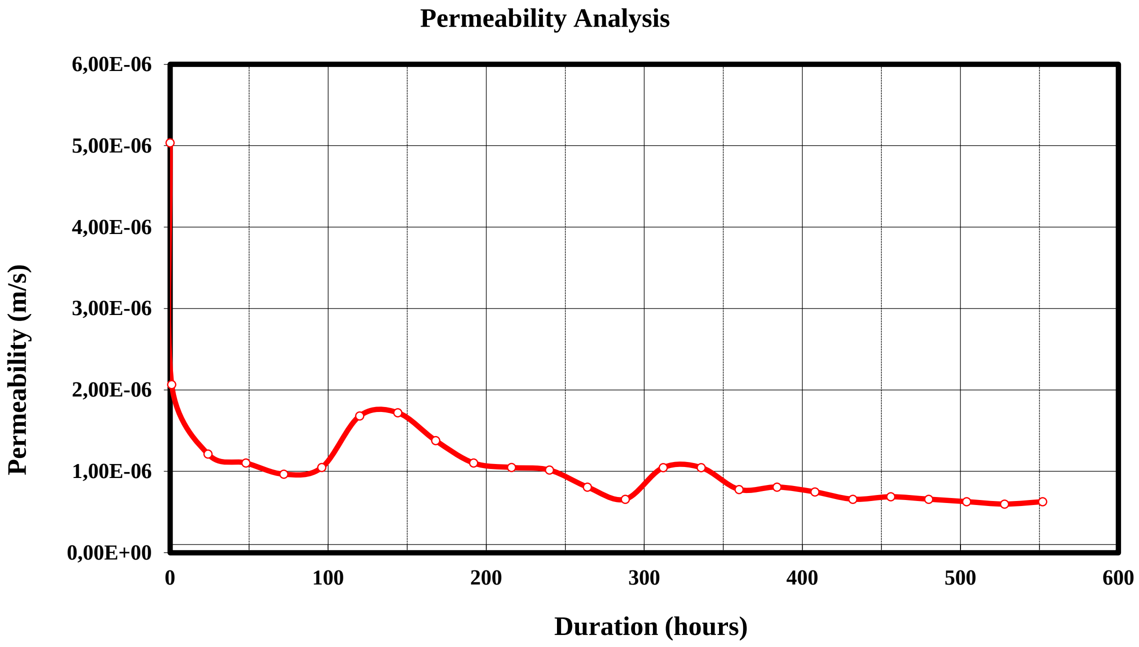


Figure 4.31: Permeability of the system (sand gravel vs. Kaytape S270)

The gradient ratio of the system started low at the beginning of the test varying between 0.8 and 1.4. GR then increased after 24 hours to 2 and continued increasing which suggest that the system was either partially clogging or blinding (fig 4.32). The highest GR was observed at 144 hours.

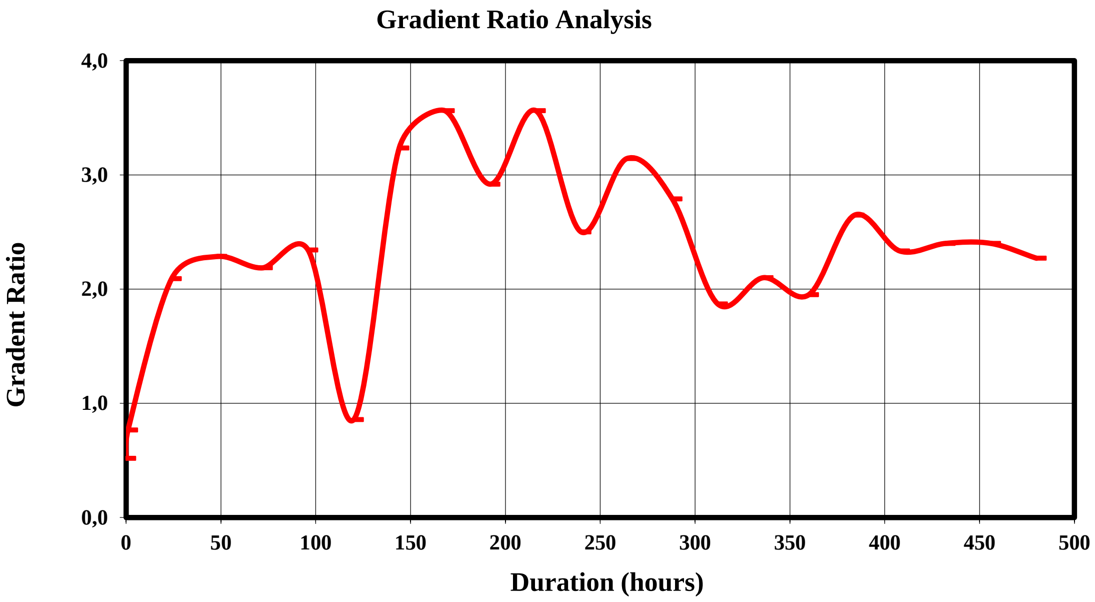


Figure 4.32: Gradient Ratio of the system (sand gravel vs. Kaytape S270)

## 4.3 Analysis

The criteria listed in paragraph 2.6.1 for geotextile filters is used to evaluate and compare the results from the different laboratory systems using the three soil types and four different geotextiles.

*Permeability Criterion*

According to Giroud (2010), permeability of the filter should be greater or equals to that of the base soil as expressed by equation 4.1 below.

$$K_f \geq K_s \qquad (4.1)$$

*Where*:

$K_f$ is the permeability of the filter and Ks is the permeability of the base soil

Table 4.19 below compares the permeabilities of the three soils and five geotextiles tested for the purpose of this study. All the geotextiles have higher permeability than the soils and therefore satisfy equation 4.1.

***Table 4.19: Permeabilities of soils vs permeabilities of geotextiles***

| Soils | Permeability (cm/s) | Geotextiles | Permeability (m/s) |
|---|---|---|---|
| **Clayey Silt** | $9.81 \times 10^{-10}$ | **Bidim A2** | $4.7 \times 10^{-3}$ |
| **Clayey Sand** | $4.47 \times 10^{-9}$ | **Bidim A4** | $4.2 \times 10^{-3}$ |
| **Sandy Gravel** | $4.54 \times 10^{-8}$ | **Bidim A6** | $3.9 \times 10^{-3}$ |
| | | **Kaytape S120** | $2.0 \times 10^{-4}$ |
| | | **Kaytape S270** | $4.25 \times 10^{-4}$ |

*Retention Criterion*

Retention criterion takes into account coefficient of uniformity and internal stability of the base soil.

Sherard (1984) developed guidelines for evaluating internal stability of soil based on coefficient of uniformity. Calculations of the coefficient of uniformity (Cu) and coefficient of curvature (Cc) of the soils are shown in table 4.20 below including comment on their internal stability. Clayey silt and clayey sand do not have $D_{10}$ particle sizes and therefore internal stability could not be calculated based on Cu and Cc.

Coefficient of uniformity was calculated using the formula: $Cu = D_{60}/D_{10}$

Coefficient of curvature was calculated using the formula: $Cu = (D_{30})^2/D_{10} \text{ x } D_{60}$

***Table 4.20: Coefficient of uniformity, coefficient of curvature and internal stability of soils as per Sherard 1984***

| Soil Type | $D_{10}$ (mm) | $D_{30}$ (mm) | $D_{60}$ (mm) | Coefficient of uniformity (Cu) | Coefficient of curvature (Cc) | Well graded? | Internally stable? |
|---|---|---|---|---|---|---|---|
| **Clayey Silt** | - | 0.0035 | 0.030 | - | - | - | - |
| **Clayey Sand** | - | - | 0.082 | - | - | - | - |
| **Sandy Gravel** | 0.045 | 0.0035 | 7.80 | 173.3 | 1.82 | Yes | No |

A soil with a high coefficient of uniformity and a coefficient of curvature of between 1 and 3 is regarded as "well-graded". Sandy gravel satisfies these conditions, however, it does not satisfy the condition for internally stable soils.

A filter should have opening sizes enough to allow easy flow of water and retain particles of the base soil. The five geotextiles tested have a soil retention of at least 99% as per Tables 4.21, 4.22 and 4.23 and satisfy the retention criterion.

Performance of the geotextiles are measured against the system permeabilities and their respective gradient ratios. All gradient ratio tests started with high system permeabilities which reduced over time due to fine particle migration on and into the filter causing blinding, clogging and sometimes piping. All the tests with Zone 1 and Zone 2 soils show partial clogging at the end of the test suggesting that had the test been carried out for longer, the possibility of the filter being completely clogged cannot be ruled out. Tests with Zone 3 soils suggest that the system started with high permeabilities but decreased slightly during the formation of a filter bridge which resulted in a constant but significantly high flow. Zone 3 soil with Kaytape S120 and S270 are exceptions to the above because the reduction in permeability over time is indicative of partial clogging. In general, woven and non-woven filtration grade geotextile would function optimally with soils that contain lower clay and silt fractions. Sand and gravel particles are the fractions responsible for the formation of a filter bridge and hold back finer particle sizes. Fig 4.33 shows permeabilities for all the tests conducted with a comparison of the performances of the five geotextiles with the three soil types. A total of 15 soil-geotextile systems were tested and it was observed from the results that the best performers are Sandy Gravel/A2 and Sandy Gravel/A4 (fig 4.33)

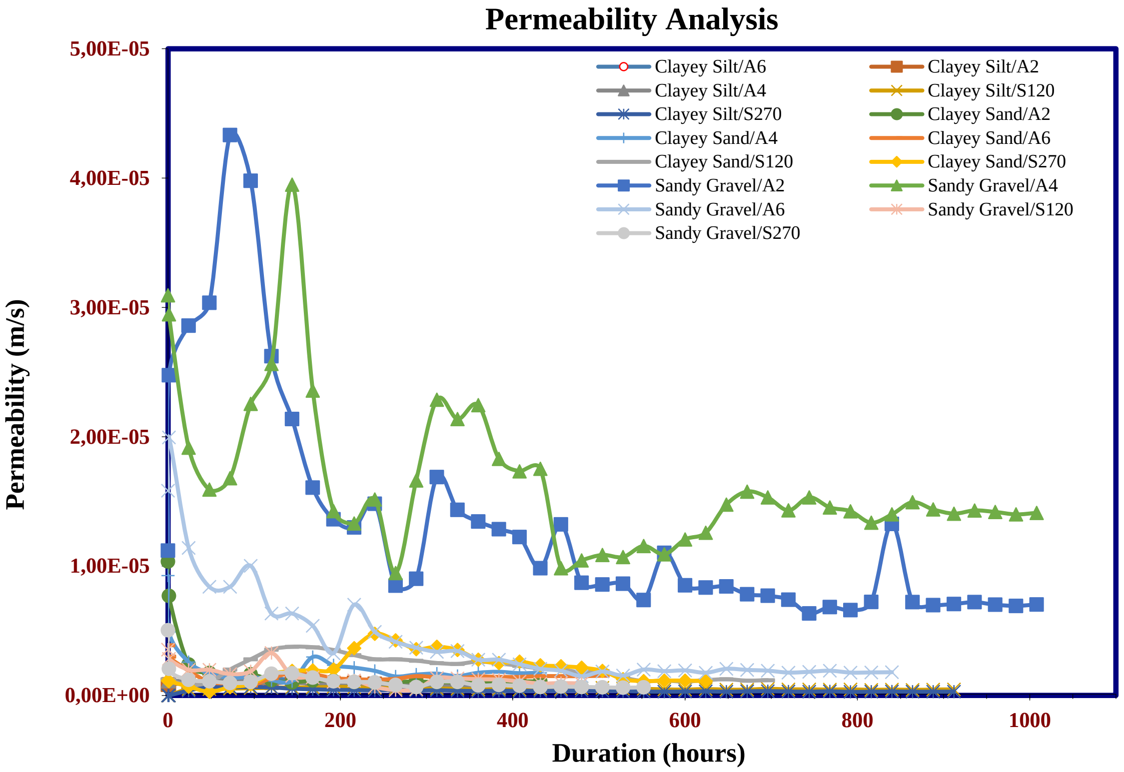


Figure 4.33: Permeability of the systems for all the tests

Figure 4.34 shows the gradient ratios of the different tests. The solid straight green line represents the preferred gradient ratio as per ASTM D5101 and it can be interpreted as follows:

- A gradient ratio of one is an indication that some soil particles have migrated towards and moved through the filter resulting in the formation of a filter bridge.
- A continued decrease in gradient ratio indicates movement of fine soil particles through the filter in a process known as piping and may require further evaluation. This is

common in geotextiles with large pore sizes like the Bidim A2 especially when the base soil contains fine clay and silt particles.

- A gradient ratio of more than one is indicative of flow reduction and clogging. This can also be favourable if the system reaches equilibrium before it is fully clogged which result in a slow but steady flow. From the 15 soil-geotextile systems, Sandy Gravel/A2 and Sandy Gravel/A4 stayed below the GR line for the duration of the test. All the other systems either started below the line and finished above or started above and finished above.

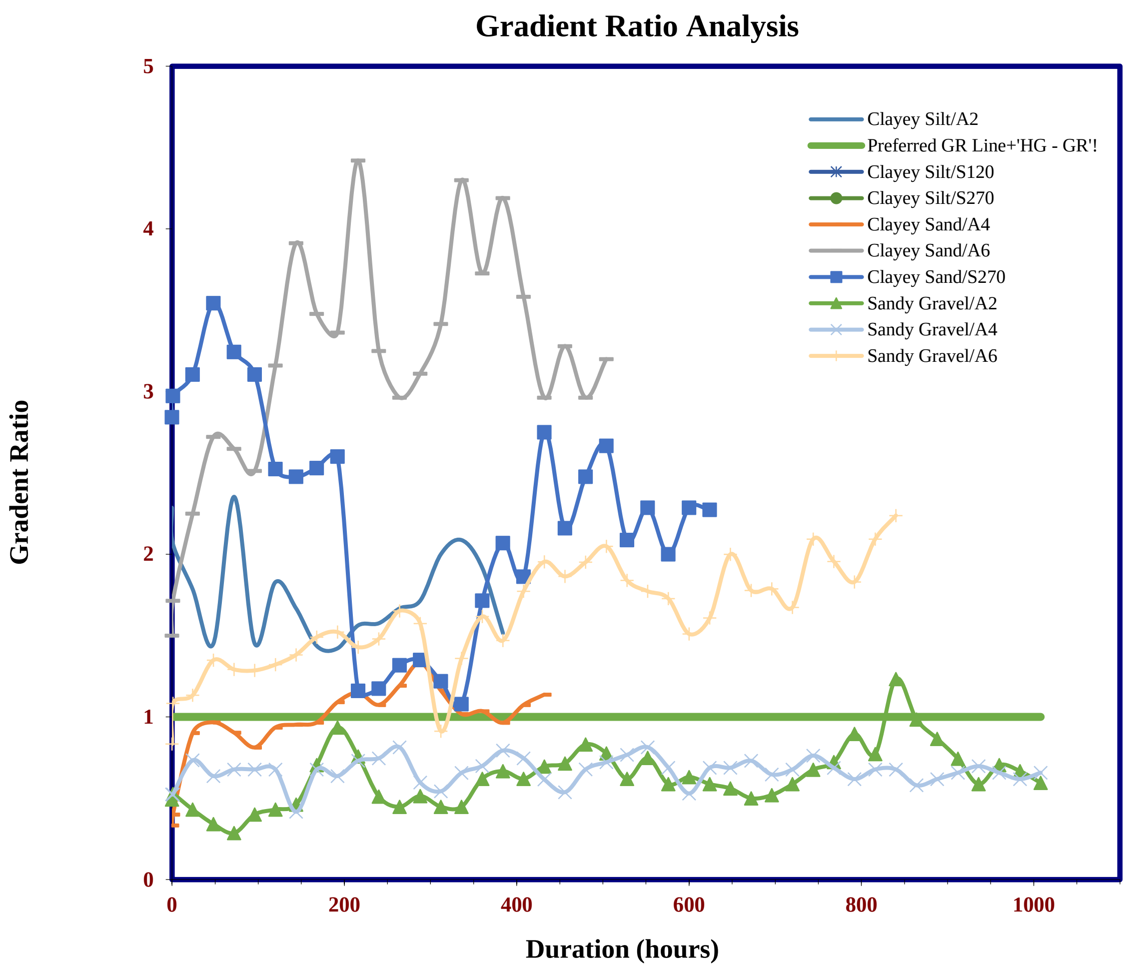


Figure 4.34: Gradient ratio of the system for a few selected tests

In conclusion, a gradient ratio of less than one can sometimes lead to excessive piping which results in loss of fine particles, whilst a GR of more than one can lead to clogging. In both of the cases above if the filter reaches equilibrium and remains permeable, then it satisfy design requirements. Therefore, even though performance testing make it easy to select a filter for a given soil type, it is difficult to predict the future performance of the filter.

### Problematic Soil Particle Sizes

In any sub-soil drainage environment, the base soil particle size distribution is always a challenge when it comes to selecting the best filter that will perform optimally without completely clogging or blinding.

Tables 4.21, 4.22 and 4.23 show masses of the soils and geotextiles at the start and end of the tests. These masses are used to determine filter soil retention. Filter soil retention is one of the most important parameter in deciding on the best filter for a given filtration application.

### Soil Zone 1 – Clayey Silt

***Table 4.21: Masses of soil samples and geotextiles before and after test for zone 1***

| Geotextile | Mass soil sample used (g) | Mass of soil sample after test (g) | Mass Geotextile Before test (g) | Mass Geotextile After test (g) | Material entrapped in the geotextile (g) | Material lost during de-assembly (g) | Mass soil caught on filter paper (g) | Soil retained by filter (%) |
|---|---|---|---|---|---|---|---|---|
| ***Bidim A2*** | 908.1 | 897.55 | 2.40 | 5.78 | 3.38 | 5.11 | 2.06 | 99.8 |
| ***Bidim A4*** | 930.0 | 914.69 | 3.40 | 6.95 | 3.55 | 10.32 | 1.44 | 99.8 |
| ***Bidim A6*** | 1017.3 | 1010.47 | 5.80 | 7.71 | 1.91 | 4.62 | 0.30 | 99.9 |
| ***S120*** | 1105.6 | 1101.45 | 3.70 | 4.23 | 0.53 | 3.11 | 0.51 | 99.6 |
| ***S270*** | 943.2 | 940.16 | 3.90 | 4.37 | 0.47 | 2.07 | 0.50 | 99.7 |

### Soil Zone 2 – Clayey Sand

***Table 4.22: Masses of soil samples and geotextiles before and after test for zone 2***

| Geotextile | Mass soil sample used (g) | Mass of soil sample after test (g) | Mass Geotextile Before test (g) | Mass Geotextile After test (g) | Material entrapped in the geotextile (g) | Material lost during de-assembly (g) | Mass soil caught on filter paper (g) | Soil retained by filter (%) |
|---|---|---|---|---|---|---|---|---|
| ***Bidim A2*** | 1203.4 | 1196.40 | 2.90 | 5.39 | 2.49 | 3.01 | 1.50 | 99.9 |
| ***Bidim A4*** | 1214.7 | 1204.74 | 3.80 | 7.50 | 3.70 | 5.52 | 0.74 | 99.9 |
| ***Bidim A6*** | 1165.3 | 1161.67 | 5.30 | 7.16 | 1.86 | 1.50 | 0.27 | 99.9 |
| ***S120*** | 1035.3 | 1028.23 | 3.50 | 4.14 | 0.64 | 6.33 | 0.10 | 99.9 |
| ***S270*** | 1042.9 | 1039.4 | 4.00 | 4.41 | 0.41 | 2.95 | 0.14 | 99.9 |

### Soil Zone 3 – Sand Gravel

***Table 4.23: Masses of soil samples and geotextiles before and after test for zone 3***

| Geotextile | Mass soil sample used (g) | Mass of soil sample after test (g) | Mass Geotextile Before test (g) | Mass Geotextile After test (g) | Material entrapped in the geotextile (g) | Material lost during de-assembly (g) | Mass soil caught on filter paper (g) | Soil retained by filter (%) |
|---|---|---|---|---|---|---|---|---|
| ***Bidim A2*** | 1181.2 | 1174.72 | 2.70 | 5.80 | 3.10 | 2.57 | 0.81 | 99.9 |
| ***Bidim A4*** | 1157.6 | 1146.07 | 3.65 | 5.85 | 2.20 | 9.11 | 0.22 | 99.9 |
| ***Bidim A6*** | 1168.5 | 1163.46 | 5.34 | 7.60 | 2.26 | 2.78 | 0.0 | 100 |
| ***S120*** | 1227.5 | 1224.48 | 3.60 | 4.10 | 0.50 | 2.52 | 0.0 | 100 |

| Geotextile | Mass soil sample used (g) | Mass of soil sample after test (g) | Mass Geotextile Before test (g) | Mass Geotextile After test (g) | Material entrapped in the geotextile (g) | Material lost during de-assembly (g) | Mass soil caught on filter paper (g) | Soil retained by filter (%) |
|---|---|---|---|---|---|---|---|---|
| ***S270*** | 1205.7 | 1201.96 | 3.90 | 4.30 | 0.40 | 3.24 | 0.10 | 99.9 |

### Particle Size Analysis

Soil particle diameter and pore opening size of geotextiles are used in the determination of the range of problematic sizes in the soil gradation curve. Particles passing the 0.075 mm sieve (silt and clay) are commonly referred as problematic in sub-soil drainage systems as they tend to clog, block or blind geotextile filters. In this section, results from scanning electron microscope of the different geotextiles will be discussed and analysed in detail.

#### *Clayey Silt (Zone 1)*

This soil type has a higher clay/silt fraction than the other two soils and therefore would be considered "problematic". With a clay fraction of 31% and a silt fraction of 50%, the soil has 81% of particles less than 75 µm which are responsible for blocking and piping through the filter. Scanning electron microscope images taken at different magnifications showing soil particles entrapped in the fibres of the geotextile are presented in the following figures. Figure 4.35 shows an entrapped soil particle of approximately 80 – 100 µm in diameter in the Bidim A2 geotextile. The distance between individual fibres suggest that the geotextile has large pore openings and it may be prone to soil particles clogging and even piping through.

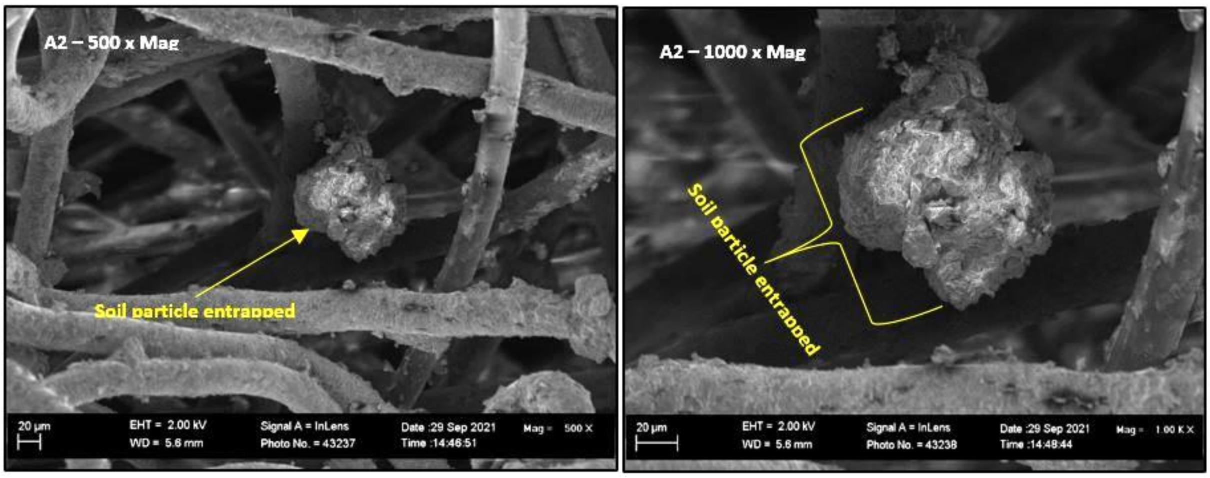


Figure 4.35: Scanning electron microscope images of the Bidim A2 zoomed at 500x magnification on the right and 1000x magnification on the left showing entrapped soil particle

Figure 4.36 shows Bidim A4 geotextile with denser fibre structure and an entrapped particle with an approximate diameter of 100 µm which is slightly larger than the one shown in figure 4.35. Bidim A4 has a pore size of 136 µm and is less prone to clogging and piping than Bidim A2 with a pore size of 175 µm.

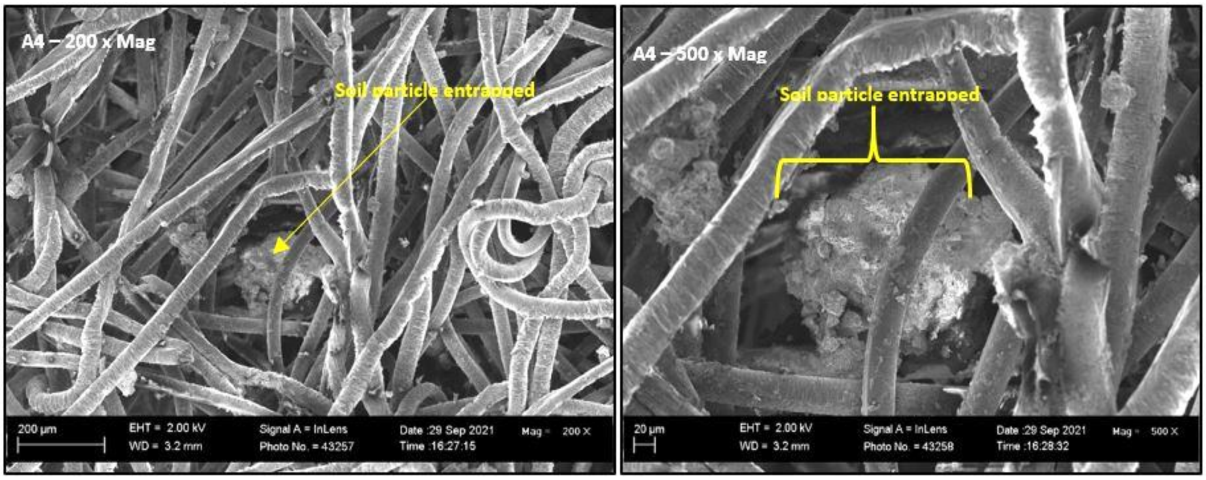


Figure 4.36: Scanning electron microscope images of the Bidim A4 zoomed at 200x magnification on the right and 500x magnification on the left showing entrapped soil particle

Bidim A6 has the most densely packed fibre structure compared to A2 and A4. The pore size is 128 µm that is less prone to clogging and piping than the other two. The particle diameter shown in figure 4.37 is approximately 50 – 60 µm in diameter.

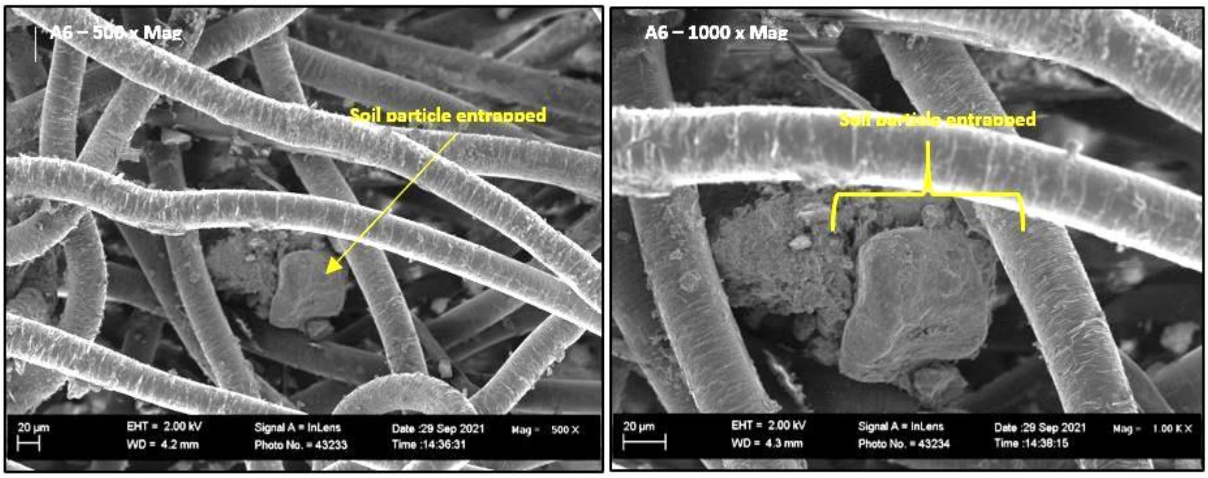


Figure 4.37: Scanning electron microscope images of the Bidim A6 zoomed at 500x mag on the right and 1000x mag on the left showing entrapped soil particle.

### *Clayey Sand*

This soil type has a less clay and silt fraction than Clayey Silt and would be less problematic. The 50% sand fraction would assist in the formation of a filter bridge and prevent the fraction with diameter of 75 µm and less from blocking or piping through the filter. Figure 4.38 shows microscope images of Bidim A2 zoom at 500x and 200x magnification and at different positions on the geotextile. The images shows entrapped soil particles of approximately 120 µm (left) and 160 – 180 µm (right). The particle diameter on the right is the largest size that the pores of the geotextile can take, anything more than 175µm should be retained.

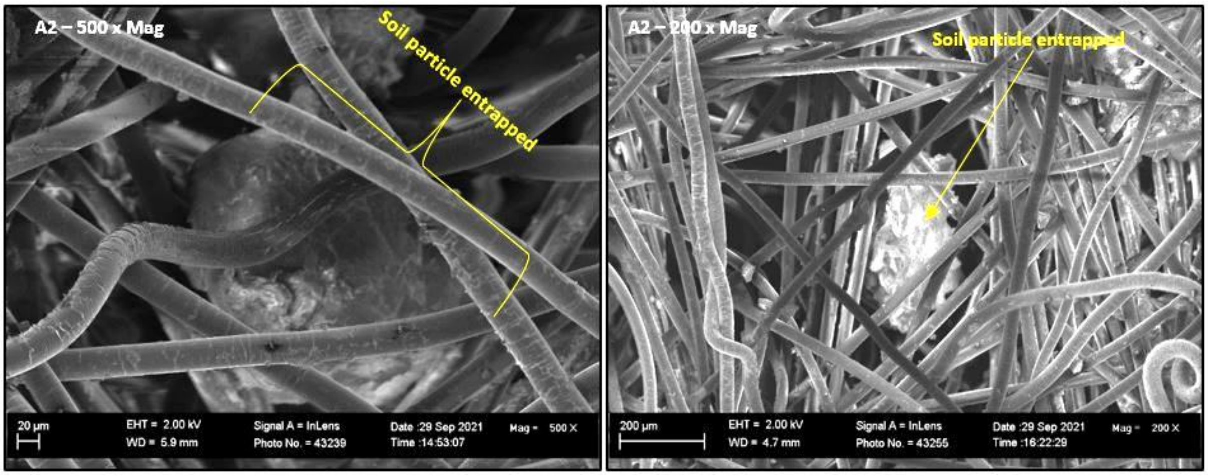


Figure 4.38: Scanning electron microscope images of the Bidim A2 zoomed at 500x magnification on the right and 200x mag on the left showing entrapped soil particle. Images takes at different positions.

Figure 4.39 shows images of Bidim A4 zoomed at 200x (left) and 500x (right) magnification. The particle size is approximately 120 – 130 µm and with a pore size of about 136 µm, this could be the largest particle size that the geotextile can accommodate.

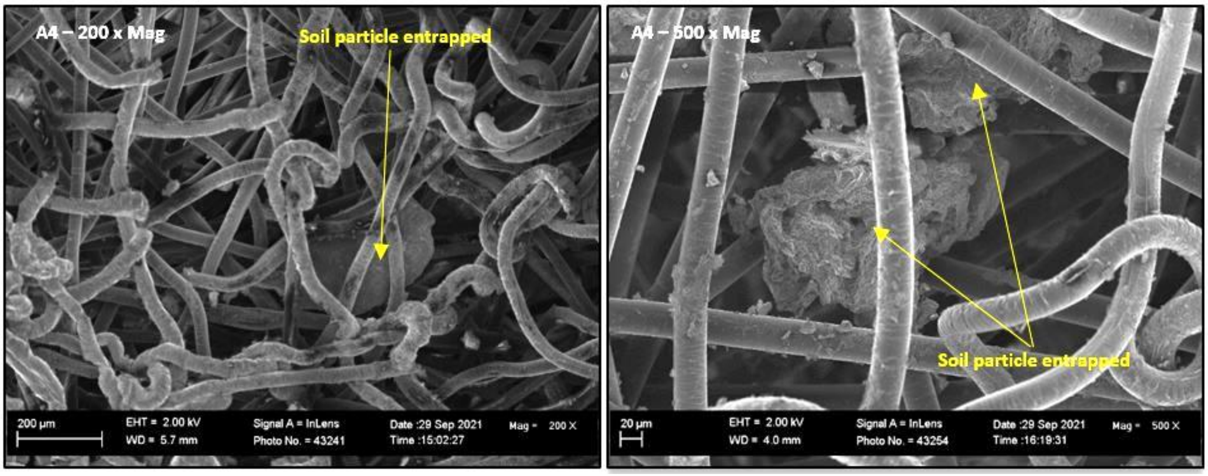


Figure 4.39: Scanning electron microscope images of the Bidim A4 zoomed at 200x magnification on the right and 500x magnification on the left showing entrapped soil particle. Images takes at different positions.

Images for Bidim A6 are shown in figure 4.40 and there are minimal particles that were partially clogged or entrapped in the geotextile. Evidence of the particles entrapped after the test was recorded by a slight increase in weight of the geotextile after the test.

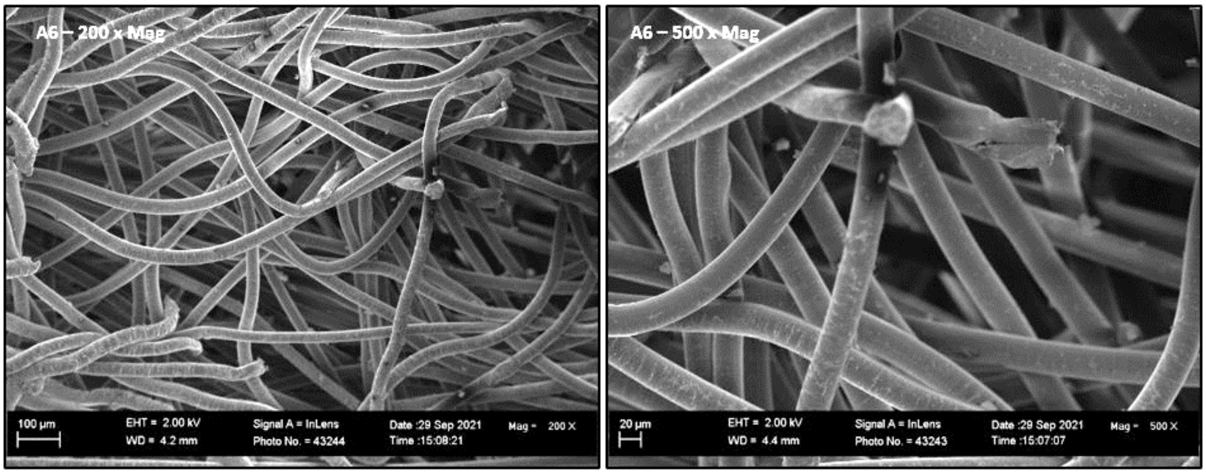


Figure 4.40: Scanning electron microscope images of the Bidim A6 zoomed at 200x magnification on the right and 500x magnification on the left.

*Sandy Gravel*

Sandy Gravel has higher gravel and sand content than silt and clay. This would be considered the least problematic soil in filtration and drainage due to a lower potential to cause any clogging, blinding or piping. The sand and gravel form a filter bridge and retain the fine particles preventing them from reaching the geotextile-soil interface. The images in figure 4.41 show 200x magnification of Bidim A2. The image on the left doesn't have any particles entrapped whilst the image on the right indicates a particle of approximately 100 µm. This particle completely blocks the constriction or path whereby soil particles travel through the geotextile.

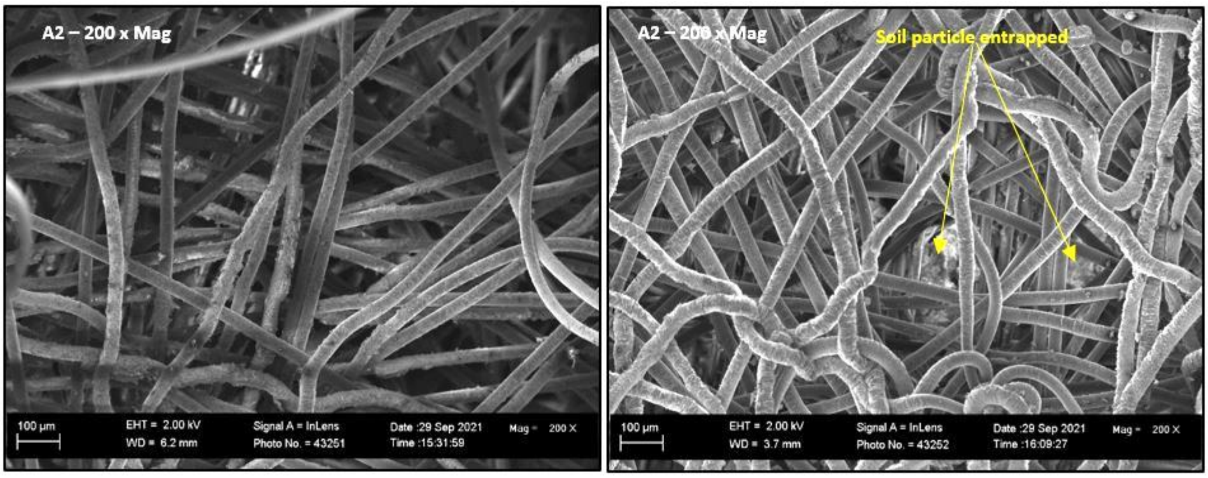


Figure 4.41: Scanning electron microscope images of the Bidim A2 both zoomed at 200x. Right image showing entrapped soil particle.

Microscopic images in figure 4.42 show Bidim A4 zoomed at 200x and 500x magnifications with no evidence of particles entrapped although the weight of the filter after the test suggests a small percentage of particles was actually entrapped.

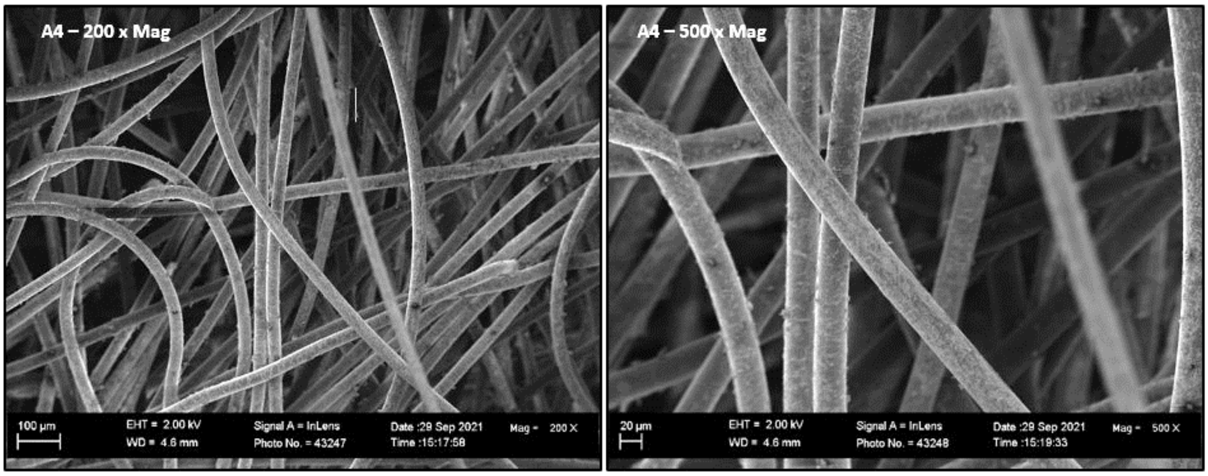


Figure 4.42: Scanning electron microscope images of the Bidim A4 zoomed at 200x mag on the right and 500x mag on the left.

Since the A6 has a dense fibre structure and small pore opening size, it is less prone to clogging and piping as shown in figure 4.43. Sandy gravel has a small clay/silt ratio and therefore would be less likely to cause any clogging nor piping.

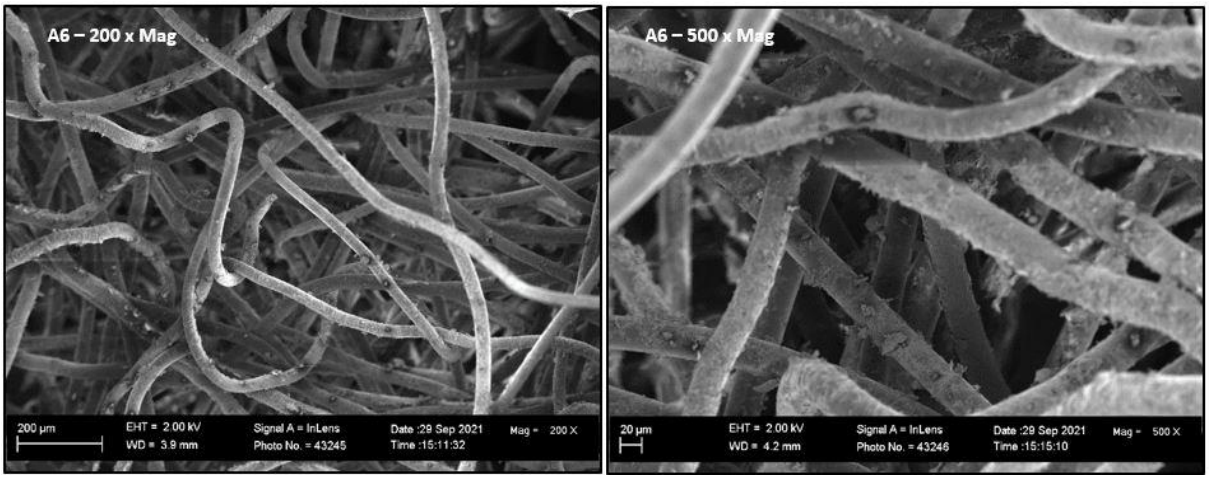


Figure 4.43: Scanning electron microscope images of the Bidim A6 zoomed at 200x magnification on the right and 500x magnification on the left.

Clayey silt and clayey sand have a significant amount of clay/silt fraction which tend to blind, block or cause piping in most geotextiles with large pore sizes like the A2, A4 and sometimes the A6. However, from the electron microscope images above it is clear that particles with diameter of 100 µm or less are the most problematic. This is inconclusive because only a small portion of the geotextiles were cut out for microscopic evaluation and may not be representative of the whole sample but do give an indication of the range of problematic particle sizes..

Woven tapes (S120 and S270) were not analysed through the microscope due to their relatively flat structure that may obscure the structure and entrapped particles.

# CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

This research encompassed an experimental study of three different soil types in combination with five different "filtration grade" geotextiles in a fixed wall permeameter test, formally known as Long Term Gradient Ratio test (ASTM D5101). The test proved to be reliable in providing insight on the determination of soil-geotextile compatibility, problematic soil particle sizes and associated clogging mechanisms, effect of time on the performance of geotextiles, and the influence of coefficient of uniformity of soils on geotextile selection.

The main conclusions drawn from the test results and analysis are summarized as follows:

- Gradient ratio (GR) cannot be used in isolation to evaluate performance of geotextile filters. Higher or lower GR values may indicate positive or negative results depending on site conditions. In all the tests conducted in this study, no geotextile was completely clogged, however, some tests showed gradient ratios of more than 3 which is usually an indication of a severe case of clogging (fig 4.34). Two tests that yielded gradient ratios of less than 1 are sandy gravel (Zone 3 soil) combined with Bidim A2 and A4. The permeabilities of these tests were also significantly higher compared to rest. The sandy gravel/A2 and sandy gravel/A4 soil-geotextile combination were the best performers and no long term clogging was foreseen. Although the other systems were not completely clogged, there is no guarantee for the long term performance of these systems.
- Soil particle sizes in the range 200 – 80 µm could potentially cause clogging on filters with pore opening sizes of between 130 and 180 µm whilst particles of sizes of 80 µm and less can cause blocking or piping through the filter.
- Soils with high percentage of fine clay and silt sized particles are the most problematic in filtration and drainage environments, however, even though coarse or gravelly soils are regarded less problematic, they are more susceptible to internal erosion and can loose a significant amount of the finer particle sizes making it unstable. It is evident from systems paired with clayey silt and clayey sand that fine soil particles causes a reduction in permeability which can ultimately lead to clogging. There was no severe case of piping observed in any of the systems.
- Coefficient of uniformity (CU) calculated for the sandy gravel suggests that the soil is internally unstable and susceptible to internal erosion which can lead to piping of fine grained soil particles.

- Most of the tests showed partial clogging conditions with very high gradient ratios and no guarantee can be made as to the long term effect of the soil on the filter. All the systems reached equilibrium, however, this does not guarantee long term performance of the systems. Table 5.1 summarizes the overall performance of the different systems.

***5.1: Summary of the performance of soil-geotextile systems***

| Soil-Geotextile System | Duration of Test (hours) | Clogging? | Overall Performance |
|---|---|---|---|
| Clayey silt/A2 | 384 | Partially clogged | Poor |
| Clayey silt/A4 | 384 | Partially clogged | Poor |
| Clayey silt/A6 | 384 | Partially clogged | Poor |
| Clayey silt/S120 | 912 | Partially clogged | Poor |
| Clayey silt/S270 | 912 | Partially clogged | Poor |
| Clayey sand/A2 | 432 | Partially clogged | Poor |
| Clayey sand/A4 | 432 | Partially clogged | Poor |
| Clayey sand/A6 | 432 | Partially clogged | Poor |
| Clayey sand/S120 | 552 | Partially clogged | Poor |
| Clayey sand/S270 | 552 | Partially clogged | Poor |
| Sandy gravel/A2 | 1008 | No clogging | Very good |
| Sandy gravel/A4 | 1008 | No clogging | Very good |
| Sandy gravel/A6 | 840 | Partially clogged | Poor |
| Sandy gravel/S120 | 432 | Partially clogged | Poor |
| Sandy gravel/S270 | 432 | Partially clogged | Poor |

- Although the pore sizes of the A2 and A4 are larger than the most dominant particle size of the three soils; clayey sand/A2, clayey silt/A2, clayey sand/A4 and clayey silt combinations yielded poor performance in terms of their permeabilities and gradient ratios. This is an unusual case because clay and silt sized particles would have piped through the system and this might have resulted in high permeability and a loss of particles. The loss of fine soil particles can leave voids in the remaining larger particles and ultimately resulting in collapse of the soil structure (Zornberg and Christopher, 2007). However, it is suspected that the fine clay sized particles might have caused blinding on the surface of the filter with some causing partial clogging in the filter.
- System permeabilities generally for all the tests started high and decreased with time which is indicative of fine particles migration into the filter and causing blinding or partial clogging. However, not all fine particle migrating into the filter causes partial clogging or blinding, some only partially reduces the permeability of the filter but does not cause any of these mechanisms. Evidence can be seen from the two best performing systems (sandy gravel/A2 and sandy gravel/A4), their flows started very high and

decreased to a fairly constant flow over time. Their gradient ratios also remained below 1.

- The larger the pores of a geotextile the more the risk of piping and partial clogging. The smaller the pores the more the risk of blinding and sometimes clogging.
- Every application is unique and no paper or research can guarantee performance of a filter if no test was conducted with the specific soil. Furthermore, results from a filtration test does not guarantee future or long term performance of the filter as the information is limited to the duration of which the was run.

## Recommendations

Due to every filtration and drainage environment being unique they should be treated differently. It is nearly impossible to predict the interaction between a certain soil type and a geotextile without laboratory performance tests, especially those soils with high clay/silt fractions. Furthermore, soils with high susceptibility to internal erosion, gap graded soils and internally unstable soils are some of the most problematic and should be treated with care in critical applications such as filtration and drainage. Performance tests should always be carried out to determine soil-geotextile filtration behaviour and assist in the selection of the optimal filter for a given filtration or drainage application.

The results reported in this dissertation are based on gradient ratio tests conducted on a limited number of geotextiles and soil samples. More research is needed to better understand the behaviours of soils and geotextiles in filtration and drainage applications. The longest test carried out was 1008 hours and it is recommended that longer tests be carried out to determine the effect of time on the filtration behaviour of geotextiles. However, this study made it possible to better understand problem soils for planning and design of subsoil drainage systems.

Further recommendation for future studies is to include the effect of compaction of the base soil on its permeability and also the chemistry (more especially pH) of the base soil.

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# APPENDICES

**APPENDIX A**: Laboratory Results – Zone 1 Soil (Clayey Silt Vs Bidim A2)
**APPENDIX B**: Laboratory Results – Zone 1 Soil (Clayey Silt Vs Bidim A4)
**APPENDIX C:** Laboratory Results – Zone 1 Soil (Clayey Silt Vs Bidim A6)
**APPENDIX D**: Laboratory Results – Zone 1 Soil (Clayey Silt Vs S120)
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# APPENDIX A

## Laboratory Results – Zone 1 Soil (Clayey Silt Vs Bidim A2)

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## LONG TERM GRADIENT RATIO TEST REPORT

# Permeameter Summary

### GL Test Method 1 (Adapted from Kaytech Engineerred Fabrics)

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A2 - Zone 1* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *28-Jun-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *15-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A2* |
| | | **Soil Sample** | *Clayey Silt* |

| | | | | |
|---|---|---|---|---|
| **Equipment** | *GL MK1 Permeameter* | | **Support Above** | *none* |
| **Internal Diameter** | *100mm* | | **Support Below** | *wire mesh* |
| **Wetting Up** | *Below* | | **Preparation** | *Oven Dried* |
| | **Mass @ Start (g)** | **Mass @ Finish (g)** | **Thickness (mm)** | **k estimate** |
| **Geosynthetic** | *2,40* | *5.78* | *1.69* | |
| **Soil Sample** | *908,10* | *897.55* | *120* | |

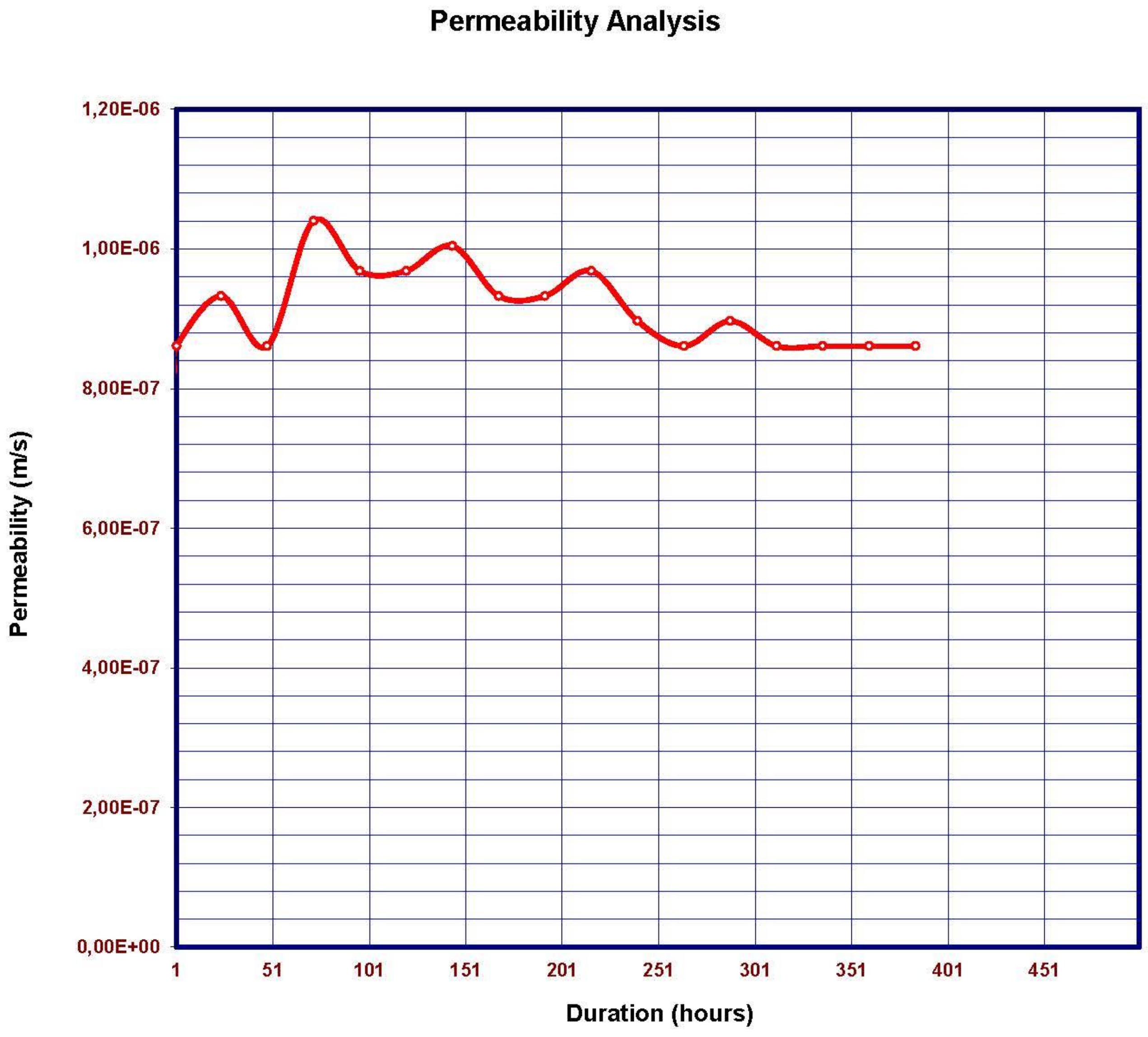
| Date | Test Accummulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| ***28-Jun-21*** | *0* | *23* | *10* | *8,249E-07* | *120* | *1140* | | *1300* | | *880* | *670* | *430* |
| ***29-Jun-21*** | *1* | *24* | *10* | *8,608E-07* | *120* | *1140* | | *1300* | | *1060* | *750* | *430* |
| ***30-Jun-21*** | *24* | *26* | *10* | *9,325E-07* | *120* | *1140* | | *1300* | | *1130* | *760* | *430* |
| ***01-Jul-21*** | *48* | *24* | *10* | *8,608E-07* | *120* | *1140* | | *1300* | | *1120* | *720* | *430* |
| ***02-Jul-21*** | *72* | *29* | *10* | *1,040E-06* | *120* | *1140* | | *1300* | | *1170* | *830* | *430* |
| ***03-Jul-21*** | *96* | *27* | *10* | *9,684E-07* | *120* | *1140* | | *1300* | | *1120* | *720* | *430* |
| ***04-Jul-21*** | *120* | *27* | *10* | *9,684E-07* | *120* | *1140* | | *1300* | | *1100* | *750* | *430* |
| ***05-Jul-21*** | *144* | *28* | *10* | *1,004E-06* | *120* | *1140* | | *1300* | | *1090* | *730* | *430* |
| ***06-Jul-21*** | *168* | *26* | *10* | *9,325E-07* | *120* | *1140* | | *1300* | | *1100* | *710* | *430* |
| ***07-Jul-21*** | *192* | *26* | *10* | *9,325E-07* | *120* | *1140* | | *1300* | | *1080* | *700* | *430* |
| ***08-Jul-21*** | *216* | *27* | *10* | *9,684E-07* | *120* | *1140* | | *1300* | | *1000* | *680* | *430* |
| ***09-Jul-21*** | *240* | *25* | *10* | *8,966E-07* | *120* | *1140* | | *1300* | | *1020* | *690* | *430* |
| ***10-Jul-21*** | *264* | *24* | *10* | *8,608E-07* | *120* | *1140* | | *1300* | | *980* | *680* | *430* |
| ***11-Jul-21*** | *288* | *25* | *10* | *8,966E-07* | *120* | *1140* | | *1300* | | *950* | *670* | *430* |
| ***12-Jul-21*** | *312* | *24* | *10* | *8,608E-07* | *120* | *1140* | | *1300* | | *910* | *670* | *430* |
| ***13-Jul-21*** | *336* | *24* | *10* | *8,608E-07* | *120* | *1140* | | *1300* | | *900* | *670* | *430* |
| ***14-Jul-21*** | *360* | *24* | *10* | *8,608E-07* | *120* | *1140* | | *1300* | | *900* | *660* | *430* |
| ***15-Jul-21*** | *384* | *24* | *10* | *8,608E-07* | *120* | *1140* | | *1300* | | *1010* | *680* | *430* |

***Disclaimer:***

*The test results contained herein refers only to the specific product tested as per the referenced test standard and should not be compared to any similar product not tested. The Laboratory does not imply suitability of this product to be used in any particular application, nor does it imply approval of the quality of the product. This test report shall not be reproduced except in full, and only with written approval of the Laboratory.*

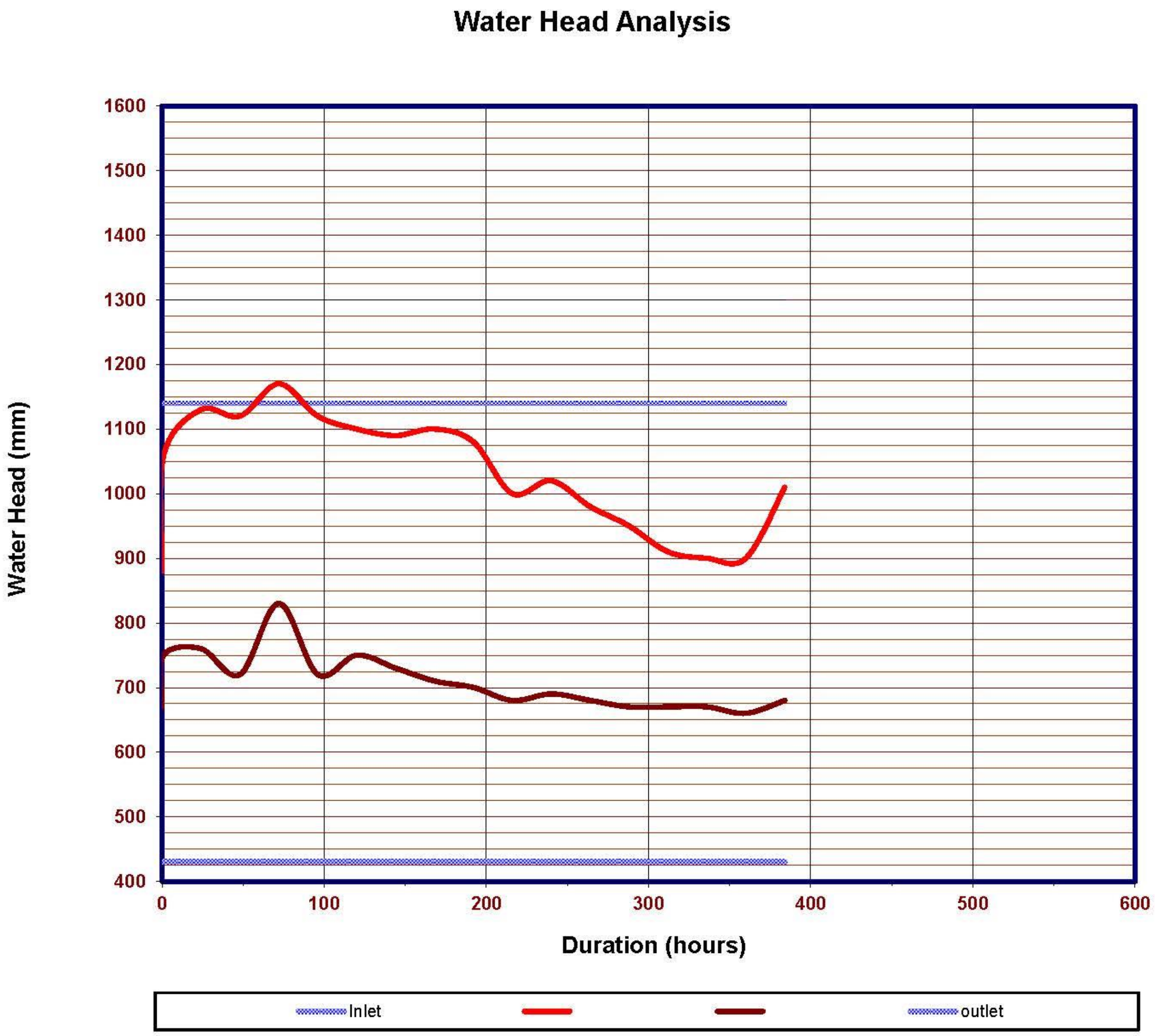
# Permeability Analysis

| | | | |
|---|---|---|---|
| Client | *Vincent Mukwevho* | Test Number | *A2 - Zone 1* |
| Consultant | *230 Albertus Street, La Montagne, Silverton, 0184* | Date | *28-Jun-21* |
| Project | *Masters Thesis* | Product | *Bidim A2* |
| | | Soil Sample | *Clayey Silt* |



# Water Head Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A2 - Zone 1* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *28-Jun-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A2* |
| | | **Soil Sample** | *Clayey Silt* |



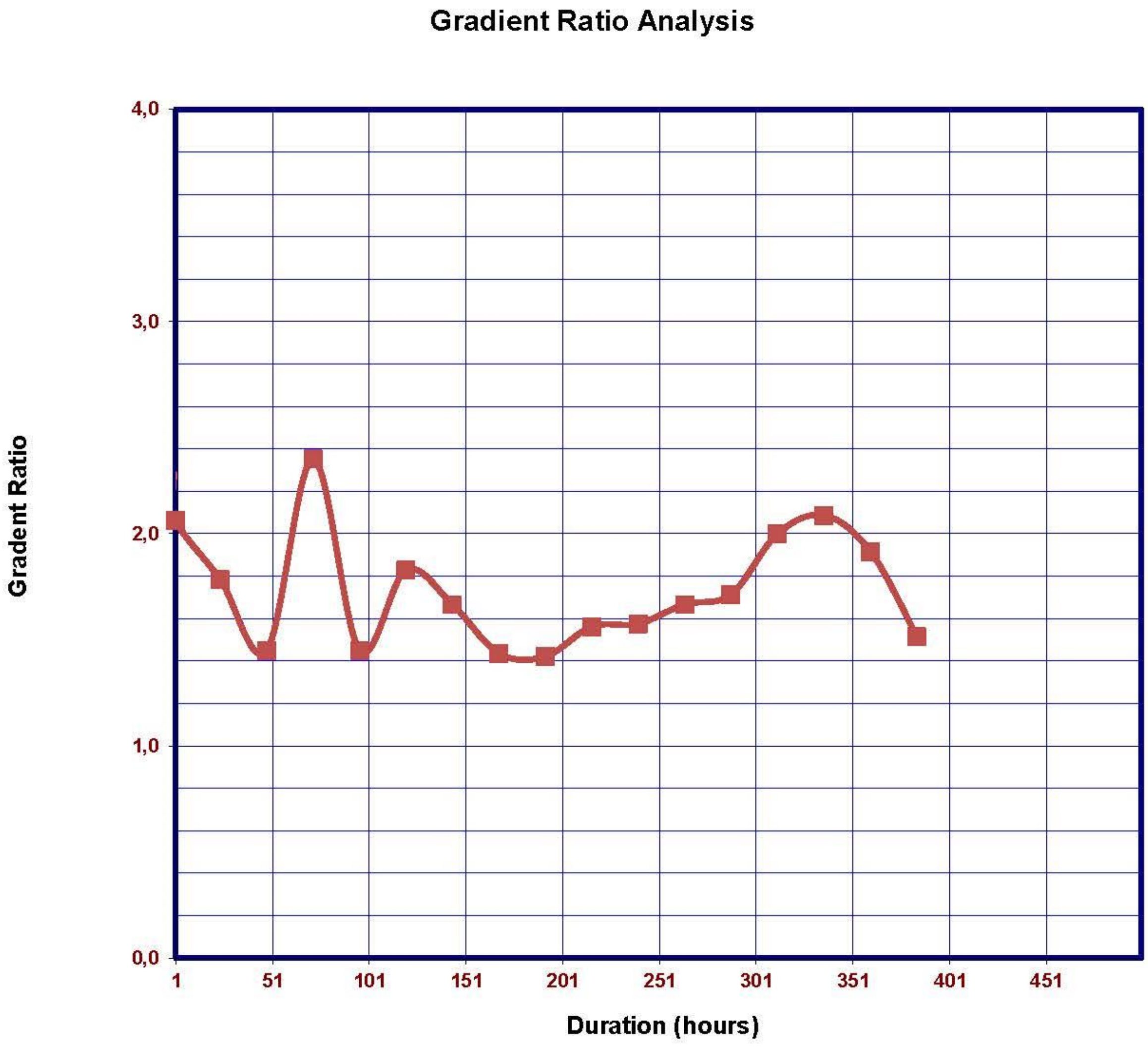
## Hydraulic Gradients and Gradient Ratios of the System

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A2 - Zone 1* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *28-Jun-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *15-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A2* |
| | | **Soil Sample** | *Clayey Silt* |

| Date | Test Accummulative Hours | *L* | *Δh* | Hydraulic Gradient (*i*) | Sample Height mm | Standpipe Readings - mm | | | | Gradient Ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 300 | 100 | 50 | 0 | |
| | | | | | | Inlet | h75 | h25 | h0 | |
| **28-Jun-21** | 0 | 120 | 210 | 1,750 | 120 | 1140 | 880 | 670 | 430 | 2,3 |
| **29-Jun-21** | 1 | 120 | 310 | 2,583 | 120 | 1140 | 1060 | 750 | 430 | 2,1 |
| **30-Jun-21** | 24 | 120 | 370 | 3,083 | 120 | 1140 | 1130 | 760 | 430 | 1,8 |
| **01-Jul-21** | 48 | 120 | 400 | 3,333 | 120 | 1140 | 1120 | 720 | 430 | 1,5 |
| **02-Jul-21** | 72 | 120 | 340 | 2,833 | 120 | 1140 | 1170 | 830 | 430 | 2,4 |
| **03-Jul-21** | 96 | 120 | 400 | 3,333 | 120 | 1140 | 1120 | 720 | 430 | 1,5 |
| **04-Jul-21** | 120 | 120 | 350 | 2,917 | 120 | 1140 | 1100 | 750 | 430 | 1,8 |
| **05-Jul-21** | 144 | 120 | 360 | 3,000 | 120 | 1140 | 1090 | 730 | 430 | 1,7 |
| **06-Jul-21** | 168 | 120 | 390 | 3,250 | 120 | 1140 | 1100 | 710 | 430 | 1,4 |
| **07-Jul-21** | 192 | 120 | 380 | 3,167 | 120 | 1140 | 1080 | 700 | 430 | 1,4 |
| **08-Jul-21** | 216 | 120 | 320 | 2,667 | 120 | 1140 | 1000 | 680 | 430 | 1,6 |
| **09-Jul-21** | 240 | 120 | 330 | 2,750 | 120 | 1140 | 1020 | 690 | 430 | 1,6 |
| **10-Jul-21** | 264 | 120 | 300 | 2,500 | 120 | 1140 | 980 | 680 | 430 | 1,7 |
| **11-Jul-21** | 288 | 120 | 280 | 2,333 | 120 | 1140 | 950 | 670 | 430 | 1,7 |
| **12-Jul-21** | 312 | 120 | 240 | 2,000 | 120 | 1140 | 910 | 670 | 430 | 2,0 |
| **13-Jul-21** | 336 | 120 | 230 | 1,917 | 120 | 1140 | 900 | 670 | 430 | 2,1 |
| **14-Jul-21** | 360 | 120 | 240 | 2,000 | 120 | 1140 | 900 | 660 | 430 | 1,9 |
| **15-Jul-21** | 384 | 120 | 330 | 2,750 | 120 | 1140 | 1010 | 680 | 430 | 1,5 |

# Gradient Ratio

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A2 - Zone 1* |
| **Consultant** | *Vincent Mukwevho* | **Date** | *15-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A2* |
| | | **Soil Sample** | *Clayey Silt* |



# APPENDIX B

## Laboratory Results – Zone 1 Soil (Clayey Silt Vs Bidim A4)

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# LONG TERM GRADIENT RATIO TEST REPORT

## Permeameter Summary

### GL Test Method 1 (Adapted from Kaytech Engineerred Fabrics)

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A4 - Zone 1* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *28-Jun-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *15-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A4* |
| | | **Soil Sample** | *Clayey Silt* |

| | | | | |
|---|---|---|---|---|
| **Equipment** | *GL MK1 Permeameter* | | **Support Above** | *none* |
| **Internal Diameter** | *100mm* | | **Support Below** | *wire mesh* |
| **Wetting Up** | *Below* | | **Preparation** | *Oven Dried* |
| | **Mass @ Start (g)** | **Mass @ Finish (g)** | **Thickness (mm)** | **k estimate** |
| **Geosynthetic** | *3,40* | *6.95* | *2.37* | |
| **Soil Sample** | *930,00* | *914.69* | *120* | |

| Date Start 31-03-2016 11h00 | Test Accummulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Standpipe Readings - mm | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| ***28-Jun-21*** | *0* | *31* | *10* | *1,112E-06* | *120* | *1140* | | *1300* | | *1000* | *620* | *430* |
| ***29-Jun-21*** | *1* | *32* | *10* | *1,148E-06* | *120* | *1140* | | *1300* | | *1050* | *630* | *430* |
| ***30-Jun-21*** | *24* | *30* | *10* | *1,076E-06* | *120* | *1140* | | *1300* | | *1100* | *610* | *430* |
| ***01-Jul-21*** | *48* | *26* | *10* | *9,325E-07* | *120* | *1140* | | *1300* | | *1060* | *690* | *430* |
| ***02-Jul-21*** | *72* | *37* | *10* | *1,327E-06* | *120* | *1140* | | *1300* | | *1040* | *610* | *430* |
| ***03-Jul-21*** | *96* | *30* | *10* | *1,076E-06* | *120* | *1140* | | *1300* | | *1000* | *660* | *430* |
| ***04-Jul-21*** | *120* | *27* | *10* | *9,684E-07* | *120* | *1140* | | *1300* | | *960* | *620* | *430* |
| ***05-Jul-21*** | *144* | *28* | *10* | *1,004E-06* | *120* | *1140* | | *1300* | | *970* | *630* | *430* |
| ***06-Jul-21*** | *168* | *25* | *10* | *8,966E-07* | *120* | *1140* | | *1300* | | *980* | *640* | *430* |
| ***07-Jul-21*** | *192* | *24* | *10* | *8,608E-07* | *120* | *1140* | | *1300* | | *960* | *630* | *430* |
| ***08-Jul-21*** | *216* | *26* | *10* | *9,325E-07* | *120* | *1140* | | *1300* | | *950* | *640* | *430* |
| ***09-Jul-21*** | *240* | *23* | *10* | *8,249E-07* | *120* | *1140* | | *1300* | | *940* | *650* | *430* |
| ***10-Jul-21*** | *264* | *22* | *10* | *7,890E-07* | *120* | *1140* | | *1300* | | *950* | *660* | *430* |
| ***11-Jul-21*** | *288* | *21* | *10* | *7,532E-07* | *120* | *1140* | | *1300* | | *960* | *660* | *430* |
| ***12-Jul-21*** | *312* | *20* | *10* | *7,173E-07* | *120* | *1140* | | *1300* | | *960* | *670* | *430* |
| ***13-Jul-21*** | *336* | *20* | *10* | *7,173E-07* | *120* | *1140* | | *1300* | | *980* | *660* | *430* |
| ***14-Jul-21*** | *360* | *19* | *10* | *6,815E-07* | *120* | *1140* | | *1300* | | *990* | *680* | *430* |
| ***15-Jul-21*** | *384* | *18* | *10* | *6,456E-07* | *120* | *1140* | | *1300* | | *1010* | *680* | *430* |

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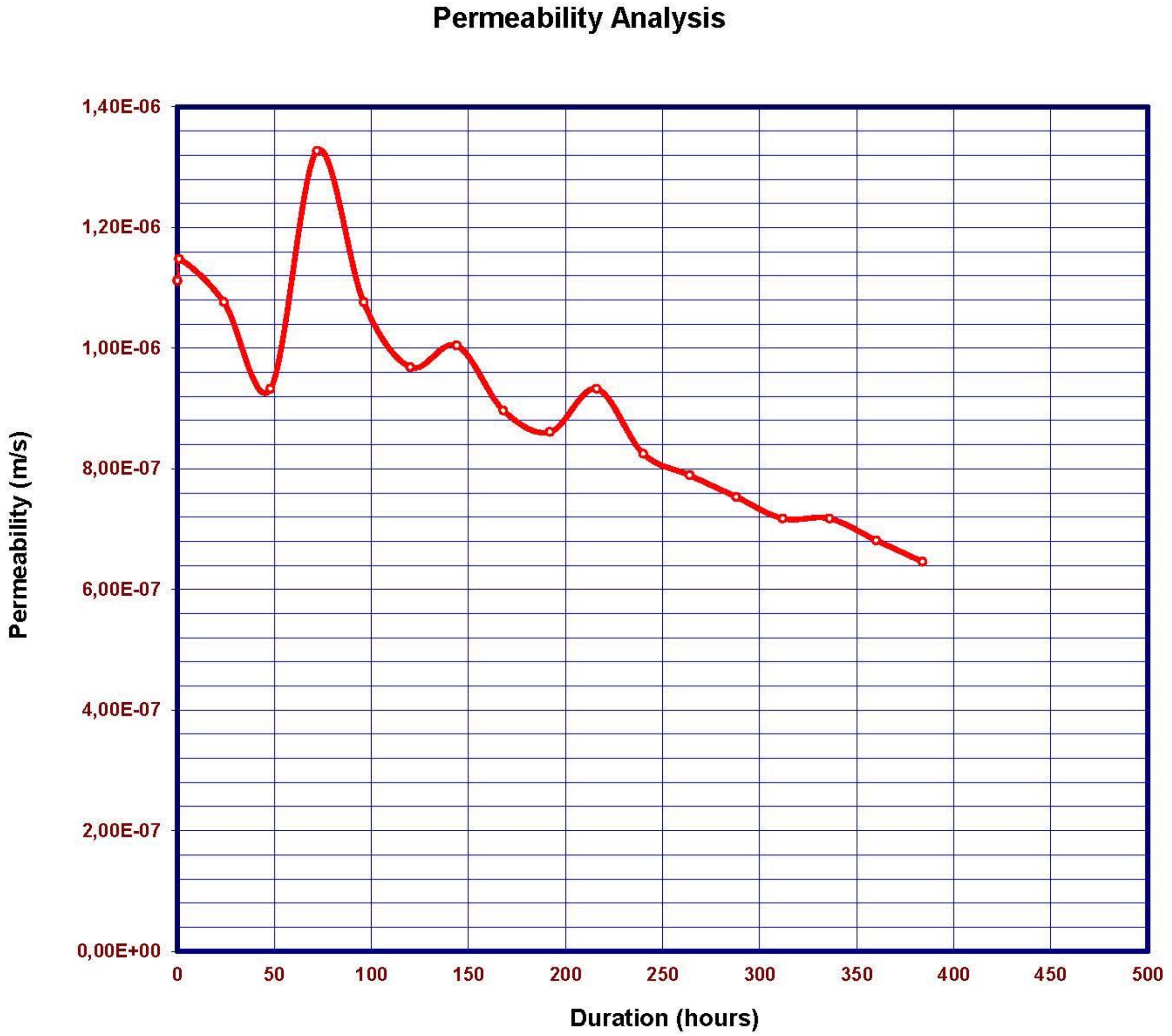
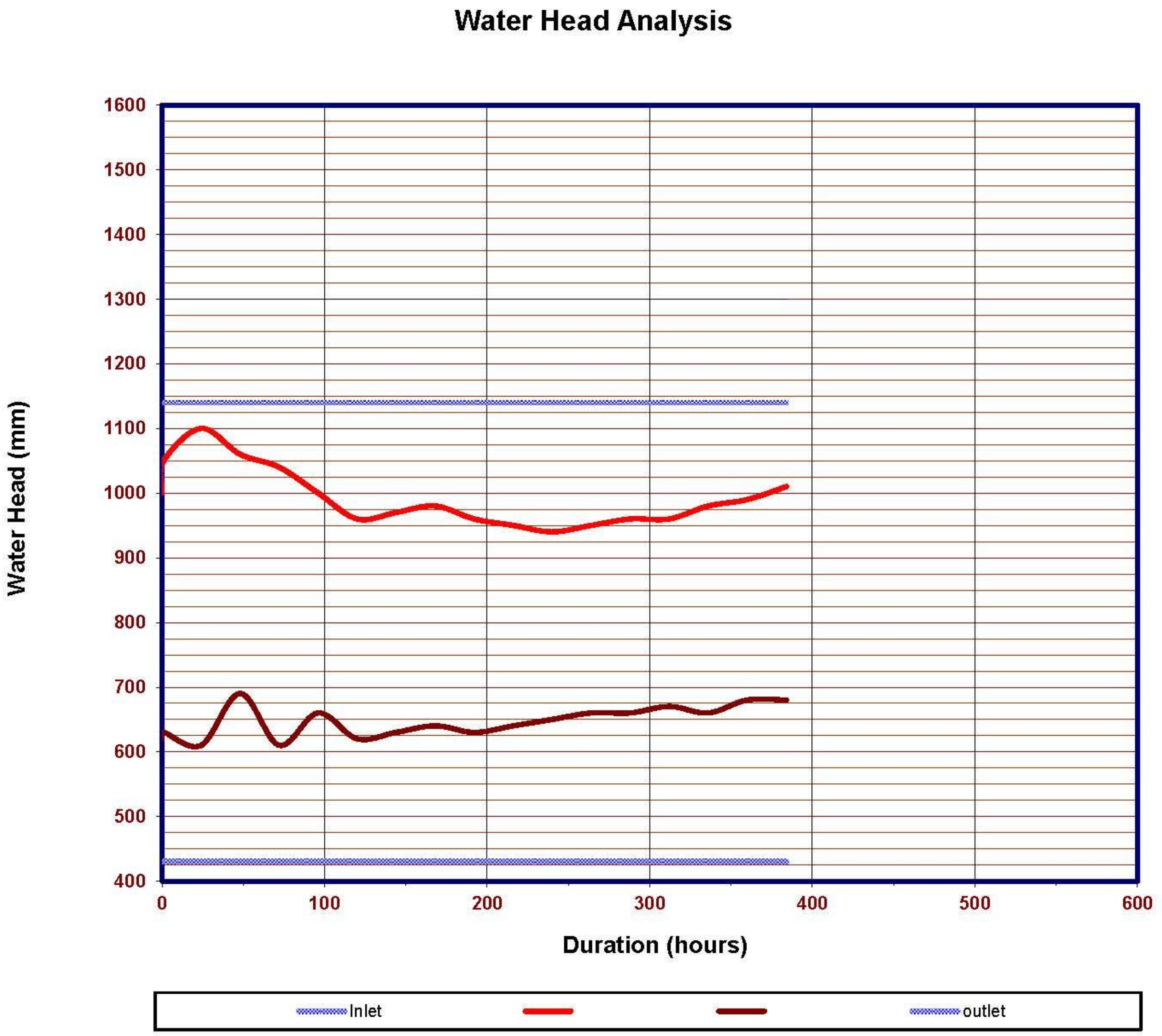
# Permeability Analysis

| | | | |
|---|---|---|---|
| Client | *Vincent Mukwevho* | Test Number | *A4 - Zone 1* |
| Consultant | *230 Albertus Street, La Montagne, Silverton, 0184* | Date | *28-Jun-21* |
| Project | *Masters Thesis* | Product | *Bidim A4* |
| | | Soil Sample | *Clayey Silt* |



# Water Head Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A4 - Zone 1* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *28-Jun-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A4* |
| | | **Soil Sample** | *Clayey Silt* |



## Hydraulic Gradients and Gradient Ratios of the System

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A4 - Zone 1* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *28-Jun-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *15-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A4* |
| | | **Soil Sample** | *Clayey Silt* |

| Date | Test Accummulative Hours | | | Hydraulic Gradient $(i)$ | Sample Height mm | Standpipe Readings - mm | | | | Gradient Ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 300 | 100 | 50 | 0 | |
| | | $L$ | $\Delta h$ | | | Inlet | h75 | h25 | h0 | |
| **28-Jun-21** | 0 | 120 | 380 | 3,167 | 120 | 1140 | 1000 | 620 | 430 | 1,0 |
| **29-Jun-21** | 1 | 120 | 420 | 3,500 | 120 | 1140 | 1050 | 630 | 430 | 1,0 |
| **30-Jun-21** | 24 | 120 | 490 | 4,083 | 120 | 1140 | 1100 | 610 | 430 | 0,7 |
| **01-Jul-21** | 48 | 120 | 370 | 3,083 | 120 | 1140 | 1060 | 690 | 430 | 1,4 |
| **02-Jul-21** | 72 | 120 | 430 | 3,583 | 120 | 1140 | 1040 | 610 | 430 | 0,8 |
| **03-Jul-21** | 96 | 120 | 340 | 2,833 | 120 | 1140 | 1000 | 660 | 430 | 1,4 |
| **04-Jul-21** | 120 | 120 | 340 | 2,833 | 120 | 1140 | 960 | 620 | 430 | 1,1 |
| **05-Jul-21** | 144 | 120 | 340 | 2,833 | 120 | 1140 | 970 | 630 | 430 | 1,2 |
| **06-Jul-21** | 168 | 120 | 340 | 2,833 | 120 | 1140 | 980 | 640 | 430 | 1,2 |
| **07-Jul-21** | 192 | 120 | 330 | 2,750 | 120 | 1140 | 960 | 630 | 430 | 1,2 |
| **08-Jul-21** | 216 | 120 | 310 | 2,583 | 120 | 1140 | 950 | 640 | 430 | 1,4 |
| **09-Jul-21** | 240 | 120 | 290 | 2,417 | 120 | 1140 | 940 | 650 | 430 | 1,5 |
| **10-Jul-21** | 264 | 120 | 290 | 2,417 | 120 | 1140 | 950 | 660 | 430 | 1,6 |
| **11-Jul-21** | 288 | 120 | 300 | 2,500 | 120 | 1140 | 960 | 660 | 430 | 1,5 |
| **12-Jul-21** | 312 | 120 | 290 | 2,417 | 120 | 1140 | 960 | 670 | 430 | 1,7 |
| **13-Jul-21** | 336 | 120 | 320 | 2,667 | 120 | 1140 | 980 | 660 | 430 | 1,4 |
| **14-Jul-21** | 360 | 120 | 310 | 2,583 | 120 | 1140 | 990 | 680 | 430 | 1,6 |
| **15-Jul-21** | 384 | 120 | 330 | 2,750 | 120 | 1140 | 1010 | 680 | 430 | 1,5 |
| | | | | | | | | | | |
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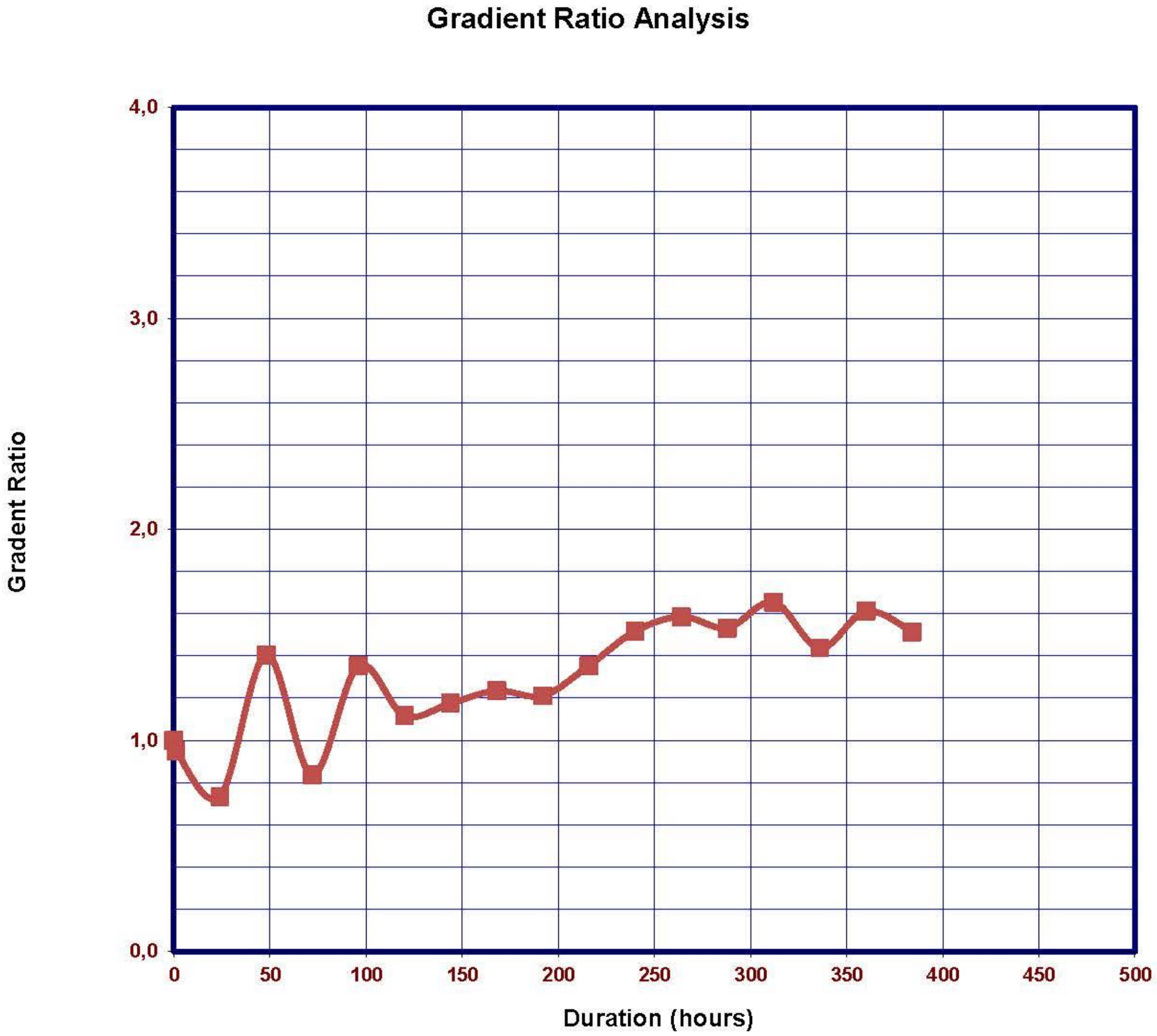
# Gradient Ratio

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A4 - Zone 1* |
| **Consultant** | *Vincent Mukwevho* | **Date** | *15-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A4* |
| | | **Soil Sample** | *Clayey Silt* |



# APPENDIX C

## Laboratory Results – Zone 1 Soil (Clayey Silt Vs Bidim A6)

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## LONG TERM GRADIENT RATIO TEST REPORT

# Permeameter Summary

### GL Test Method 1 (Adapted from Kaytech Engineerred Fabrics)

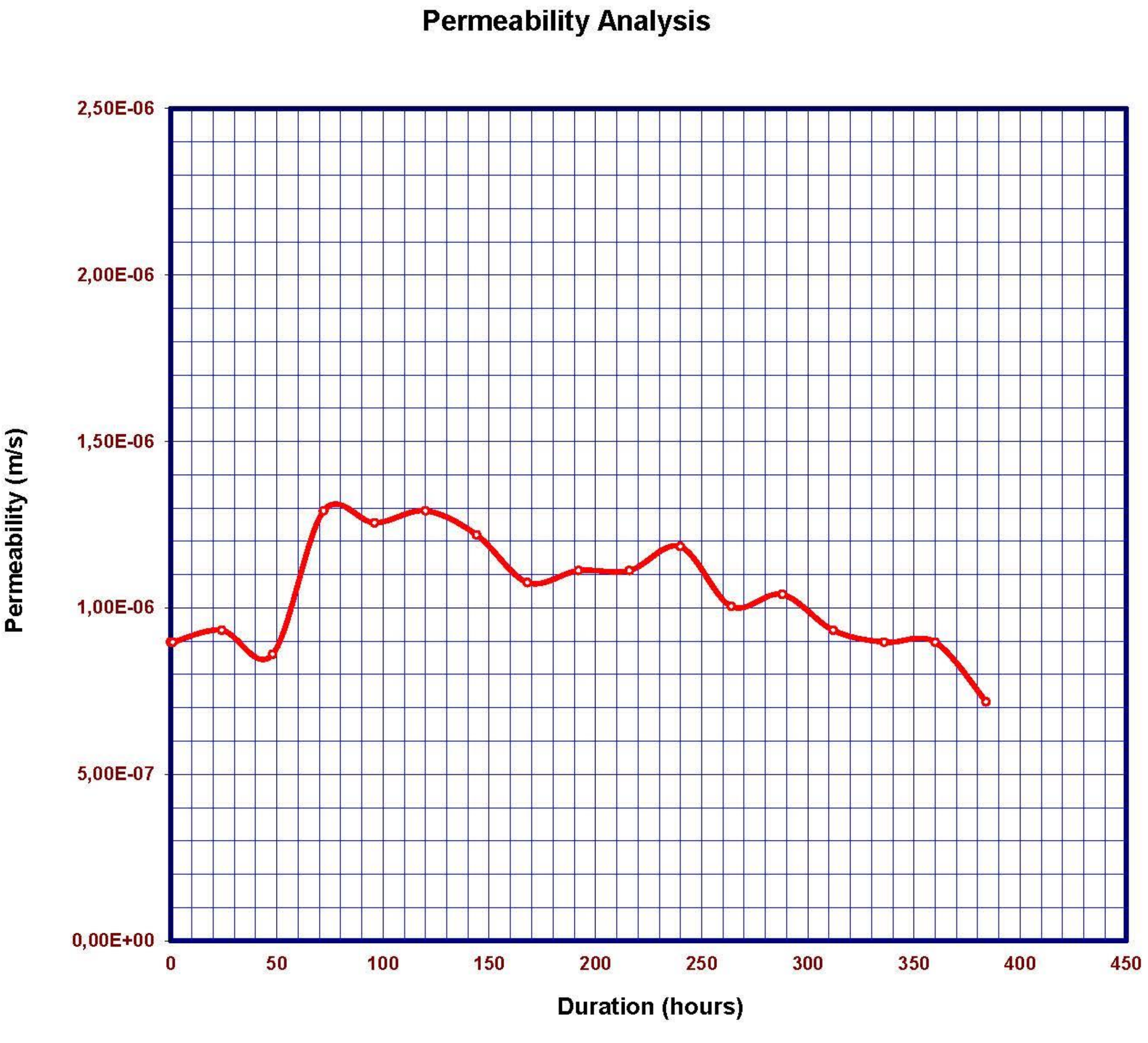
| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A6 - Zone 1* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *28-Jun-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *15-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A6* |
| | | **Soil Sample** | *Clayey Silt* |

| | | | | |
|---|---|---|---|---|
| **Equipment** | *GL MK1 Permeameter* | | **Support Above** | *none* |
| **Internal Diameter** | *100mm* | | **Support Below** | *wire mesh* |
| **Wetting Up** | *Below* | | **Preparation** | *Oven Dried* |
| | **Mass @ Start (g)** | **Mass @ Finish (g)** | **Thickness (mm)** | **k estimate** |
| **Geosynthetic** | *5,80* | *7.71* | *3.36* | |
| **Soil Sample** | *1017,30* | *1010.47* | *120* | |

| Date Start 31-03-2016 11h00 | Test Accummulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| ***28-Jun-21*** | *0* | *25* | *10* | *8,966E-07* | *120* | *1140* | | *1300* | | *1180* | *930* | *430* |
| ***29-Jun-21*** | *1* | *25* | *10* | *8,966E-07* | *120* | *1140* | | *1300* | | *1190* | *920* | *430* |
| ***30-Jun-21*** | *24* | *26* | *10* | *9,325E-07* | *120* | *1140* | | *1300* | | *1220* | *930* | *430* |
| ***01-Jul-21*** | *48* | *24* | *10* | *8,608E-07* | *120* | *1140* | | *1300* | | *1230* | *940* | *430* |
| ***02-Jul-21*** | *72* | *36* | *10* | *1,291E-06* | *120* | *1140* | | *1300* | | *1130* | *680* | *430* |
| ***03-Jul-21*** | *96* | *35* | *10* | *1,255E-06* | *120* | *1140* | | *1300* | | *1080* | *840* | *430* |
| ***04-Jul-21*** | *120* | *36* | *10* | *1,291E-06* | *120* | *1140* | | *1300* | | *1020* | *780* | *430* |
| ***05-Jul-21*** | *144* | *34* | *10* | *1,219E-06* | *120* | *1140* | | *1300* | | *1000* | *770* | *430* |
| ***06-Jul-21*** | *168* | *30* | *10* | *1,076E-06* | *120* | *1140* | | *1300* | | *1010* | *710* | *430* |
| ***07-Jul-21*** | *192* | *31* | *10* | *1,112E-06* | *120* | *1140* | | *1300* | | *1000* | *650* | *430* |
| ***08-Jul-21*** | *216* | *31* | *10* | *1,112E-06* | *120* | *1140* | | *1300* | | *1020* | *660* | *430* |
| ***09-Jul-21*** | *240* | *33* | *10* | *1,184E-06* | *120* | *1140* | | *1300* | | *1030* | *650* | *430* |
| ***10-Jul-21*** | *264* | *28* | *10* | *1,004E-06* | *120* | *1140* | | *1300* | | *1000* | *630* | *430* |
| ***11-Jul-21*** | *288* | *29* | *10* | *1,040E-06* | *120* | *1140* | | *1300* | | *1010* | *620* | *430* |
| ***12-Jul-21*** | *312* | *26* | *10* | *9,325E-07* | *120* | *1140* | | *1300* | | *1030* | *620* | *430* |
| ***13-Jul-21*** | *336* | *25* | *10* | *8,966E-07* | *120* | *1140* | | *1300* | | *1000* | *600* | *430* |
| ***14-Jul-21*** | *360* | *25* | *10* | *8,966E-07* | *120* | *1140* | | *1300* | | *990* | *600* | *430* |
| ***15-Jul-21*** | *384* | *20* | *10* | *7,173E-07* | *120* | *1140* | | *1300* | | *880* | *600* | *430* |

# Permeability Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A6 - Zone 1* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *28-Jun-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A6* |
| | | **Soil Sample** | *Clayey Silt* |



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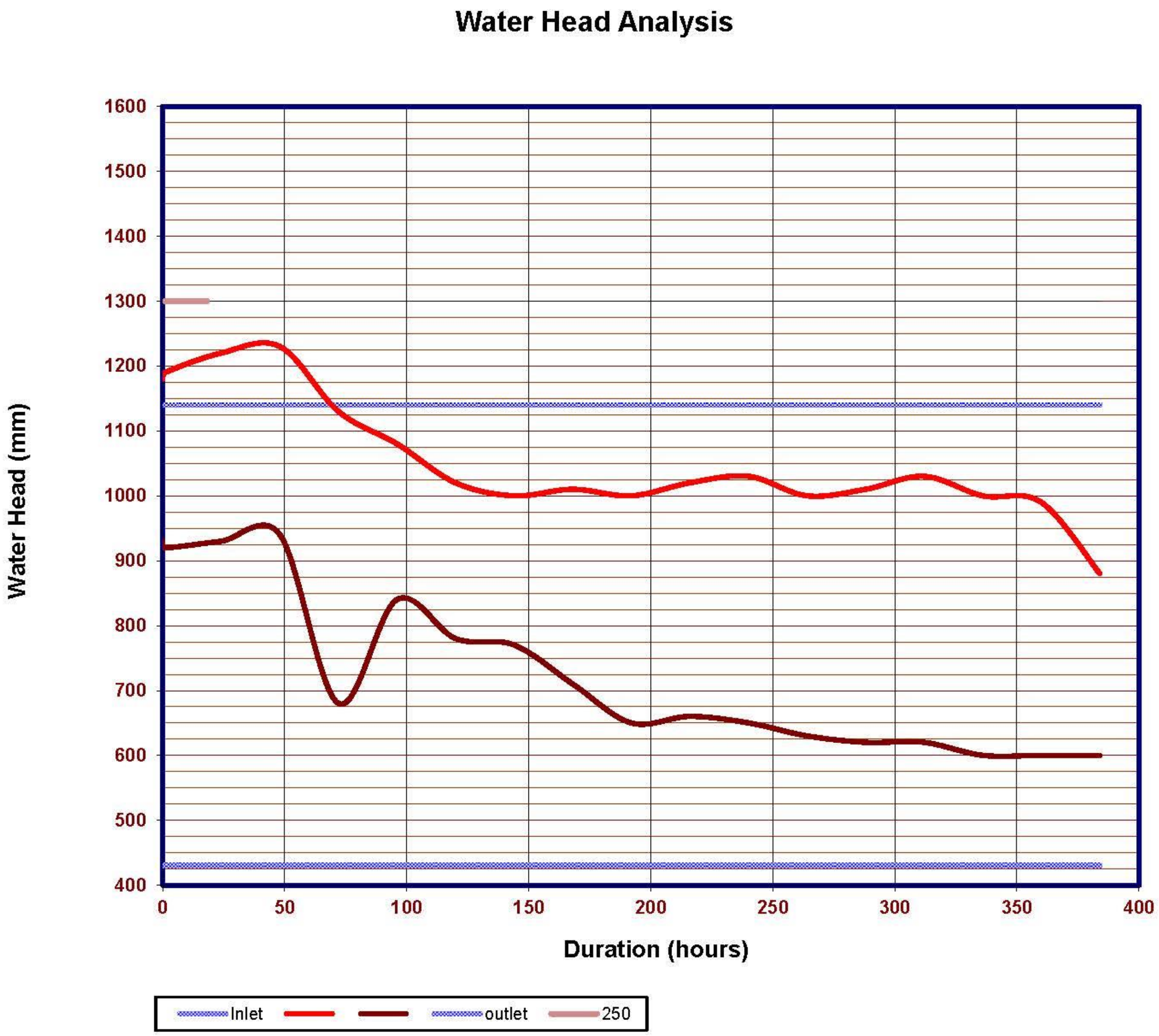
# Water Head Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A6 - Zone 1* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *28-Jun-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A6* |
| | | **Soil Sample** | *Clayey Silt* |



## Hydraulic Gradients and Gradient Ratios of the System

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A6 - Zone 1* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *28-Jun-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *15-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A6* |
| | | **Soil Sample** | *Clayey Silt* |

| Date | Test Accummulative Hours | | | Hydraulic Gradient | Sample Height | Standpipe Readings - mm | | | | Gradient Ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 300 | 100 | 50 | 0 | |
| | | *L* | Δ*h* | (*i*) | mm | Inlet | h75 | h25 | h0 | |
| ***28-Jun-21*** | *0* | *120* | *250* | *2,083* | *120* | *1140* | *1180* | *930* | *430* | 4,0 |
| ***29-Jun-21*** | *1* | *120* | *270* | *2,250* | *120* | *1140* | *1190* | *920* | *430* | 3,6 |
| ***30-Jun-21*** | *24* | *120* | *290* | *2,417* | *120* | *1140* | *1220* | *930* | *430* | 3,4 |
| ***01-Jul-21*** | *48* | *120* | *290* | *2,417* | *120* | *1140* | *1230* | *940* | *430* | 3,5 |
| ***02-Jul-21*** | *72* | *120* | *450* | *3,750* | *120* | *1140* | *1130* | *680* | *430* | 1,1 |
| ***03-Jul-21*** | *96* | *120* | *240* | *2,000* | *120* | *1140* | *1080* | *840* | *430* | 3,4 |
| ***04-Jul-21*** | *120* | *120* | *240* | *2,000* | *120* | *1140* | *1020* | *780* | *430* | 2,9 |
| ***05-Jul-21*** | *144* | *120* | *230* | *1,917* | *120* | *1140* | *1000* | *770* | *430* | 3,0 |
| ***06-Jul-21*** | *168* | *120* | *300* | *2,500* | *120* | *1140* | *1010* | *710* | *430* | 1,9 |
| ***07-Jul-21*** | *192* | *120* | *350* | *2,917* | *120* | *1140* | *1000* | *650* | *430* | 1,3 |
| ***08-Jul-21*** | *216* | *120* | *360* | *3,000* | *120* | *1140* | *1020* | *660* | *430* | 1,3 |
| ***09-Jul-21*** | *240* | *120* | *380* | *3,167* | *120* | *1140* | *1030* | *650* | *430* | 1,2 |
| ***10-Jul-21*** | *264* | *120* | *370* | *3,083* | *120* | *1140* | *1000* | *630* | *430* | 1,1 |
| ***11-Jul-21*** | *288* | *120* | *390* | *3,250* | *120* | *1140* | *1010* | *620* | *430* | 1,0 |
| ***12-Jul-21*** | *312* | *120* | *410* | *3,417* | *120* | *1140* | *1030* | *620* | *430* | 0,9 |
| ***13-Jul-21*** | *336* | *120* | *400* | *3,333* | *120* | *1140* | *1000* | *600* | *430* | 0,9 |
| ***14-Jul-21*** | *360* | *120* | *390* | *3,250* | *120* | *1140* | *990* | *600* | *430* | 0,9 |
| ***15-Jul-21*** | *384* | *120* | *280* | *2,333* | *120* | *1140* | *880* | *600* | *430* | 1,2 |

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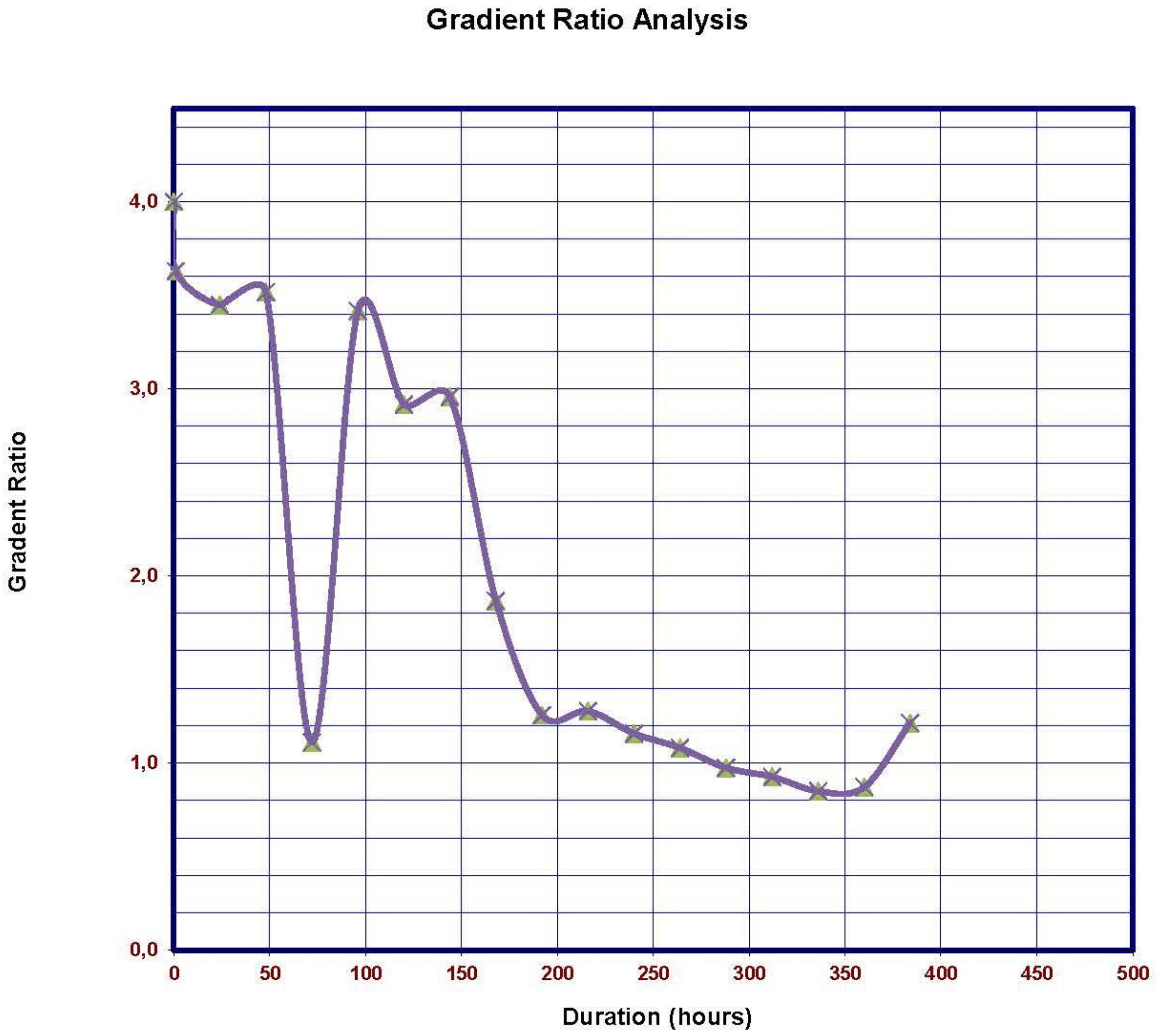
# Gradient Ratio

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A6 - Zone 1* |
| **Consultant** | *Vincent Mukwevho* | **Date** | *28-Jun-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A6* |
| | | **Soil Sample** | *Clayey Silt* |



# APPENDIX D

## Laboratory Results – Zone 1 Soil (Clayey Silt Vs S120)

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# LONG TERM GRADIENT RATIO TEST REPORT

## Permeameter Summary

### GL Test Method 1 (Adapted from Kaytech Engineerred Fabrics)

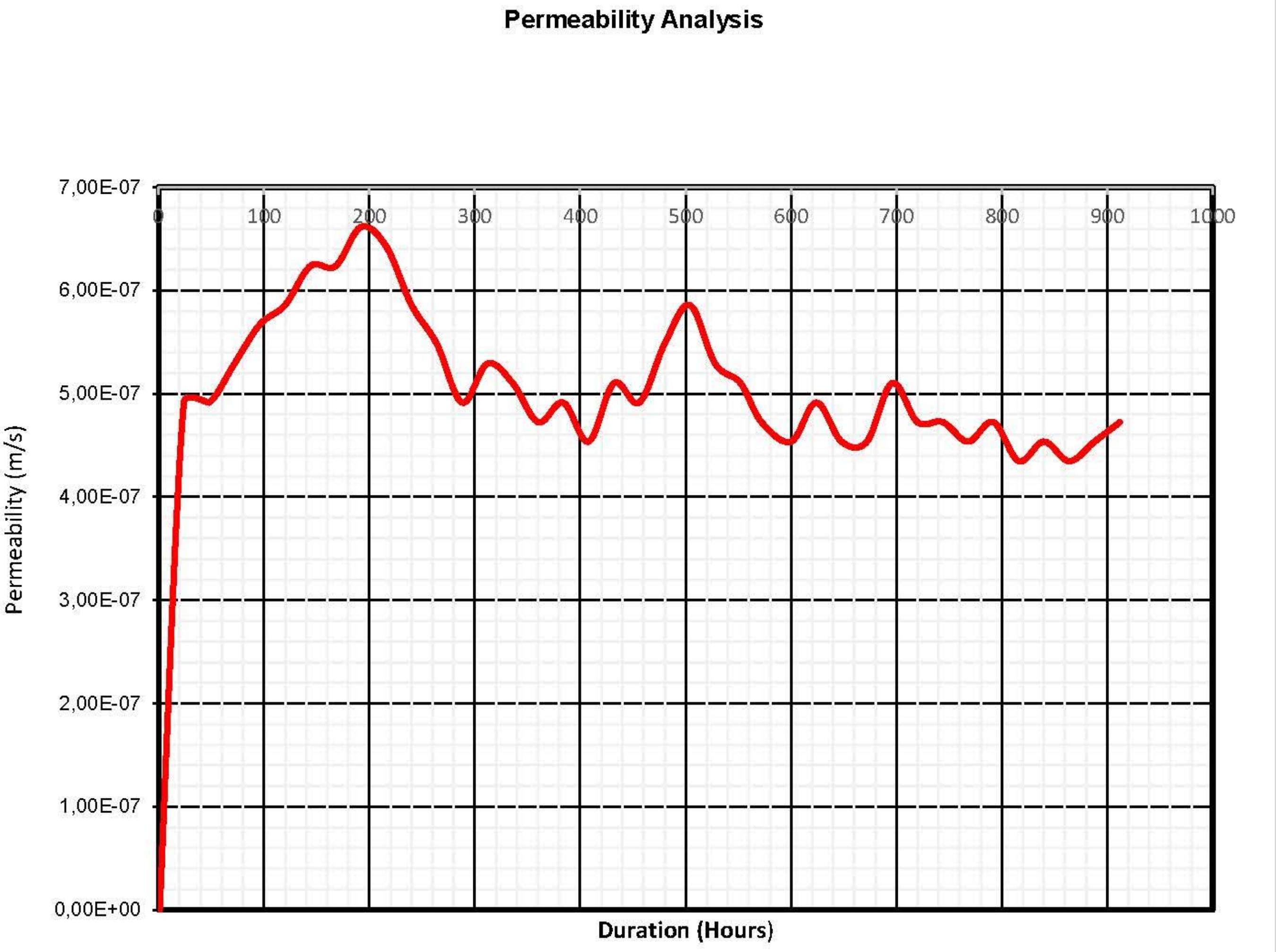
| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S120-Zone 1* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *10-Sep-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *22-Oct-21* |
| **Project** | *Masters Thesis* | **Product** | *S120* |
| | | **Soil Sample** | *Clayey Silt* |

| | | | | |
|---|---|---|---|---|
| **Equipment** | *GL MK1 Permeameter* | | **Support Above** | *none* |
| **Internal Diameter** | *100mm* | | **Support Below** | *wire mesh* |
| **Wetting Up** | *Below* | | **Preparation** | *Oven Dried* |
| | **Mass @ Start (g)** | **Mass @ Finish (g)** | **Thickness (mm)** | **k estimate** |
| **Geosynthetic** | *3.70* | *4.23* | *0.75* | |
| **Soil Sample** | *1105.6* | *1101.45* | *130* | |

| Date | Test Accummulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| 10-Sep-21 | 0 | 0 | 20 | 0,000E+00 | 130 | 1160 | | 1240 | | 700 | 560 | 430 |
| 10-Sep-21 | 1 | 0 | 20 | 0,000E+00 | 130 | 1160 | | 1240 | | 700 | 600 | 430 |
| 11-Sep-21 | 24 | 26 | 20 | 4,913E-07 | 130 | 1160 | | 1240 | | 700 | 580 | 430 |
| 12-Sep-21 | 48 | 26 | 20 | 4,913E-07 | 130 | 1160 | | 1240 | | 750 | 630 | 430 |
| 13-Sep-21 | 72 | 28 | 20 | 5,291E-07 | 130 | 1160 | | 1240 | | 770 | 650 | 430 |
| 14-Sep-21 | 96 | 30 | 20 | 5,669E-07 | 130 | 1160 | | 1240 | | 770 | 620 | 430 |
| 15-Sep-21 | 120 | 31 | 20 | 5,857E-07 | 130 | 1160 | | 1240 | | 790 | 640 | 430 |
| 16-Sep-21 | 144 | 33 | 20 | 6,235E-07 | 130 | 1160 | | 1240 | | 850 | 670 | 430 |
| 17-Sep-21 | 168 | 33 | 20 | 6,235E-07 | 130 | 1160 | | 1240 | | 860 | 680 | 430 |
| 18-Sep-21 | 192 | 35 | 20 | 6,613E-07 | 130 | 1160 | | 1240 | | 960 | 720 | 430 |
| 19-Sep-21 | 216 | 34 | 20 | 6,424E-07 | 130 | 1160 | | 1240 | | 870 | 690 | 430 |
| 20-Sep-21 | 240 | 31 | 20 | 5,857E-07 | 130 | 1160 | | 1240 | | 850 | 700 | 430 |
| 21-Sep-21 | 264 | 29 | 20 | 5,480E-07 | 130 | 1160 | | 1240 | | 860 | 710 | 430 |
| 22-Sep-21 | 288 | 26 | 20 | 4,913E-07 | 130 | 1160 | | 1240 | | 830 | 680 | 430 |
| 23-Sep-21 | 312 | 28 | 20 | 5,291E-07 | 130 | 1160 | | 1240 | | 840 | 700 | 430 |
| 24-Sep-21 | 336 | 27 | 20 | 5,102E-07 | 130 | 1160 | | 1240 | | 880 | 720 | 430 |
| 25-Sep-21 | 360 | 25 | 20 | 4,724E-07 | 130 | 1160 | | 1240 | | 920 | 750 | 430 |
| 26-Sep-21 | 384 | 26 | 20 | 4,913E-07 | 130 | 1160 | | 1240 | | 910 | 730 | 430 |
| 27-Sep-21 | 408 | 24 | 20 | 4,535E-07 | 130 | 1160 | | 1240 | | 880 | 720 | 430 |
| 28-Sep-21 | 432 | 27 | 20 | 5,102E-07 | 130 | 1160 | | 1240 | | 880 | 710 | 430 |
| 29-Sep-21 | 456 | 26 | 20 | 4,913E-07 | 130 | 1160 | | 1240 | | 880 | 700 | 430 |
| 30-Sep-21 | 480 | 29 | 20 | 5,480E-07 | 130 | 1160 | | 1240 | | 880 | 680 | 430 |
| 01-Oct-21 | 504 | 31 | 20 | 5,857E-07 | 130 | 1160 | | 1240 | | 880 | 690 | 430 |
| 02-Oct-21 | 528 | 28 | 20 | 5,291E-07 | 130 | 1160 | | 1240 | | 880 | 700 | 430 |
| 03-Oct-21 | 552 | 27 | 20 | 5,102E-07 | 130 | 1160 | | 1240 | | 880 | 710 | 430 |
| 04-Oct-21 | 572 | 25 | 20 | 4,724E-07 | 130 | 1160 | | 1240 | | 880 | 700 | 430 |
| 05-Oct-21 | 600 | 24 | 20 | 4,535E-07 | 130 | 1160 | | 1240 | | 880 | 710 | 430 |
| 06-Oct-21 | 624 | 26 | 20 | 4,913E-07 | 130 | 1160 | | 1240 | | 880 | 700 | 430 |
| 07-Oct-21 | 648 | 24 | 20 | 4,535E-07 | 130 | 1160 | | 1240 | | 880 | 680 | 430 |
| 08-Oct-21 | 672 | 24 | 20 | 4,535E-07 | 130 | 1160 | | 1240 | | 880 | 690 | 430 |
| 09-Oct-21 | 696 | 27 | 20 | 5,102E-07 | 130 | 1160 | | 1240 | | 880 | 700 | 430 |
| 10-Oct-21 | 720 | 25 | 20 | 4,724E-07 | 130 | 1160 | | 1240 | | 880 | 710 | 430 |
| 11-Oct-21 | 744 | 25 | 20 | 4,724E-07 | 130 | 1160 | | 1240 | | 880 | 700 | 430 |
| 12-Oct-21 | 768 | 24 | 20 | 4,535E-07 | 130 | 1160 | | 1240 | | 880 | 690 | 430 |
| 13-Oct-21 | 792 | 25 | 20 | 4,724E-07 | 130 | 1160 | | 1240 | | 880 | 680 | 430 |
| 14-Oct-21 | 816 | 23 | 20 | 4,346E-07 | 130 | 1160 | | 1240 | | 880 | 700 | 430 |
| 15-Oct-21 | 840 | 24 | 20 | 4,535E-07 | 130 | 1160 | | 1240 | | 880 | 690 | 430 |
| 16-Oct-21 | 864 | 23 | 20 | 4,346E-07 | 130 | 1160 | | 1240 | | 880 | 660 | 430 |
| 17-Oct-21 | 888 | 24 | 20 | 4,535E-07 | 130 | 1160 | | 1240 | | 850 | 670 | 430 |
| 18-Oct-21 | 912 | 25 | 20 | 4,724E-07 | 130 | 1160 | | 1240 | | 840 | 680 | 430 |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |

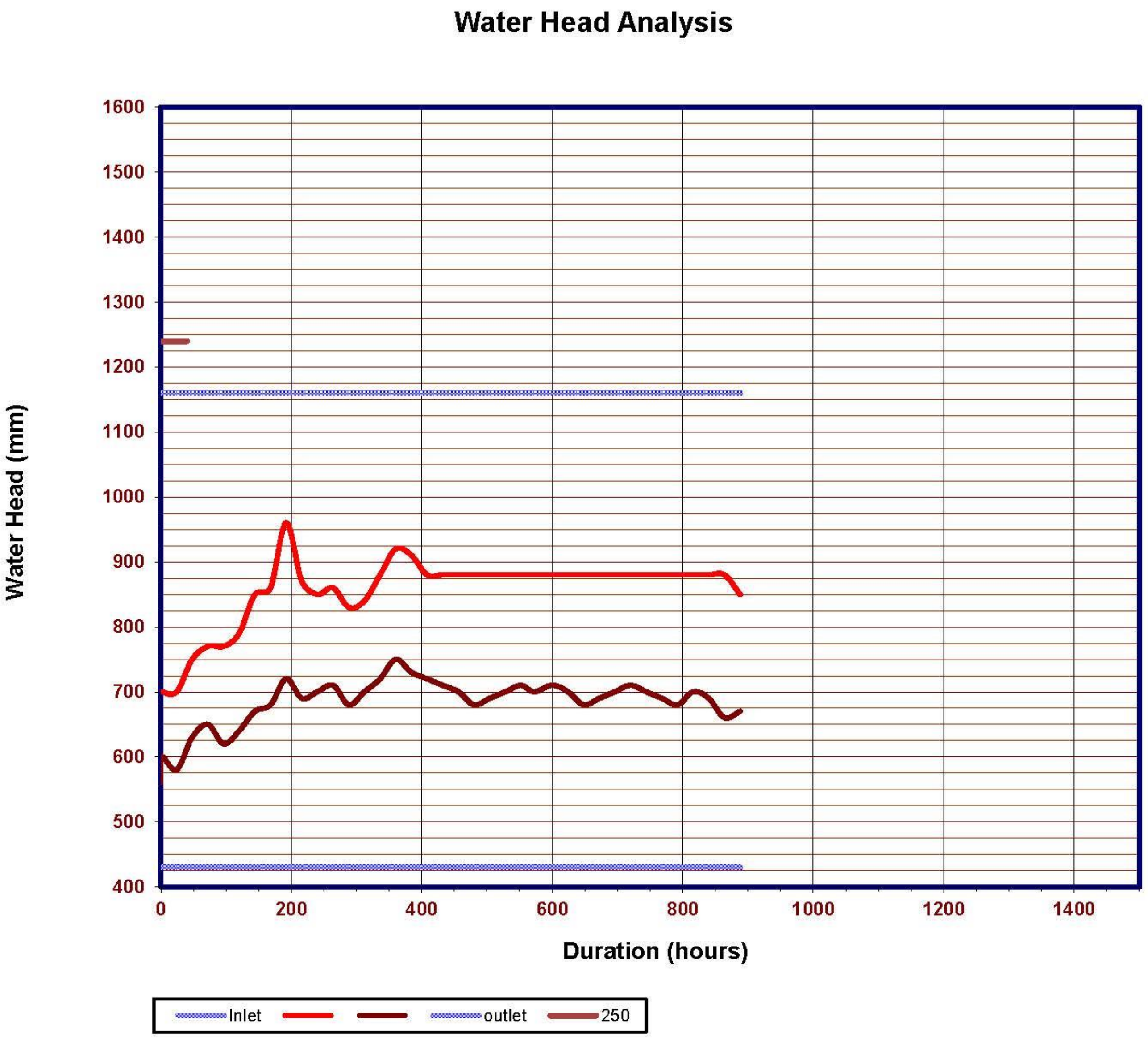
# Permeability Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S120-Zone 1* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *10-Sep-21* |
| **Project** | *Masters Thesis* | **Product** | *S120* |
| | | **Soil Sample** | *Clayey Silt* |



# Water Head Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S120-Zone 1* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *10-Sep-21* |
| **Project** | *Masters Thesis* | **Product** | *S120* |
| | | **Soil Sample** | *Clayey Silt* |



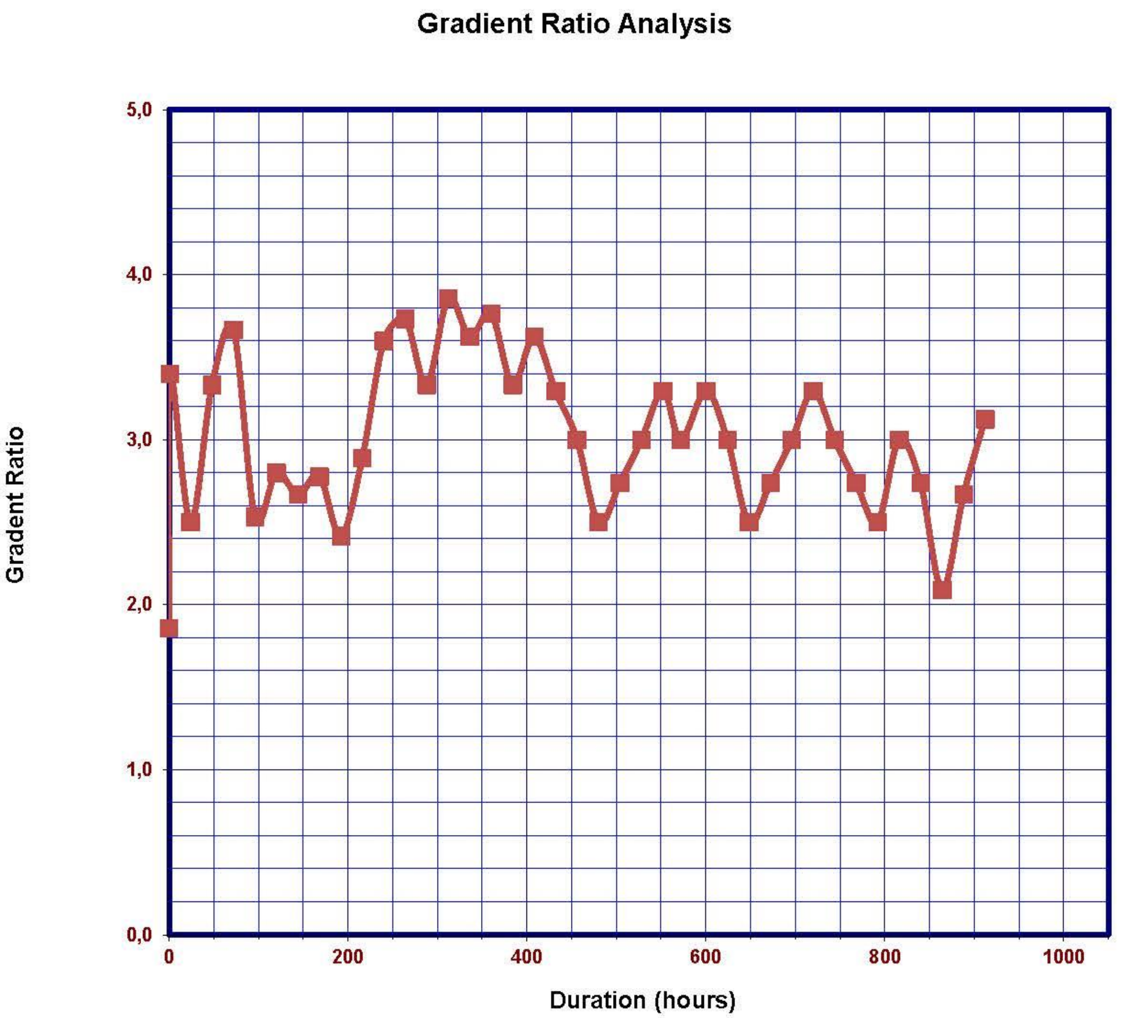
## Hydraulic Gradients and Gradient Ratios of the System

| | | | |
|---|---|---|---|
| **Client** | Vincent Mukwevho | **Test Number** | S120-Zone 1 |
| **Address** | 230 Albertus Street, La Montagne, Silverton, 0184 | **Date Start** | 10-Sep-21 |
| **Contact** | Vincent Mukwevho | **Date Fin** | 22-Oct-21 |
| **Project** | Masters Thesis | **Product** | S120 |
| | | **Soil Sample** | Clayey Silt |

| Date | Test Accummulative Hours | | | Hydraulic Gradient | Sample Height | Standpipe Readings - mm | | | | Gradient Ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 300 | 100 | 50 | 0 | |
| | | L | Δh | (i) | mm | Inlet | h75 | h25 | h0 | |
| 10-Sep-21 | 0 | 130 | 140 | 1,077 | 130 | 1160 | 700 | 560 | 430 | 1,9 |
| 10-Sep-21 | 1 | 130 | 100 | 0,769 | 130 | 1160 | 700 | 600 | 430 | 3,4 |
| 11-Sep-21 | 24 | 130 | 120 | 0,923 | 130 | 1160 | 700 | 580 | 430 | 2,5 |
| 12-Sep-21 | 48 | 130 | 120 | 0,923 | 130 | 1160 | 750 | 630 | 430 | 3,3 |
| 13-Sep-21 | 72 | 130 | 120 | 0,923 | 130 | 1160 | 770 | 650 | 430 | 3,7 |
| 14-Sep-21 | 96 | 130 | 150 | 1,154 | 130 | 1160 | 770 | 620 | 430 | 2,5 |
| 15-Sep-21 | 120 | 130 | 150 | 1,154 | 130 | 1160 | 790 | 640 | 430 | 2,8 |
| 16-Sep-21 | 144 | 130 | 180 | 1,385 | 130 | 1160 | 850 | 670 | 430 | 2,7 |
| 17-Sep-21 | 168 | 130 | 180 | 1,385 | 130 | 1160 | 860 | 680 | 430 | 2,8 |
| 18-Sep-21 | 192 | 130 | 240 | 1,846 | 130 | 1160 | 960 | 720 | 430 | 2,4 |
| 19-Sep-21 | 216 | 130 | 180 | 1,385 | 130 | 1160 | 870 | 690 | 430 | 2,9 |
| 20-Sep-21 | 240 | 130 | 150 | 1,154 | 130 | 1160 | 850 | 700 | 430 | 3,6 |
| 21-Sep-21 | 264 | 130 | 150 | 1,154 | 130 | 1160 | 860 | 710 | 430 | 3,7 |
| 22-Sep-21 | 288 | 130 | 150 | 1,154 | 130 | 1160 | 830 | 680 | 430 | 3,3 |
| 23-Sep-21 | 312 | 130 | 140 | 1,077 | 130 | 1160 | 840 | 700 | 430 | 3,9 |
| 24-Sep-21 | 336 | 130 | 160 | 1,231 | 130 | 1160 | 880 | 720 | 430 | 3,6 |
| 25-Sep-21 | 360 | 130 | 170 | 1,308 | 130 | 1160 | 920 | 750 | 430 | 3,8 |
| 26-Sep-21 | 384 | 130 | 180 | 1,385 | 130 | 1160 | 910 | 730 | 430 | 3,3 |
| 27-Sep-21 | 408 | 130 | 160 | 1,231 | 130 | 1160 | 880 | 720 | 430 | 3,6 |
| 28-Sep-21 | 432 | 130 | 170 | 1,308 | 130 | 1160 | 880 | 710 | 430 | 3,3 |
| 29-Sep-21 | 456 | 130 | 180 | 1,385 | 130 | 1160 | 880 | 700 | 430 | 3,0 |
| 30-Sep-21 | 480 | 130 | 200 | 1,538 | 130 | 1160 | 880 | 680 | 430 | 2,5 |
| 01-Oct-21 | 504 | 130 | 190 | 1,462 | 130 | 1160 | 880 | 690 | 430 | 2,7 |
| 02-Oct-21 | 528 | 130 | 180 | 1,385 | 130 | 1160 | 880 | 700 | 430 | 3,0 |
| 03-Oct-21 | 552 | 130 | 170 | 1,308 | 130 | 1160 | 880 | 710 | 430 | 3,3 |
| 04-Oct-21 | 572 | 130 | 180 | 1,385 | 130 | 1160 | 880 | 700 | 430 | 3,0 |
| 05-Oct-21 | 600 | 130 | 170 | 1,308 | 130 | 1160 | 880 | 710 | 430 | 3,3 |
| 06-Oct-21 | 624 | 130 | 180 | 1,385 | 130 | 1160 | 880 | 700 | 430 | 3,0 |
| 07-Oct-21 | 648 | 130 | 200 | 1,538 | 130 | 1160 | 880 | 680 | 430 | 2,5 |
| 08-Oct-21 | 672 | 130 | 190 | 1,462 | 130 | 1160 | 880 | 690 | 430 | 2,7 |
| 09-Oct-21 | 696 | 130 | 180 | 1,385 | 130 | 1160 | 880 | 700 | 430 | 3,0 |
| 10-Oct-21 | 720 | 130 | 170 | 1,308 | 130 | 1160 | 880 | 710 | 430 | 3,3 |
| 11-Oct-21 | 744 | 130 | 180 | 1,385 | 130 | 1160 | 880 | 700 | 430 | 3,0 |
| 12-Oct-21 | 768 | 130 | 190 | 1,462 | 130 | 1160 | 880 | 690 | 430 | 2,7 |
| 13-Oct-21 | 792 | 130 | 200 | 1,538 | 130 | 1160 | 880 | 680 | 430 | 2,5 |
| 14-Oct-21 | 816 | 130 | 180 | 1,385 | 130 | 1160 | 880 | 700 | 430 | 3,0 |
| 15-Oct-21 | 840 | 130 | 190 | 1,462 | 130 | 1160 | 880 | 690 | 430 | 2,7 |
| 16-Oct-21 | 864 | 130 | 220 | 1,692 | 130 | 1160 | 880 | 660 | 430 | 2,1 |
| 17-Oct-21 | 888 | 130 | 180 | 1,385 | 130 | 1160 | 850 | 670 | 430 | 2,7 |
| 18-Oct-21 | 912 | 130 | 160 | 1,231 | 130 | 1160 | 840 | 680 | 430 | 3,1 |

# Gradient Ratio

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S120-Zone 1* |
| **Consultant** | *Vincent Mukwevho* | **Date** | *10-Sep-21* |
| **Project** | *Masters Thesis* | **Product** | *S120* |
| | | **Soil Sample** | *Clayey Silt* |



# APPENDIX E

## Laboratory Results – Zone 1 Soil (Clayey Silt Vs S270)

SOILLAB
Part of the SMEC Group

230 Albertus Street
La Montagne, Pretoria, South Africa 0184
(PO Box 72928, Lynnwood Ridge, South Africa 0040)
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**www.soillab.co.za**

# LONG TERM GRADIENT RATIO TEST REPORT

## Permeameter Summary

### GL Test Method 1 (Adapted from Kaytech Engineerred Fabrics)

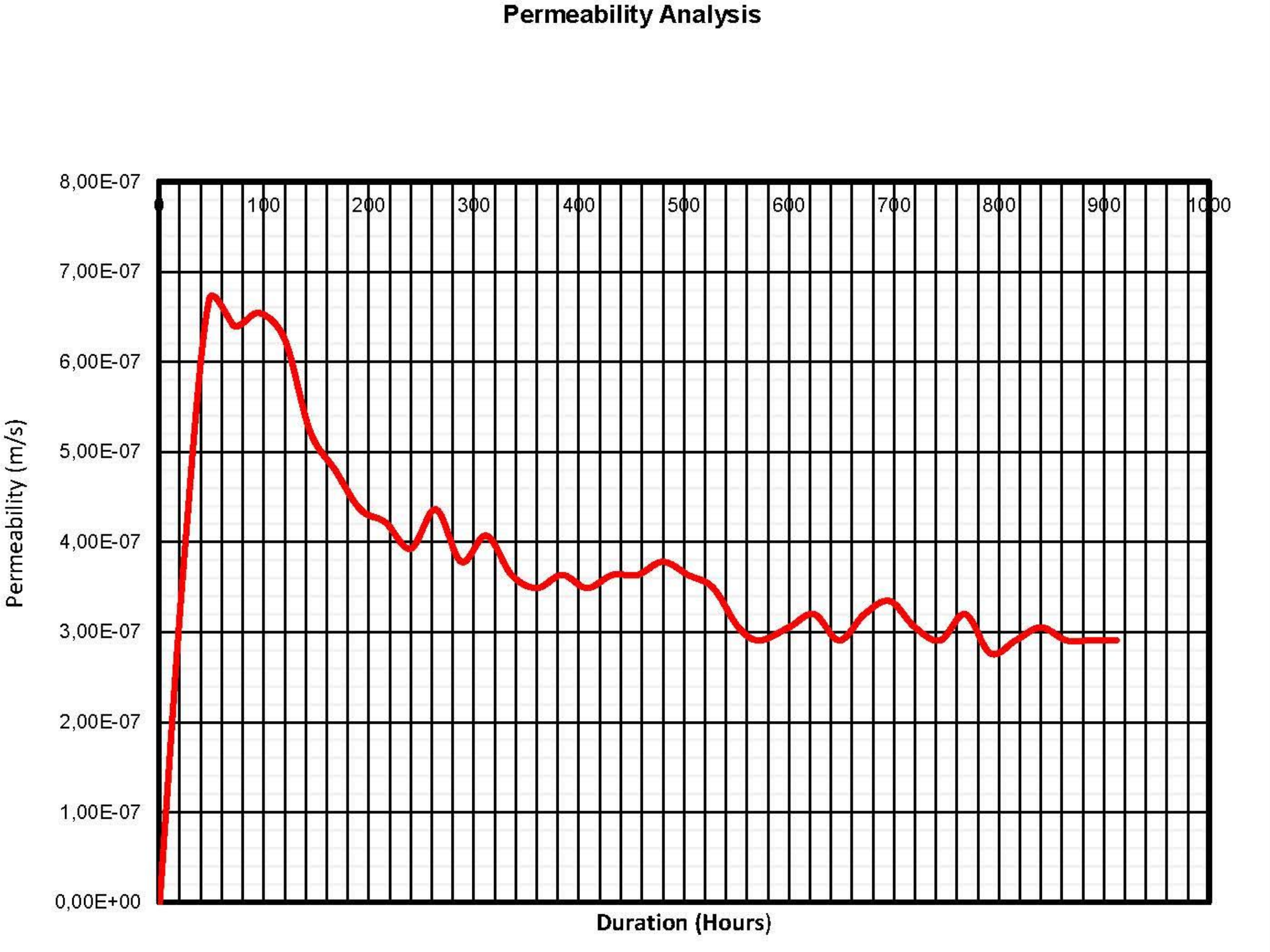
| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S270-Zone 1* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *10-Sep-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *22-Oct-21* |
| **Project** | *Masters Thesis* | **Product** | *S270* |
| | | **Soil Sample** | *Clayey Silt* |

| | | | | |
|---|---|---|---|---|
| **Equipment** | *GL MK1 Permeameter* | | **Support Above** | *none* |
| **Internal Diameter** | *100mm* | | **Support Below** | *wire mesh* |
| **Wetting Up** | *Below* | | **Preparation** | *Oven Dried* |
| | **Mass @ Start (g)** | **Mass @ Finish (g)** | **Thickness (mm)** | **k estimate** |
| **Geosynthetic** | *3.90* | *4.35* | *1.0* | |
| **Soil Sample** | *943.20* | *940.16* | *100* | |

| Date | Test Accummulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| **10-Sep-21** | 0 | 0 | 20 | 0,000E+00 | 100 | 1160 | | 1240 | | 730 | 610 | 430 |
| **10-Sep-21** | 1 | 0 | 20 | 0,000E+00 | 100 | 1160 | | 1240 | | 810 | 650 | 430 |
| **11-Sep-21** | 24 | 26 | 20 | 3,779E-07 | 100 | 1160 | | 1240 | | 850 | 660 | 430 |
| **12-Sep-21** | 48 | 46 | 20 | 6,686E-07 | 100 | 1160 | | 1240 | | 1000 | 780 | 430 |
| **13-Sep-21** | 72 | 44 | 20 | 6,395E-07 | 100 | 1160 | | 1240 | | 1110 | 800 | 430 |
| **14-Sep-21** | 96 | 45 | 20 | 6,541E-07 | 100 | 1160 | | 1240 | | 1120 | 790 | 430 |
| **15-Sep-21** | 120 | 43 | 20 | 6,250E-07 | 100 | 1160 | | 1240 | | 1100 | 760 | 430 |
| **16-Sep-21** | 144 | 36 | 20 | 5,232E-07 | 100 | 1160 | | 1240 | | 970 | 780 | 430 |
| **17-Sep-21** | 168 | 33 | 20 | 4,796E-07 | 100 | 1160 | | 1240 | | 990 | 800 | 430 |
| **18-Sep-21** | 192 | 30 | 20 | 4,360E-07 | 100 | 1160 | | 1240 | | 1100 | 820 | 430 |
| **19-Sep-21** | 216 | 29 | 20 | 4,215E-07 | 100 | 1160 | | 1240 | | 1000 | 790 | 430 |
| **20-Sep-21** | 240 | 27 | 20 | 3,924E-07 | 100 | 1160 | | 1240 | | 1010 | 810 | 430 |
| **21-Sep-21** | 264 | 30 | 20 | 4,360E-07 | 100 | 1160 | | 1240 | | 1000 | 800 | 430 |
| **22-Sep-21** | 288 | 26 | 20 | 3,779E-07 | 100 | 1160 | | 1240 | | 990 | 750 | 430 |
| **23-Sep-21** | 312 | 28 | 20 | 4,070E-07 | 100 | 1160 | | 1240 | | 980 | 770 | 430 |
| **24-Sep-21** | 336 | 25 | 20 | 3,634E-07 | 100 | 1160 | | 1240 | | 970 | 740 | 430 |
| **25-Sep-21** | 360 | 24 | 20 | 3,488E-07 | 100 | 1160 | | 1240 | | 900 | 750 | 430 |
| **26-Sep-21** | 384 | 25 | 20 | 3,634E-07 | 100 | 1160 | | 1240 | | 900 | 730 | 430 |
| **27-Sep-21** | 408 | 24 | 20 | 3,488E-07 | 100 | 1160 | | 1240 | | 900 | 730 | 430 |
| **28-Sep-21** | 432 | 25 | 20 | 3,634E-07 | 100 | 1160 | | 1240 | | 900 | 740 | 430 |
| **29-Sep-21** | 456 | 25 | 20 | 3,634E-07 | 100 | 1160 | | 1240 | | 900 | 730 | 430 |
| **30-Sep-21** | 480 | 26 | 20 | 3,779E-07 | 100 | 1160 | | 1240 | | 900 | 710 | 430 |
| **01-Oct-21** | 504 | 25 | 20 | 3,634E-07 | 100 | 1160 | | 1240 | | 960 | 750 | 430 |
| **02-Oct-21** | 528 | 24 | 20 | 3,488E-07 | 100 | 1160 | | 1240 | | 900 | 740 | 430 |
| **03-Oct-21** | 552 | 21 | 20 | 3,052E-07 | 100 | 1160 | | 1240 | | 900 | 700 | 430 |
| **04-Oct-21** | 572 | 20 | 20 | 2,907E-07 | 100 | 1160 | | 1240 | | 900 | 710 | 430 |
| **05-Oct-21** | 600 | 21 | 20 | 3,052E-07 | 100 | 1160 | | 1240 | | 910 | 700 | 430 |
| **06-Oct-21** | 624 | 22 | 20 | 3,198E-07 | 100 | 1160 | | 1240 | | 920 | 720 | 430 |
| **07-Oct-21** | 648 | 20 | 20 | 2,907E-07 | 100 | 1160 | | 1240 | | 900 | 700 | 430 |
| **08-Oct-21** | 672 | 22 | 20 | 3,198E-07 | 100 | 1160 | | 1240 | | 910 | 720 | 430 |
| **09-Oct-21** | 696 | 23 | 20 | 3,343E-07 | 100 | 1160 | | 1240 | | 900 | 740 | 430 |
| **10-Oct-21** | 720 | 21 | 20 | 3,052E-07 | 100 | 1160 | | 1240 | | 910 | 720 | 430 |
| **11-Oct-21** | 744 | 20 | 20 | 2,907E-07 | 100 | 1160 | | 1240 | | 900 | 710 | 430 |
| **12-Oct-21** | 768 | 22 | 20 | 3,198E-07 | 100 | 1160 | | 1240 | | 900 | 700 | 430 |
| **13-Oct-21** | 792 | 19 | 20 | 2,762E-07 | 100 | 1160 | | 1240 | | 960 | 750 | 430 |
| **14-Oct-21** | 816 | 20 | 20 | 2,907E-07 | 100 | 1160 | | 1240 | | 980 | 760 | 430 |
| **15-Oct-21** | 840 | 21 | 20 | 3,052E-07 | 100 | 1160 | | 1240 | | 910 | 740 | 430 |
| **16-Oct-21** | 864 | 20 | 20 | 2,907E-07 | 100 | 1160 | | 1240 | | 880 | 710 | 430 |
| **17-Oct-21** | 888 | 20 | 20 | 2,907E-07 | 100 | 1160 | | 1240 | | 890 | 720 | 430 |
| **18-Oct-21** | 912 | 20 | 20 | 2,907E-07 | 100 | 1160 | | 1240 | | 900 | 710 | 430 |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |

# Permeability Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S270-Zone 1* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *10-Sep-21* |
| **Project** | *Masters Thesis* | **Product** | *S270* |
| | | **Soil Sample** | *Clayey Silt* |



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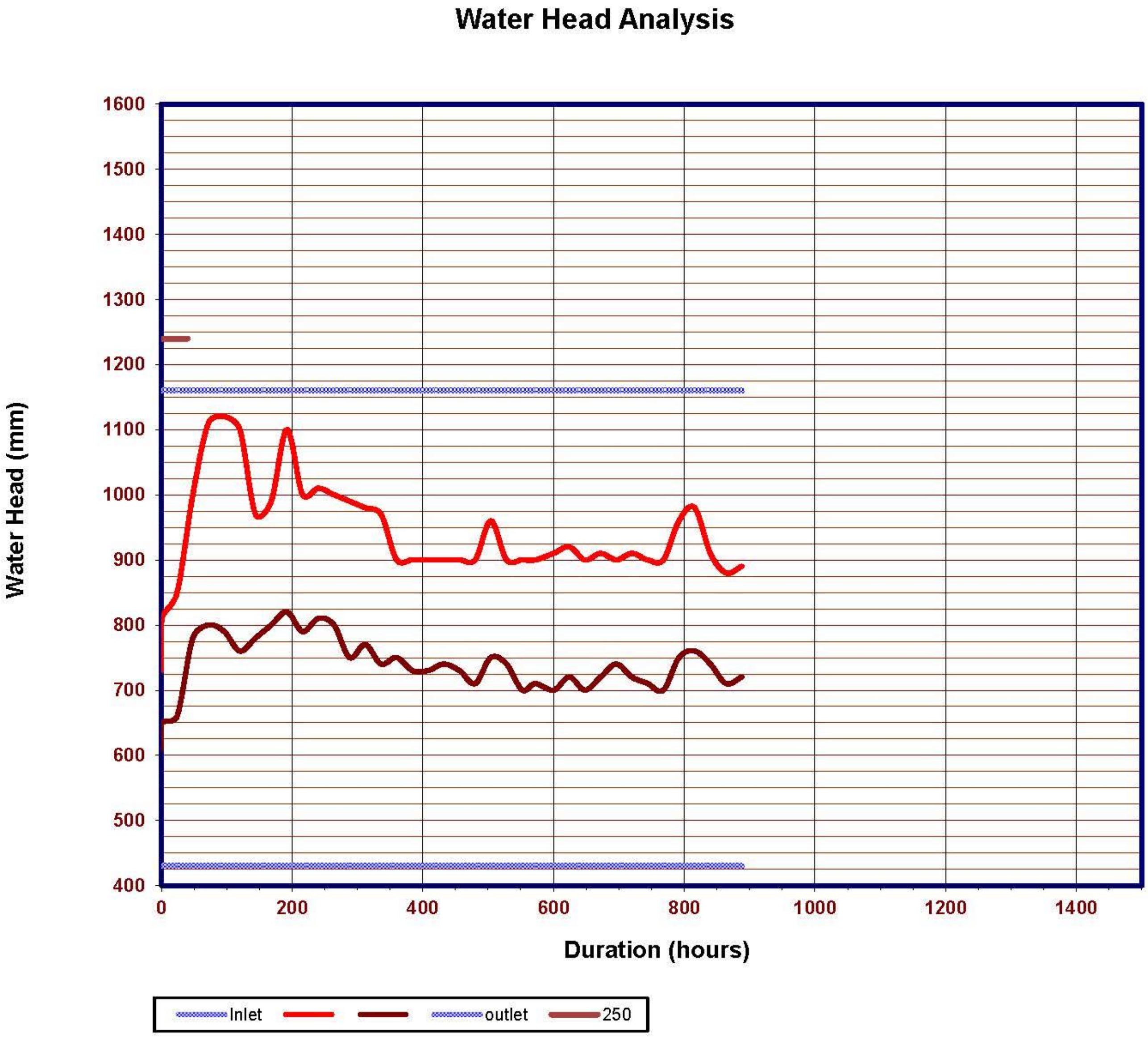
**www.soillab.co.za**

# Water Head Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S270-Zone 1* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *10-Sep-21* |
| **Project** | *Masters Thesis* | **Product** | *S270* |
| | | **Soil Sample** | *Clayey Silt* |



## Hydraulic Gradients and Gradient Ratios of the System

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S270-Zone 1* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *10-Sep-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *22-Oct-21* |
| **Project** | *Masters Thesis* | **Product** | *S270* |
| | | **Soil Sample** | *Clayey Silt* |

| Date | Test 3.90 943.20 | *L* | Δ*h* | Hydraulic Gradient (*i*) | Sample Height mm | Standpipe Readings - mm | | | | Gradient Ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 300 | 100 | 50 | 0 | |
| | | | | | | Inlet | h75 | h25 | h0 | |
| **10-Sep-21** | 0 | 100 | 120 | 1,200 | 100 | 1160 | 730 | 610 | 430 | 3,0 |
| **10-Sep-21** | 1 | 100 | 160 | 1,600 | 100 | 1160 | 810 | 650 | 430 | 2,8 |
| **11-Sep-21** | 24 | 100 | 190 | 1,900 | 100 | 1160 | 850 | 660 | 430 | 2,4 |
| **12-Sep-21** | 48 | 100 | 220 | 2,200 | 100 | 1160 | 1000 | 780 | 430 | 3,2 |
| **13-Sep-21** | 72 | 100 | 310 | 3,100 | 100 | 1160 | 1110 | 800 | 430 | 2,4 |
| **14-Sep-21** | 96 | 100 | 330 | 3,300 | 100 | 1160 | 1120 | 790 | 430 | 2,2 |
| **15-Sep-21** | 120 | 100 | 340 | 3,400 | 100 | 1160 | 1100 | 760 | 430 | 1,9 |
| **16-Sep-21** | 144 | 100 | 190 | 1,900 | 100 | 1160 | 970 | 780 | 430 | 3,7 |
| **17-Sep-21** | 168 | 100 | 190 | 1,900 | 100 | 1160 | 990 | 800 | 430 | 3,9 |
| **18-Sep-21** | 192 | 100 | 280 | 2,800 | 100 | 1160 | 1100 | 820 | 430 | 2,8 |
| **19-Sep-21** | 216 | 100 | 210 | 2,100 | 100 | 1160 | 1000 | 790 | 430 | 3,4 |
| **20-Sep-21** | 240 | 100 | 200 | 2,000 | 100 | 1160 | 1010 | 810 | 430 | 3,8 |
| **21-Sep-21** | 264 | 100 | 200 | 2,000 | 100 | 1160 | 1000 | 800 | 430 | 3,7 |
| **22-Sep-21** | 288 | 100 | 240 | 2,400 | 100 | 1160 | 990 | 750 | 430 | 2,7 |
| **23-Sep-21** | 312 | 100 | 210 | 2,100 | 100 | 1160 | 980 | 770 | 430 | 3,2 |
| **24-Sep-21** | 336 | 100 | 230 | 2,300 | 100 | 1160 | 970 | 740 | 430 | 2,7 |
| **25-Sep-21** | 360 | 100 | 150 | 1,500 | 100 | 1160 | 900 | 750 | 430 | 4,3 |
| **26-Sep-21** | 384 | 100 | 170 | 1,700 | 100 | 1160 | 900 | 730 | 430 | 3,5 |
| **27-Sep-21** | 408 | 100 | 170 | 1,700 | 100 | 1160 | 900 | 730 | 430 | 3,5 |
| **28-Sep-21** | 432 | 100 | 160 | 1,600 | 100 | 1160 | 900 | 740 | 430 | 3,9 |
| **29-Sep-21** | 456 | 100 | 170 | 1,700 | 100 | 1160 | 900 | 730 | 430 | 3,5 |
| **30-Sep-21** | 480 | 100 | 190 | 1,900 | 100 | 1160 | 900 | 710 | 430 | 2,9 |
| **01-Oct-21** | 504 | 100 | 210 | 2,100 | 100 | 1160 | 960 | 750 | 430 | 3,0 |
| **02-Oct-21** | 528 | 100 | 160 | 1,600 | 100 | 1160 | 900 | 740 | 430 | 3,9 |
| **03-Oct-21** | 552 | 100 | 200 | 2,000 | 100 | 1160 | 900 | 700 | 430 | 2,7 |
| **04-Oct-21** | 572 | 100 | 190 | 1,900 | 100 | 1160 | 900 | 710 | 430 | 2,9 |
| **05-Oct-21** | 600 | 100 | 210 | 2,100 | 100 | 1160 | 910 | 700 | 430 | 2,6 |
| **06-Oct-21** | 624 | 100 | 200 | 2,000 | 100 | 1160 | 920 | 720 | 430 | 2,9 |
| **07-Oct-21** | 648 | 100 | 200 | 2,000 | 100 | 1160 | 900 | 700 | 430 | 2,7 |
| **08-Oct-21** | 672 | 100 | 190 | 1,900 | 100 | 1160 | 910 | 720 | 430 | 3,1 |
| **09-Oct-21** | 696 | 100 | 160 | 1,600 | 100 | 1160 | 900 | 740 | 430 | 3,9 |
| **10-Oct-21** | 720 | 100 | 190 | 1,900 | 100 | 1160 | 910 | 720 | 430 | 3,1 |
| **11-Oct-21** | 744 | 100 | 190 | 1,900 | 100 | 1160 | 900 | 710 | 430 | 2,9 |
| **12-Oct-21** | 768 | 100 | 200 | 2,000 | 100 | 1160 | 900 | 700 | 430 | 2,7 |
| **13-Oct-21** | 792 | 100 | 210 | 2,100 | 100 | 1160 | 960 | 750 | 430 | 3,0 |
| **14-Oct-21** | 816 | 100 | 220 | 2,200 | 100 | 1160 | 980 | 760 | 430 | 3,0 |
| **15-Oct-21** | 840 | 100 | 170 | 1,700 | 100 | 1160 | 910 | 740 | 430 | 3,6 |
| **16-Oct-21** | 864 | 100 | 170 | 1,700 | 100 | 1160 | 880 | 710 | 430 | 3,3 |
| **17-Oct-21** | 888 | 100 | 170 | 1,700 | 100 | 1160 | 890 | 720 | 430 | 3,4 |
| **18-Oct-21** | 912 | 100 | 190 | 1,900 | 100 | 1160 | 900 | 710 | 430 | 2,9 |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |

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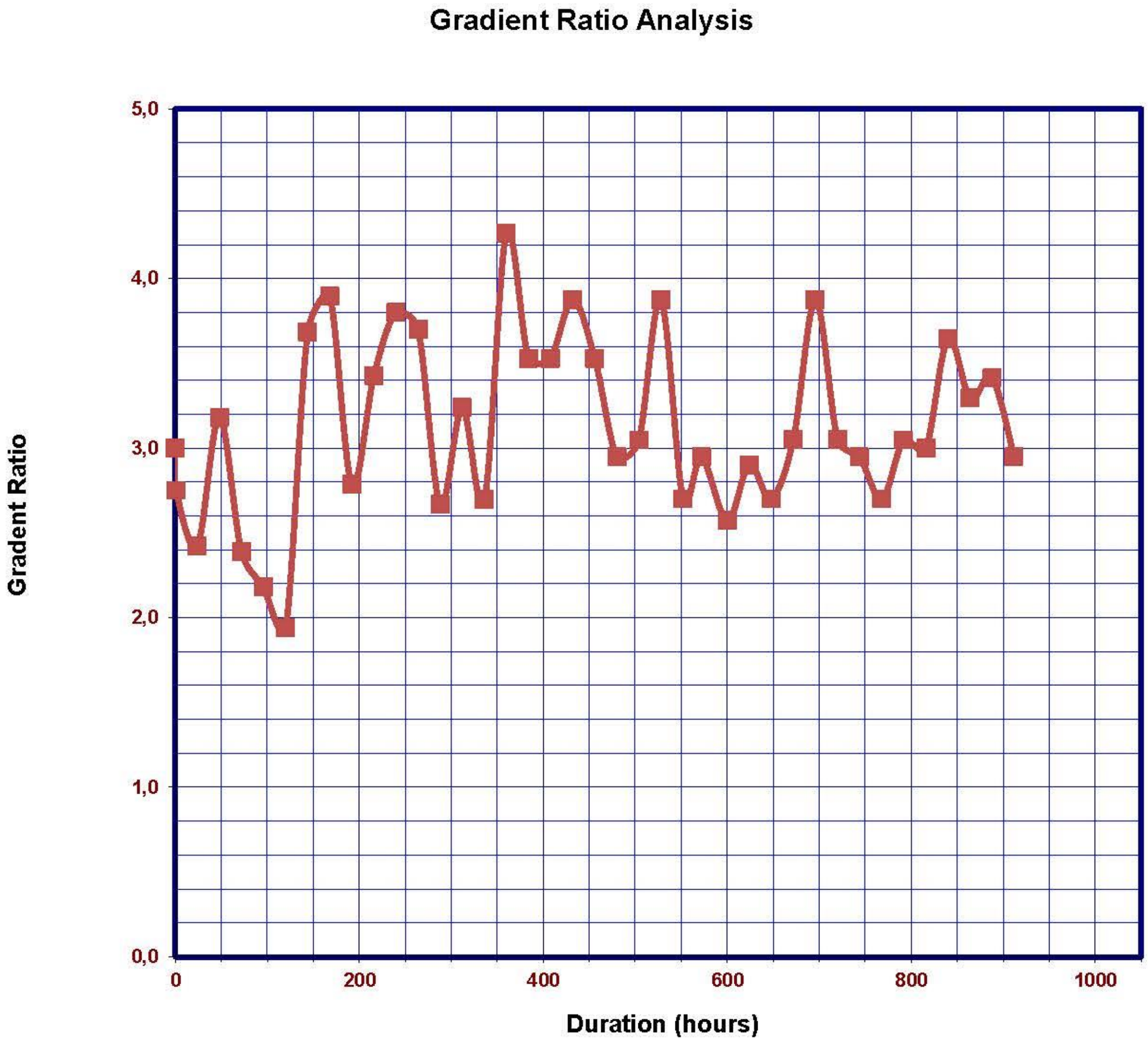
# Gradient Ratio

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S270-Zone 1* |
| **Consultant** | *Vincent Mukwevho* | **Date** | *10-Sep-21* |
| **Project** | *Masters Thesis* | **Product** | *S270* |
| | | **Soil Sample** | *Clayey Silt* |



Gradient Ratio Analysis

# APPENDIX F

## Laboratory Results – Zone 2 Soil (Clayey Sand Vs A2)

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# LONG TERM GRADIENT RATIO TEST REPORT

## Permeameter Summary

### GL Test Method 1 (Adapted from Kaytech Engineerred Fabrics)

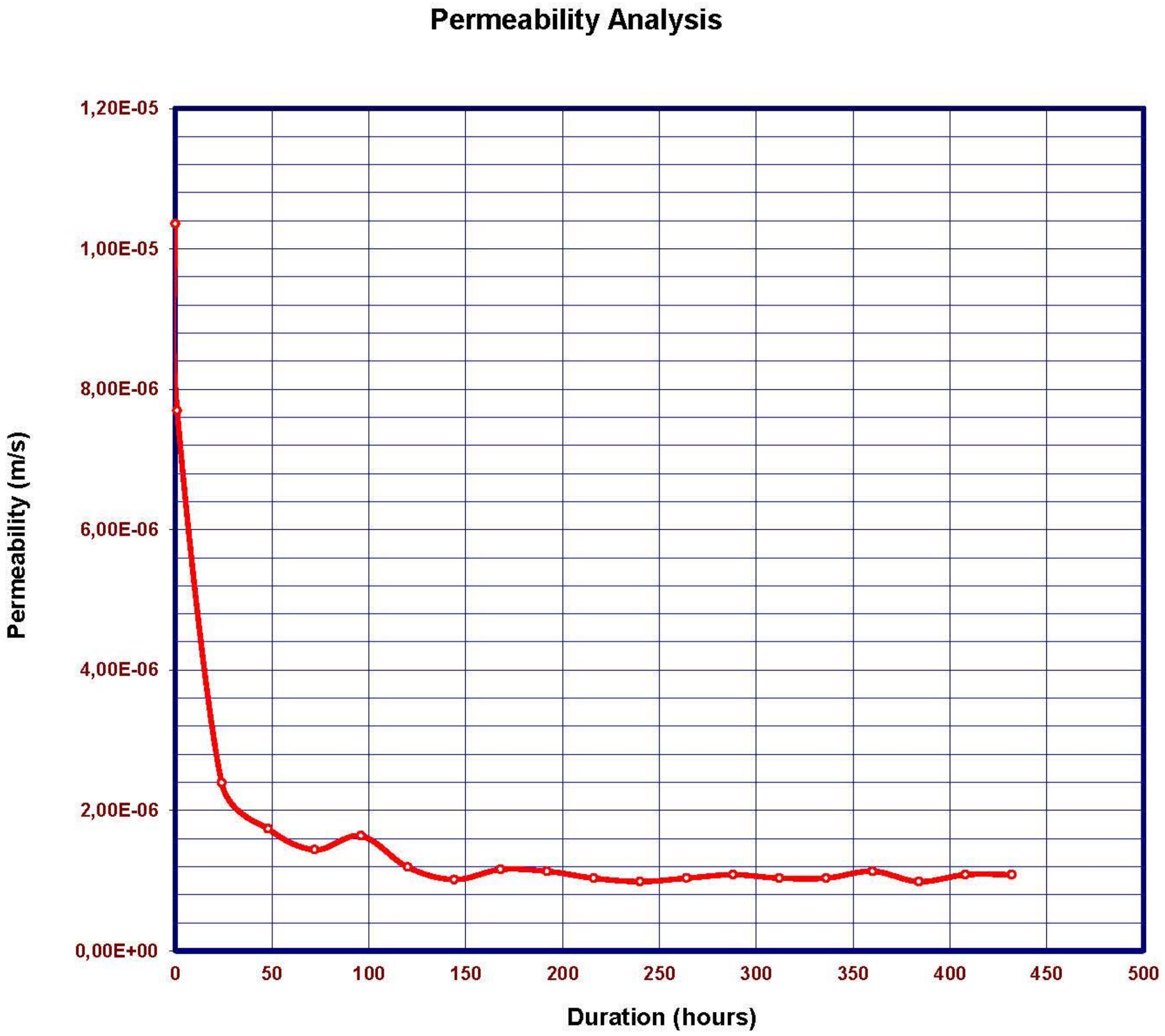
| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A2 - Zone 2* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *29-Jun-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *17-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A2* |
| | | **Soil Sample** | *Clayey Sand* |

| | | | | |
|---|---|---|---|---|
| **Equipment** | *GL MK1 Permeameter* | | **Support Above** | *none* |
| **Internal Diameter** | *100mm* | | **Support Below** | *wire mesh* |
| **Wetting Up** | *Below* | | **Preparation** | *Oven Dried* |
| | **Mass @ Start (g)** | **Mass @ Finish (g)** | **Thickness (mm)** | **k estimate** |
| **Geosynthetic** | *2,90* | *5,39* | *1.69* | |
| **Soil Sample** | *1203,40* | *1196.40* | *160* | |

| Date Start 31-03-2016 11h00 | Test Accummulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| ***29-Jun-21*** | *0* | *183* | *10* | *1,036E-05* | *160* | *1030* | | *1290* | | *1390* | *460* | *430* |
| ***29-Jun-21*** | *1* | *136* | *10* | *7,696E-06* | *160* | *1030* | | *1310* | | *1410* | *590* | *430* |
| ***30-Jun-21*** | *24* | *50* | *10* | *2,391E-06* | *160* | *1140* | | *1340* | | *1430* | *880* | *430* |
| ***01-Jul-21*** | *48* | *35* | *10* | *1,735E-06* | *160* | *1115* | | *1290* | | *1390* | *890* | *430* |
| ***02-Jul-21*** | *72* | *29* | *10* | *1,437E-06* | *160* | *1115* | | *1290* | | *1400* | *875* | *430* |
| ***03-Jul-21*** | *96* | *33* | *10* | *1,636E-06* | *160* | *1115* | | *1290* | | *1390* | *850* | *430* |
| ***04-Jul-21*** | *120* | *24* | *10* | *1,190E-06* | *160* | *1115* | | *1290* | | *1400* | *880* | *430* |
| ***05-Jul-21*** | *144* | *20* | *10* | *1,014E-06* | *160* | *1100* | | *1290* | | *1400* | *860* | *430* |
| ***06-Jul-21*** | *168* | *23* | *10* | *1,157E-06* | *160* | *1105* | | *1300* | | *1390* | *870* | *430* |
| ***07-Jul-21*** | *192* | *23* | *10* | *1,132E-06* | *160* | *1120* | | *1300* | | *1390* | *850* | *430* |
| ***08-Jul-21*** | *216* | *21* | *10* | *1,033E-06* | *160* | *1120* | | *1300* | | *1390* | *860* | *430* |
| ***09-Jul-21*** | *240* | *20* | *10* | *9,841E-07* | *160* | *1120* | | *1300* | | *1390* | *880* | *430* |
| ***10-Jul-21*** | *264* | *21* | *10* | *1,033E-06* | *160* | *1120* | | *1300* | | *1390* | *870* | *430* |
| ***11-Jul-21*** | *288* | *22* | *10* | *1,083E-06* | *160* | *1120* | | *1300* | | *1390* | *890* | *430* |
| ***12-Jul-21*** | *312* | *21* | *10* | *1,033E-06* | *160* | *1120* | | *1300* | | *1390* | *880* | *430* |
| ***13-Jul-21*** | *336* | *21* | *10* | *1,033E-06* | *160* | *1120* | | *1300* | | *1390* | *860* | *430* |
| ***14-Jul-21*** | *360* | *23* | *10* | *1,132E-06* | *160* | *1120* | | *1300* | | *1390* | *870* | *430* |
| ***15-Jul-21*** | *384* | *20* | *10* | *9,841E-07* | *160* | *1120* | | *1300* | | *1390* | *880* | *430* |
| ***16-Jul-21*** | *408* | *22* | *10* | *1,083E-06* | *160* | *1120* | | *1300* | | *1390* | *880* | *430* |
| ***17-Jul-21*** | *432* | *22* | *10* | *1,083E-06* | *160* | *1120* | | *1300* | | *1390* | *880* | *430* |

# Permeability Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A2 - Zone 2* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *29-Jun-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A2* |
| | | **Soil Sample** | *Clayey Sand* |



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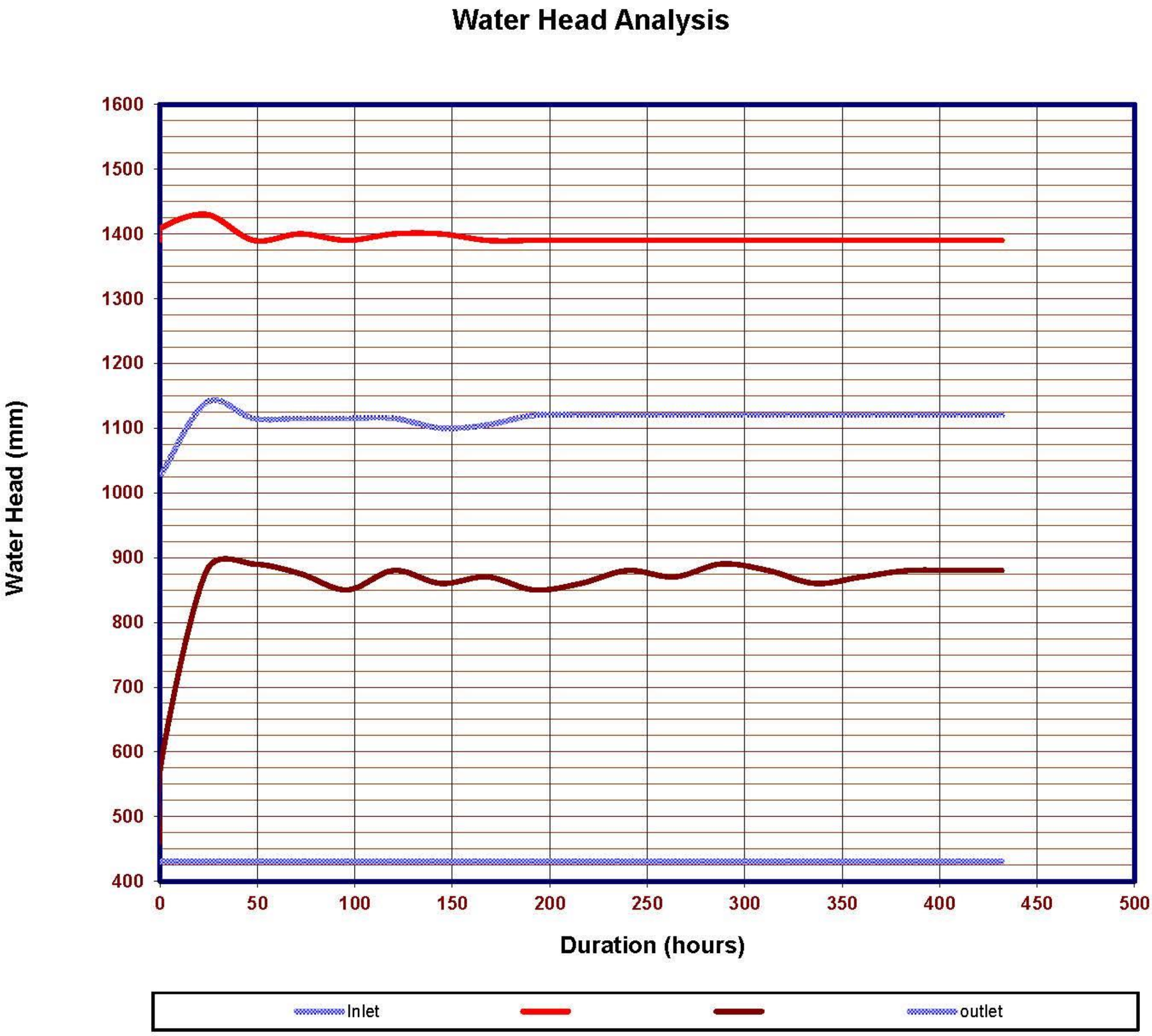
# Water Head Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A2 - Zone 2* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *17-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A2* |
| | | **Soil Sample** | *Clayey Sand* |



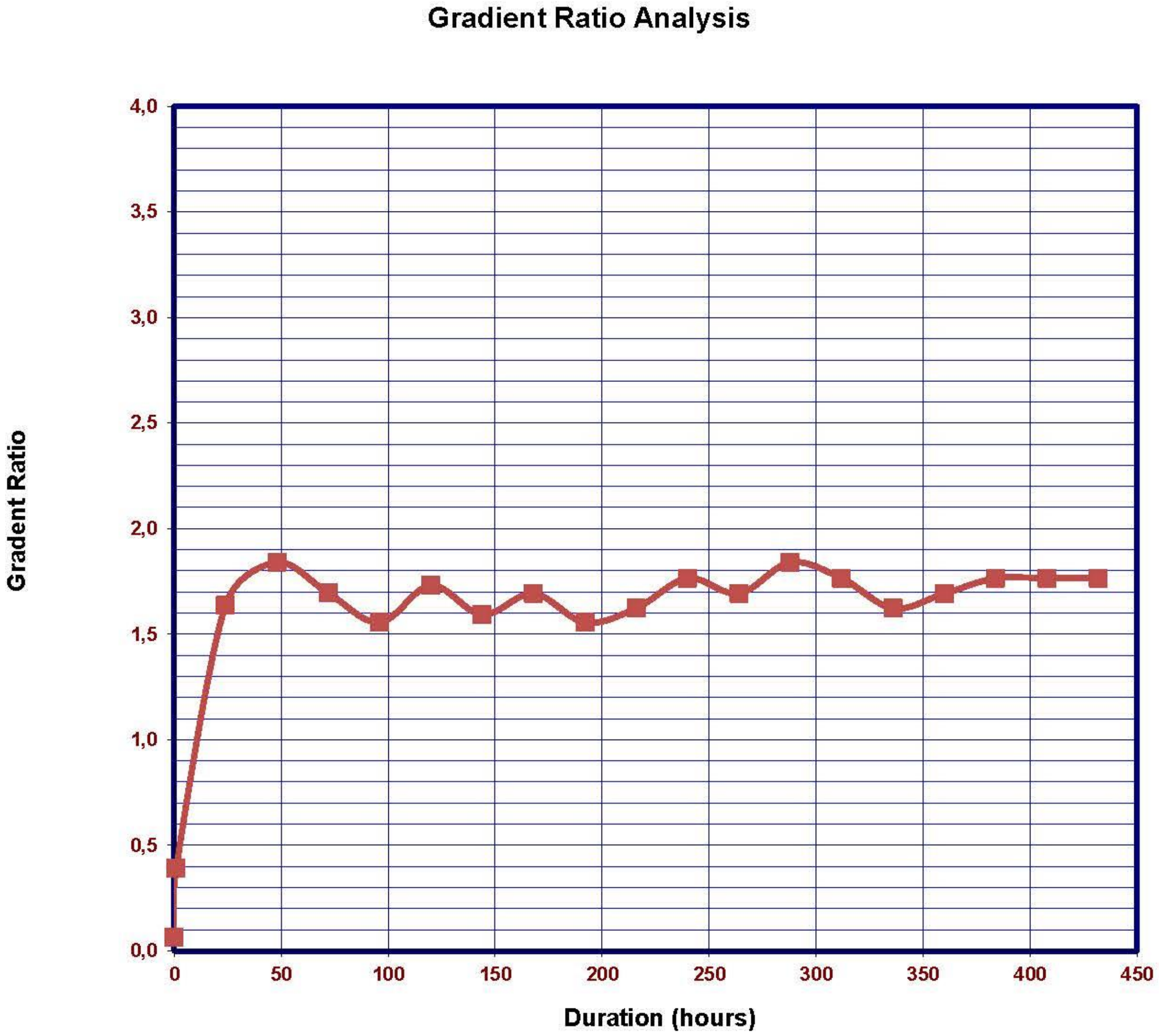
## Hydraulic Gradients and Gradient Ratios of the System

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A2 - Zone 2* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *29-Jun-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *17-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A2* |
| | | **Soil Sample** | *Quartz Sand 1* |

| Date | Test Accummulative Hours | | | Hydraulic Gradient (*i*) | Sample Height mm | Standpipe Readings - mm | | | | Gradient Ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *L* | Δ*h* | | | 300 | 100 | 50 | 0 | |
| | | | | | | Inlet | h75 | h25 | h0 | |
| **29-Jun-21** | *0* | *160* | *930* | *5,813* | *160* | *1030* | *1390* | *460* | *430* | 0,1 |
| **29-Jun-21** | *1* | *160* | *820* | *5,125* | *160* | *1030* | *1410* | *590* | *430* | 0,4 |
| **30-Jun-21** | *24* | *160* | *550* | *3,438* | *160* | *1140* | *1430* | *880* | *430* | 1,6 |
| **01-Jul-21** | *48* | *160* | *500* | *3,125* | *160* | *1115* | *1390* | *890* | *430* | 1,8 |
| **02-Jul-21** | *72* | *160* | *525* | *3,281* | *160* | *1115* | *1400* | *875* | *430* | 1,7 |
| **03-Jul-21** | *96* | *160* | *540* | *3,375* | *160* | *1115* | *1390* | *850* | *430* | 1,6 |
| **04-Jul-21** | *120* | *160* | *520* | *3,250* | *160* | *1115* | *1400* | *880* | *430* | 1,7 |
| **05-Jul-21** | *144* | *160* | *540* | *3,375* | *160* | *1100* | *1400* | *860* | *430* | 1,6 |
| **06-Jul-21** | *168* | *160* | *520* | *3,250* | *160* | *1105* | *1390* | *870* | *430* | 1,7 |
| **07-Jul-21** | *192* | *160* | *540* | *3,375* | *160* | *1120* | *1390* | *850* | *430* | 1,6 |
| **08-Jul-21** | *216* | *160* | *530* | *3,313* | *160* | *1120* | *1390* | *860* | *430* | 1,6 |
| **09-Jul-21** | *240* | *160* | *510* | *3,188* | *160* | *1120* | *1390* | *880* | *430* | 1,8 |
| **10-Jul-21** | *264* | *160* | *520* | *3,250* | *160* | *1120* | *1390* | *870* | *430* | 1,7 |
| **11-Jul-21** | *288* | *160* | *500* | *3,125* | *160* | *1120* | *1390* | *890* | *430* | 1,8 |
| **12-Jul-21** | *312* | *160* | *510* | *3,188* | *160* | *1120* | *1390* | *880* | *430* | 1,8 |
| **13-Jul-21** | *336* | *160* | *530* | *3,313* | *160* | *1120* | *1390* | *860* | *430* | 1,6 |
| **14-Jul-21** | *360* | *160* | *520* | *3,250* | *160* | *1120* | *1390* | *870* | *430* | 1,7 |
| **15-Jul-21** | *384* | *160* | *510* | *3,188* | *160* | *1120* | *1390* | *880* | *430* | 1,8 |
| **16-Jul-21** | *408* | *160* | *510* | *3,188* | *160* | *1120* | *1390* | *880* | *430* | 1,8 |
| **17-Jul-21** | *432* | *160* | *510* | *3,188* | *160* | *1120* | *1390* | *880* | *430* | 1,8 |

# Gradient Ratio

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A2 - Zone 2* |
| **Consultant** | *Vincent Mukwevho* | **Date** | *17-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A2* |
| | | **Soil Sample** | *Clayey Sand* |



# APPENDIX G

## Laboratory Results – Zone 2 Soil (Clayey Sand Vs A4)

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# LONG TERM GRADIENT RATIO TEST REPORT

## Permeameter Summary

### GL Test Method 1 (Adapted from Kaytech Engineerred Fabrics)

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A4 - Zone 2* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *2021-06-129* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *17-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A4* |
| | | **Soil Sample** | *Clayey Sand* |

| | | | | |
|---|---|---|---|---|
| **Equipment** | *GL MK1 Permeameter* | | **Support Above** | *none* |
| **Internal Diameter** | *100mm* | | **Support Below** | *wire mesh* |
| **Wetting Up** | *Below* | | **Preparation** | *Oven Dried* |
| | **Mass @ Start (g)** | **Mass @ Finish (g)** | **Thickness (mm)** | **k estimate** |
| **Geosynthetic** | *3.80* | *7.50* | *2.37* | |
| **Soil Sample** | *1214.7* | *1204.74* | *120* | |

| Date Start 31-03-2016 11h00 | Test Accummulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | Silica Sand | | | Soil Sample | | Outlet |
| ***29-Jun-21*** | *0* | *182* | *10* | *9,269E-06* | *120* | *930* | | *1300* | | *500* | *440* | *430* |
| ***29-Jun-21*** | *1* | *131* | *10* | *4,906E-06* | *120* | *1110* | | *1310* | | *550* | *450* | *430* |
| ***30-Jun-21*** | *24* | *78* | *10* | *2,580E-06* | *120* | *1200* | | *1340* | | *1170* | *660* | *430* |
| ***01-Jul-21*** | *48* | *48* | *10* | *1,722E-06* | *120* | *1140* | | *1290* | | *1320* | *720* | *430* |
| ***02-Jul-21*** | *72* | *38* | *10* | *1,363E-06* | *120* | *1140* | | *1290* | | *1330* | *710* | *430* |
| ***03-Jul-21*** | *96* | *40* | *10* | *1,435E-06* | *120* | *1140* | | *1290* | | *1330* | *690* | *430* |
| ***04-Jul-21*** | *120* | *33* | *10* | *1,184E-06* | *120* | *1140* | | *1290* | | *1340* | *720* | *430* |
| ***05-Jul-21*** | *144* | *31* | *10* | *1,112E-06* | *120* | *1140* | | *1290* | | *1360* | *730* | *430* |
| ***06-Jul-21*** | *168* | *83* | *10* | *2,977E-06* | *120* | *1140* | | *1300* | | *1290* | *710* | *430* |
| ***07-Jul-21*** | *192* | *65* | *10* | *2,331E-06* | *120* | *1140* | | *1300* | | *1280* | *730* | *430* |
| ***08-Jul-21*** | *216* | *60* | *10* | *2,152E-06* | *120* | *1140* | | *1300* | | *1225* | *720* | *430* |
| ***09-Jul-21*** | *240* | *53* | *10* | *1,901E-06* | *120* | *1140* | | *1300* | | *1260* | *720* | *430* |
| ***10-Jul-21*** | *264* | *41* | *10* | *1,470E-06* | *120* | *1140* | | *1300* | | *1260* | *740* | *430* |
| ***11-Jul-21*** | *288* | *45* | *10* | *1,614E-06* | *120* | *1140* | | *1300* | | *1230* | *750* | *430* |
| ***12-Jul-21*** | *312* | *47* | *10* | *1,686E-06* | *120* | *1140* | | *1300* | | *1260* | *735* | *430* |
| ***13-Jul-21*** | *336* | *42* | *10* | *1,506E-06* | *120* | *1140* | | *1300* | | *1260* | *710* | *430* |
| ***14-Jul-21*** | *360* | *49* | *10* | *1,757E-06* | *120* | *1140* | | *1300* | | *1280* | *720* | *430* |
| ***15-Jul-21*** | *384* | *51* | *10* | *1,829E-06* | *120* | *1140* | | *1300* | | *1260* | *700* | *430* |
| ***16-Jul-21*** | *408* | *48* | *10* | *1,722E-06* | *120* | *1140* | | *1300* | | *1260* | *720* | *430* |
| ***17-Jul-21*** | *432* | *49* | *10* | *1,757E-06* | *120* | *1140* | | *1300* | | *1230* | *720* | *430* |

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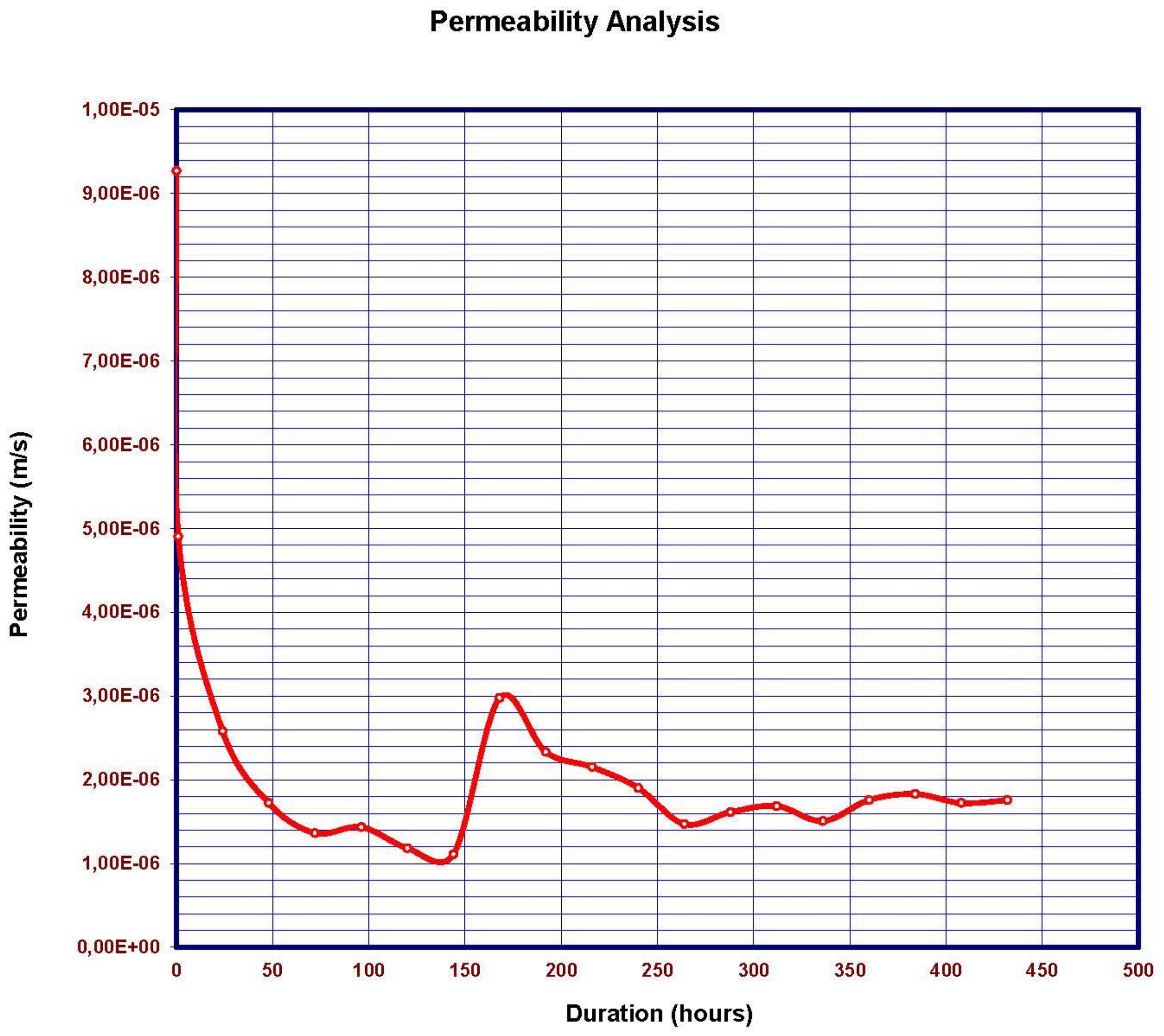
# Permeability Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A4 - Zone 2* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *2021-06-129* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A4* |
| | | **Soil Sample** | *Clayey Sand* |



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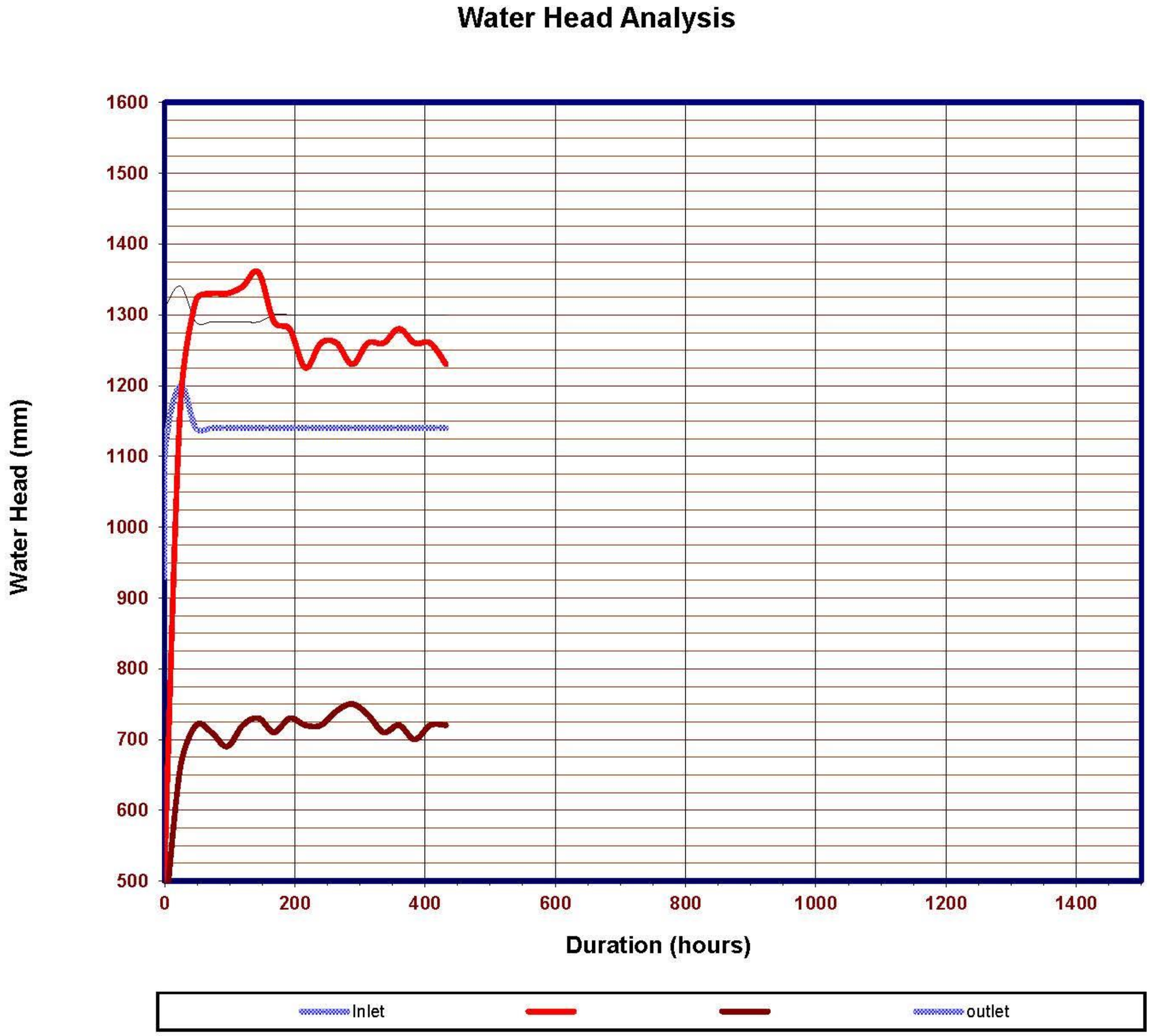
# Water Head Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A4 - Zone 2* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *2021-06-129* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A4* |
| | | **Soil Sample** | *Clayey Sand* |



## Hydraulic Gradients and Gradient Ratios of the System

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *P2017020/05* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *19-May-17* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *17-Jul-17* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A2* |
| | | **Soil Sample** | *Quartz Sand 1* |

| Date | Test<br>3.80<br>1214.7 | L | Δh | Hydraulic Gradient (i) | Sample Height mm | Standpipe Readings - mm<br>300<br>Inlet | <br>100<br>h75 | <br>50<br>h25 | <br>0<br>h0 | Gradient Ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| **29-Jun-21** | *0* | *120* | *60* | *0,500* | *120* | *930* | *500* | *440* | *430* | 0,3 |
| **29-Jun-21** | *1* | *120* | *100* | *0,833* | *120* | *1110* | *550* | *450* | *430* | 0,4 |
| **30-Jun-21** | *24* | *120* | *510* | *4,250* | *120* | *1200* | *1170* | *660* | *430* | 0,9 |
| **01-Jul-21** | *48* | *120* | *600* | *5,000* | *120* | *1140* | *1320* | *720* | *430* | 1,0 |
| **02-Jul-21** | *72* | *120* | *620* | *5,167* | *120* | *1140* | *1330* | *710* | *430* | 0,9 |
| **03-Jul-21** | *96* | *120* | *640* | *5,333* | *120* | *1140* | *1330* | *690* | *430* | 0,8 |
| **04-Jul-21** | *120* | *120* | *620* | *5,167* | *120* | *1140* | *1340* | *720* | *430* | 0,9 |
| **05-Jul-21** | *144* | *120* | *630* | *5,250* | *120* | *1140* | *1360* | *730* | *430* | 1,0 |
| **06-Jul-21** | *168* | *120* | *580* | *4,833* | *120* | *1140* | *1290* | *710* | *430* | 1,0 |
| **07-Jul-21** | *192* | *120* | *550* | *4,583* | *120* | *1140* | *1280* | *730* | *430* | 1,1 |
| **08-Jul-21** | *216* | *120* | *505* | *4,208* | *120* | *1140* | *1225* | *720* | *430* | 1,1 |
| **09-Jul-21** | *240* | *120* | *540* | *4,500* | *120* | *1140* | *1260* | *720* | *430* | 1,1 |
| **10-Jul-21** | *264* | *120* | *520* | *4,333* | *120* | *1140* | *1260* | *740* | *430* | 1,2 |
| **11-Jul-21** | *288* | *120* | *480* | *4,000* | *120* | *1140* | *1230* | *750* | *430* | 1,3 |
| **12-Jul-21** | *312* | *120* | *525* | *4,375* | *120* | *1140* | *1260* | *735* | *430* | 1,2 |
| **13-Jul-21** | *336* | *120* | *550* | *4,583* | *120* | *1140* | *1260* | *710* | *430* | 1,0 |
| **14-Jul-21** | *360* | *120* | *560* | *4,667* | *120* | *1140* | *1280* | *720* | *430* | 1,0 |
| **15-Jul-21** | *384* | *120* | *560* | *4,667* | *120* | *1140* | *1260* | *700* | *430* | 1,0 |
| **16-Jul-21** | *408* | *120* | *540* | *4,500* | *120* | *1140* | *1260* | *720* | *430* | 1,1 |
| **17-Jul-21** | *432* | *120* | *510* | *4,250* | *120* | *1140* | *1230* | *720* | *430* | 1,1 |

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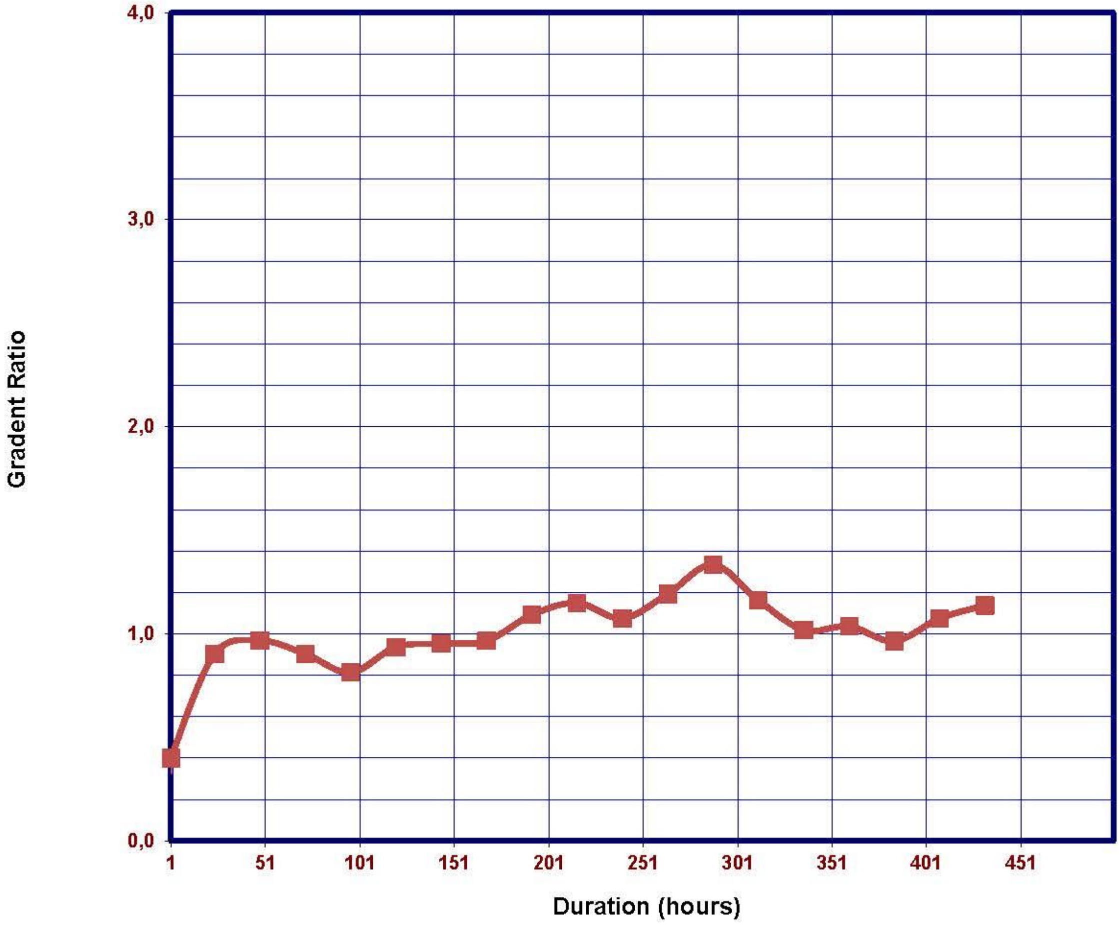
## Gradient Ratio

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A4 - Zone 2* |
| **Consultant** | *Vincent Mukwevho* | **Date** | *17-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A4* |
| | | **Soil Sample** | *Clayey Sand* |

### Gradient Ratio Analysis



# APPENDIX H

## Laboratory Results – Zone 2 Soil (Clayey Sand Vs A6)

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# LONG TERM GRADIENT RATIO TEST REPORT
## Permeameter Summary
### GL Test Method 1 (Adapted from Kaytech Engineerred Fabrics)

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A6 - Zone 2* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *12-Jun-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *30-Jun-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A6* |
| | | **Soil Sample** | *Clayey Sand* |

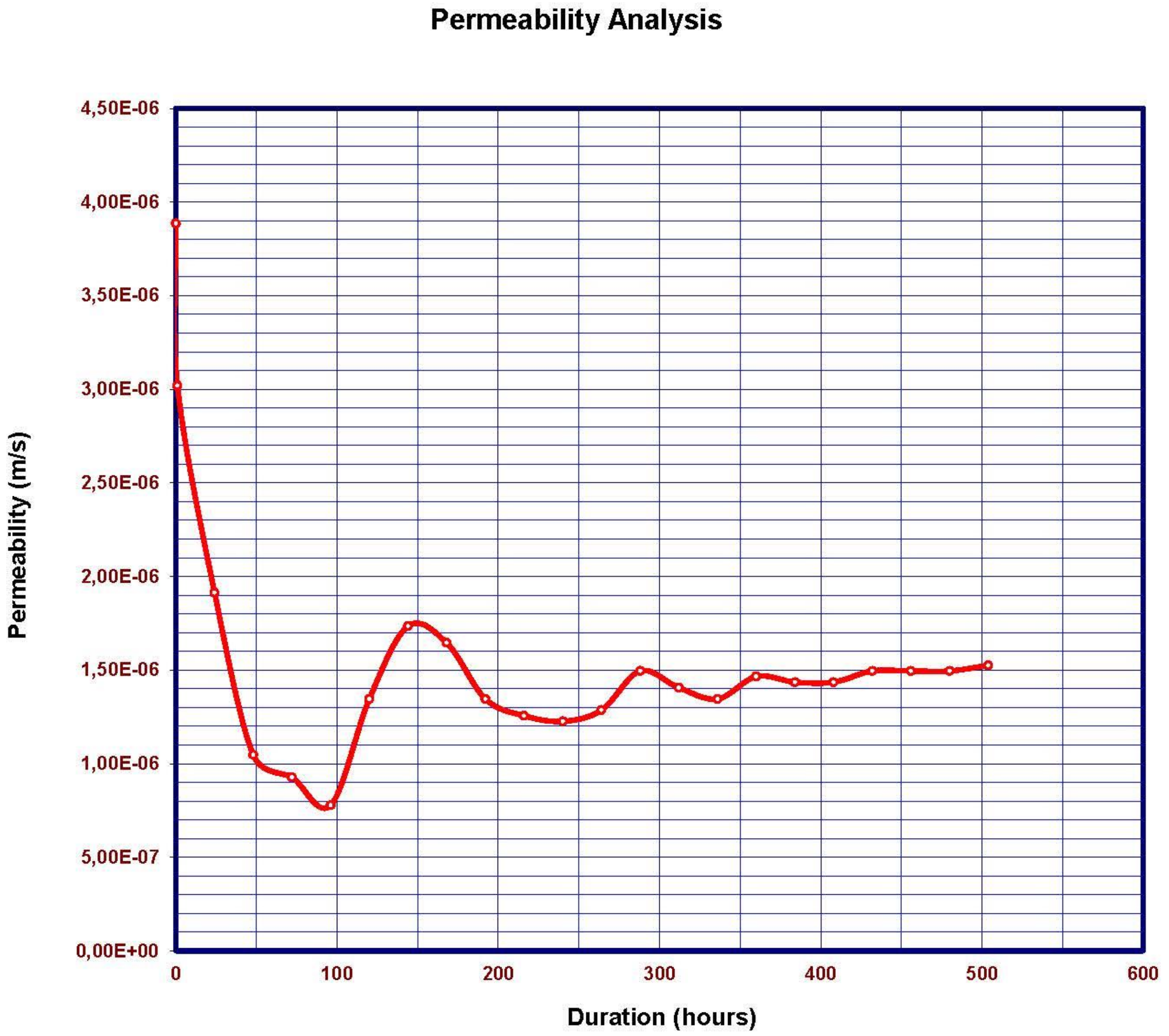
| | | | |
|---|---|---|---|
| **Equipment** | *GL MK1 Permeameter* | **Support Above** | *none* |
| **Internal Diameter** | *100mm* | **Support Below** | *wire mesh* |
| **Wetting Up** | *Below* | **Preparation** | *Oven Dried* |

| | Mass @ Start (g) | Mass @ Finish (g) | Thickness (mm) | k estimate |
|---|---|---|---|---|
| **Geosynthetic** | *5.30* | *7.16* | *3.36* | |
| **Soil Sample** | *1165.3* | *1161.67* | *100* | |

| Date Start 31-03-2016 11h00 | Test Accummulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| **12-Jun-21** | 0 | 130 | 10 | 3,885E-06 | 100 | 1140 | | 1250 | | 1060 | 700 | 430 |
| **12-Jun-21** | 1 | 101 | 10 | 3,019E-06 | 100 | 1140 | | 1270 | | 1210 | 790 | 430 |
| **13-Jun-21** | 24 | 64 | 10 | 1,913E-06 | 100 | 1140 | | 1290 | | 1280 | 880 | 430 |
| **14-Jun-21** | 48 | 35 | 10 | 1,046E-06 | 100 | 1140 | | 1290 | | 1280 | 920 | 430 |
| **15-Jun-21** | 72 | 31 | 10 | 9,265E-07 | 100 | 1140 | | 1290 | | 1290 | 920 | 430 |
| **16-Jun-21** | 96 | 26 | 10 | 7,771E-07 | 100 | 1140 | | 1290 | | 1310 | 920 | 430 |
| **17-Jun-21** | 120 | 45 | 10 | 1,345E-06 | 100 | 1140 | | 1300 | | 1230 | 920 | 430 |
| **18-Jun-21** | 144 | 58 | 10 | 1,734E-06 | 100 | 1140 | | 1300 | | 1110 | 880 | 430 |
| **19-Jun-21** | 168 | 55 | 10 | 1,644E-06 | 100 | 1140 | | 1300 | | 1060 | 830 | 430 |
| **20-Jun-21** | 192 | 45 | 10 | 1,345E-06 | 100 | 1140 | | 1300 | | 1020 | 800 | 430 |
| **21-Jun-21** | 216 | 42 | 10 | 1,255E-06 | 100 | 1140 | | 1300 | | 1040 | 850 | 430 |
| **22-Jun-21** | 240 | 41 | 10 | 1,225E-06 | 100 | 1140 | | 1300 | | 1060 | 820 | 430 |
| **23-Jun-21** | 264 | 43 | 10 | 1,285E-06 | 100 | 1140 | | 1300 | | 1100 | 830 | 430 |
| **24-Jun-21** | 288 | 50 | 10 | 1,494E-06 | 100 | 1140 | | 1300 | | 1120 | 850 | 430 |
| **25-Jun-21** | 312 | 47 | 10 | 1,405E-06 | 100 | 1140 | | 1300 | | 1080 | 840 | 430 |
| **26-Jun-21** | 336 | 45 | 10 | 1,345E-06 | 100 | 1140 | | 1300 | | 1060 | 860 | 430 |
| **27-Jun-21** | 360 | 49 | 10 | 1,465E-06 | 100 | 1140 | | 1300 | | 1060 | 840 | 430 |
| **28-Jun-21** | 384 | 48 | 10 | 1,435E-06 | 100 | 1140 | | 1300 | | 1080 | 870 | 430 |
| **29-Jun-21** | 408 | 48 | 10 | 1,435E-06 | 100 | 1140 | | 1300 | | 1100 | 860 | 430 |
| **30-Jun-21** | 432 | 50 | 10 | 1,494E-06 | 100 | 1140 | | 1300 | | 1100 | 830 | 430 |
| **01-Jul-21** | 456 | 50 | 10 | 1,494E-06 | 100 | 1140 | | 1300 | | 1090 | 840 | 430 |
| **02-Jul-21** | 480 | 50 | 10 | 1,494E-06 | 100 | 1140 | | 1300 | | 1100 | 830 | 430 |
| **03-Jul-21** | 504 | 51 | 10 | 1,524E-06 | 100 | 1140 | | 1300 | | 1080 | 830 | 430 |

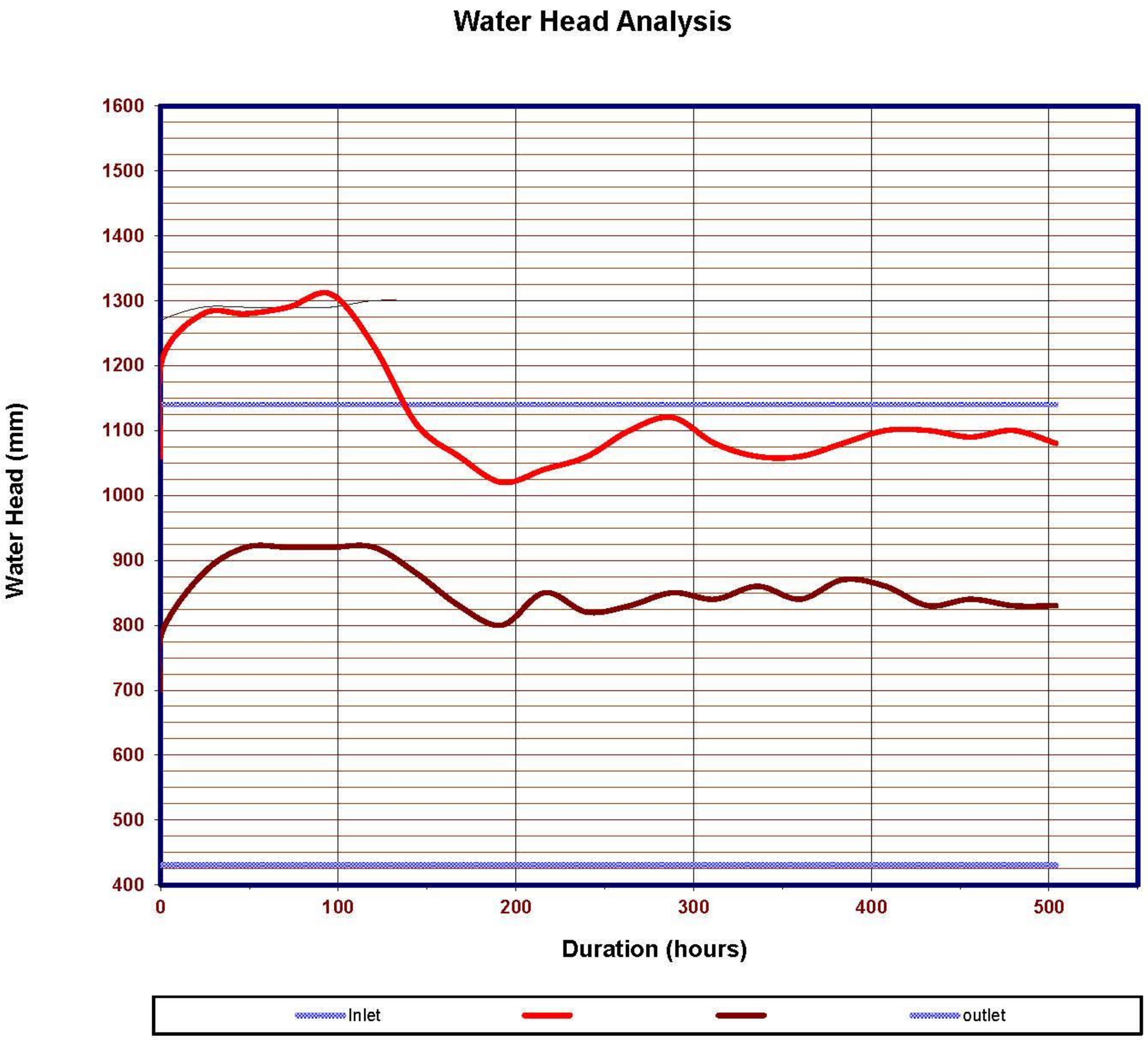
# Permeability Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A6 - Zone 2* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *12-Jun-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A6* |
| | | **Soil Sample** | *Clayey Sand* |



# Water Head Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A6 - Zone 2* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *12-Jun-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A6* |
| | | **Soil Sample** | *Clayey Sand* |



## Hydraulic Gradients and Gradient Ratios of the System

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A6 - Zone 2* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *19-May-17* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *17-Jul-17* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A2* |
| | | **Soil Sample** | *Quartz Sand 1* |

| Date | Test Accummulative 5.30 | L | Δh | Hydraulic Gradient (i) | Sample Height mm | Standpipe Readings - mm<br>300<br>Inlet | 100<br>h75 | 50<br>h25 | 0<br>h0 | Gradient Ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| **12-Jun-21** | 0 | 100 | 360 | 3,600 | 100 | 1140 | 1060 | 700 | 430 | 1,5 |
| **12-Jun-21** | 1 | 100 | 420 | 4,200 | 100 | 1140 | 1210 | 790 | 430 | 1,7 |
| **13-Jun-21** | 24 | 100 | 400 | 4,000 | 100 | 1140 | 1280 | 880 | 430 | 2,3 |
| **14-Jun-21** | 48 | 100 | 360 | 3,600 | 100 | 1140 | 1280 | 920 | 430 | 2,7 |
| **15-Jun-21** | 72 | 100 | 370 | 3,700 | 100 | 1140 | 1290 | 920 | 430 | 2,6 |
| **16-Jun-21** | 96 | 100 | 390 | 3,900 | 100 | 1140 | 1310 | 920 | 430 | 2,5 |
| **17-Jun-21** | 120 | 100 | 310 | 3,100 | 100 | 1140 | 1230 | 920 | 430 | 3,2 |
| **18-Jun-21** | 144 | 100 | 230 | 2,300 | 100 | 1140 | 1110 | 880 | 430 | 3,9 |
| **19-Jun-21** | 168 | 100 | 230 | 2,300 | 100 | 1140 | 1060 | 830 | 430 | 3,5 |
| **20-Jun-21** | 192 | 100 | 220 | 2,200 | 100 | 1140 | 1020 | 800 | 430 | 3,4 |
| **21-Jun-21** | 216 | 100 | 190 | 1,900 | 100 | 1140 | 1040 | 850 | 430 | 4,4 |
| **22-Jun-21** | 240 | 100 | 240 | 2,400 | 100 | 1140 | 1060 | 820 | 430 | 3,3 |
| **23-Jun-21** | 264 | 100 | 270 | 2,700 | 100 | 1140 | 1100 | 830 | 430 | 3,0 |
| **24-Jun-21** | 288 | 100 | 270 | 2,700 | 100 | 1140 | 1120 | 850 | 430 | 3,1 |
| **25-Jun-21** | 312 | 100 | 240 | 2,400 | 100 | 1140 | 1080 | 840 | 430 | 3,4 |
| **26-Jun-21** | 336 | 100 | 200 | 2,000 | 100 | 1140 | 1060 | 860 | 430 | 4,3 |
| **27-Jun-21** | 360 | 100 | 220 | 2,200 | 100 | 1140 | 1060 | 840 | 430 | 3,7 |
| **28-Jun-21** | 384 | 100 | 210 | 2,100 | 100 | 1140 | 1080 | 870 | 430 | 4,2 |
| **29-Jun-21** | 408 | 100 | 240 | 2,400 | 100 | 1140 | 1100 | 860 | 430 | 3,6 |
| **30-Jun-21** | 432 | 100 | 270 | 2,700 | 100 | 1140 | 1100 | 830 | 430 | 3,0 |
| **01-Jul-21** | 456 | 100 | 250 | 2,500 | 100 | 1140 | 1090 | 840 | 430 | 3,3 |
| **02-Jul-21** | 480 | 100 | 270 | 2,700 | 100 | 1140 | 1100 | 830 | 430 | 3,0 |
| **03-Jul-21** | 504 | 100 | 250 | 2,500 | 100 | 1140 | 1080 | 830 | 430 | 3,2 |
| | | | | | | | | | | |
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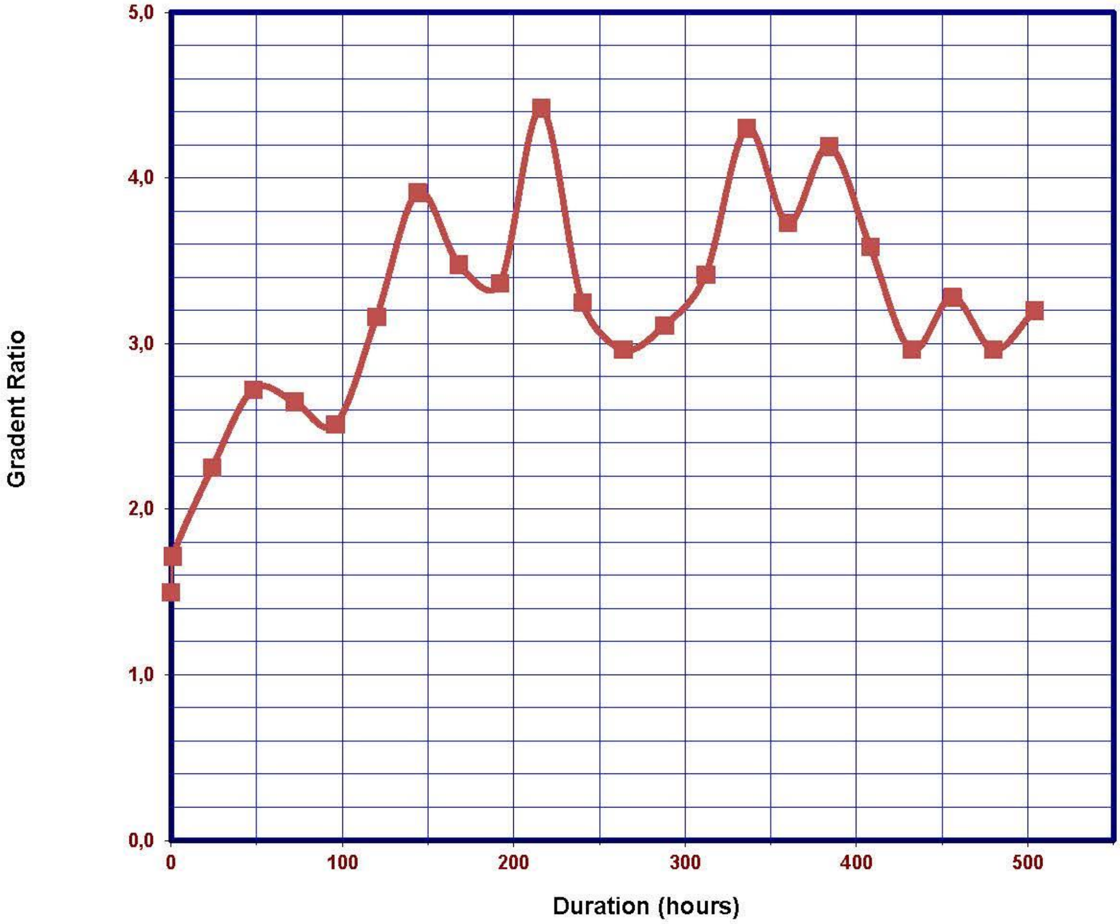
# Gradient Ratio

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A6 - Zone 2* |
| **Consultant** | *Vincent Mukwevho* | **Date** | *30-Jun-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A6* |
| | | **Soil Sample** | *Clayey Sand* |

## Gradient Ratio Analysis



# APPENDIX I

## Laboratory Results – Zone 2 Soil (Clayey Sand Vs S120)

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# LONG TERM GRADIENT RATIO TEST REPORT

## Permeameter Summary

### GL Test Method 1 (Adapted from Kaytech Engineerred Fabrics)

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S120 - Zone 2* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *18-Jul-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *16-Aug-21* |
| **Project** | *Masters Thesis* | **Product** | *S120* |
| | | **Soil Sample** | *Clayey Sand* |

| | | | | |
|---|---|---|---|---|
| **Equipment** | *GL MK1 Permeameter* | | **Support Above** | *none* |
| **Internal Diameter** | *100mm* | | **Support Below** | *wire mesh* |
| **Wetting Up** | *Below* | | **Preparation** | *Oven Dried* |
| | **Mass @ Start (g)** | **Mass @ Finish (g)** | **Thickness (mm)** | **k estimate** |
| **Geosynthetic** | *3,50* | *4.14* | *0.75* | |
| **Soil Sample** | *1035,30* | *1028.23* | *120* | |

| Date Start 31-03-2016 11h00 | Test Accummulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| ***18-Jul-21*** | *0* | *35* | *10* | *1,255E-06* | *120* | *1140* | | *1300* | | *1200* | *930* | *430* |
| ***18-Jul-21*** | *1* | *33* | *10* | *1,184E-06* | *120* | *1140* | | *1300* | | *1200* | *920* | *430* |
| ***19-Jul-21*** | *24* | *22* | *10* | *7,890E-07* | *120* | *1140* | | *1300* | | *1280* | *990* | *430* |
| ***20-Jul-21*** | *48* | *29* | *10* | *1,040E-06* | *120* | *1140* | | *1300* | | *1300* | *1000* | *430* |
| ***21-Jul-21*** | *72* | *56* | *10* | *2,008E-06* | *120* | *1140* | | *1300* | | *1280* | *960* | *430* |
| ***22-Jul-21*** | *96* | *78* | *10* | *2,798E-06* | *120* | *1140* | | *1300* | | *1220* | *920* | *430* |
| ***23-Jul-21*** | *120* | *99* | *10* | *3,551E-06* | *120* | *1140* | | *1300* | | *1170* | *820* | *430* |
| ***24-Jul-21*** | *144* | *105* | *10* | *3,766E-06* | *120* | *1140* | | *1300* | | *1100* | *800* | *430* |
| ***25-Jul-21*** | *168* | *104* | *10* | *3,730E-06* | *120* | *1140* | | *1300* | | *1140* | *840* | *430* |
| ***26-Jul-21*** | *192* | *98* | *10* | *3,515E-06* | *120* | *1140* | | *1300* | | *1060* | *780* | *430* |
| ***27-Jul-21*** | *216* | *87* | *10* | *3,120E-06* | *120* | *1140* | | *1300* | | *960* | *750* | *430* |
| ***28-Jul-21*** | *240* | *78* | *10* | *2,798E-06* | *120* | *1140* | | *1300* | | *940* | *720* | *430* |
| ***29-Jul-21*** | *264* | *78* | *10* | *2,798E-06* | *120* | *1140* | | *1300* | | *890* | *690* | *430* |
| ***30-Jul-21*** | *288* | *75* | *10* | *2,690E-06* | *120* | *1140* | | *1300* | | *910* | *690* | *430* |
| ***31-Jul-21*** | *312* | *70* | *10* | *2,511E-06* | *120* | *1140* | | *1300* | | *880* | *670* | *430* |
| ***01-Aug-21*** | *336* | *68* | *10* | *2,439E-06* | *120* | *1140* | | *1300* | | *890* | *710* | *430* |
| ***02-Aug-21*** | *360* | *73* | *10* | *2,618E-06* | *120* | *1140* | | *1300* | | *900* | *710* | *430* |
| ***03-Aug-21*** | *384* | *69* | *10* | *2,475E-06* | *120* | *1140* | | *1300* | | *910* | *680* | *430* |
| ***04-Aug-21*** | *408* | *64* | *10* | *2,295E-06* | *120* | *1140* | | *1300* | | *890* | *680* | *430* |
| ***05-Aug-21*** | *432* | *58* | *10* | *2,080E-06* | *120* | *1140* | | *1300* | | *910* | *680* | *430* |
| ***06-Aug-21*** | *456* | *56* | *10* | *2,008E-06* | *120* | *1140* | | *1300* | | *920* | *680* | *430* |
| ***07-Aug-21*** | *480* | *50* | *10* | *1,793E-06* | *120* | *1140* | | *1300* | | *900* | *680* | *430* |
| ***08-Aug-21*** | *504* | *53* | *10* | *1,901E-06* | *120* | *1140* | | *1300* | | *870* | *650* | *430* |
| ***09-Aug-21*** | *528* | *39* | *10* | *1,399E-06* | *120* | *1140* | | *1300* | | *690* | *590* | *430* |
| ***10-Aug-21*** | *552* | *31* | *10* | *1,112E-06* | *120* | *1140* | | *1300* | | *710* | *610* | *430* |
| ***11-Aug-21*** | *572* | *32* | *10* | *1,148E-06* | *120* | *1140* | | *1300* | | *700* | *600* | *430* |
| ***12-Aug-21*** | *600* | *30* | *10* | *1,076E-06* | *120* | *1140* | | *1300* | | *730* | *620* | *430* |
| ***13-Aug-21*** | *624* | *33* | *10* | *1,184E-06* | *120* | *1140* | | *1300* | | *720* | *620* | *430* |
| ***14-Aug-21*** | *648* | *35* | *10* | *1,255E-06* | *120* | *1140* | | *1300* | | *720* | *620* | *430* |
| ***15-Aug-21*** | *672* | *32* | *10* | *1,148E-06* | *120* | *1140* | | *1300* | | *710* | *610* | *430* |
| ***16-Aug-21*** | *696* | *33* | *10* | *1,184E-06* | *120* | *1140* | | *1300* | | *690* | *590* | *430* |
| | | | | | | | | | | | | |
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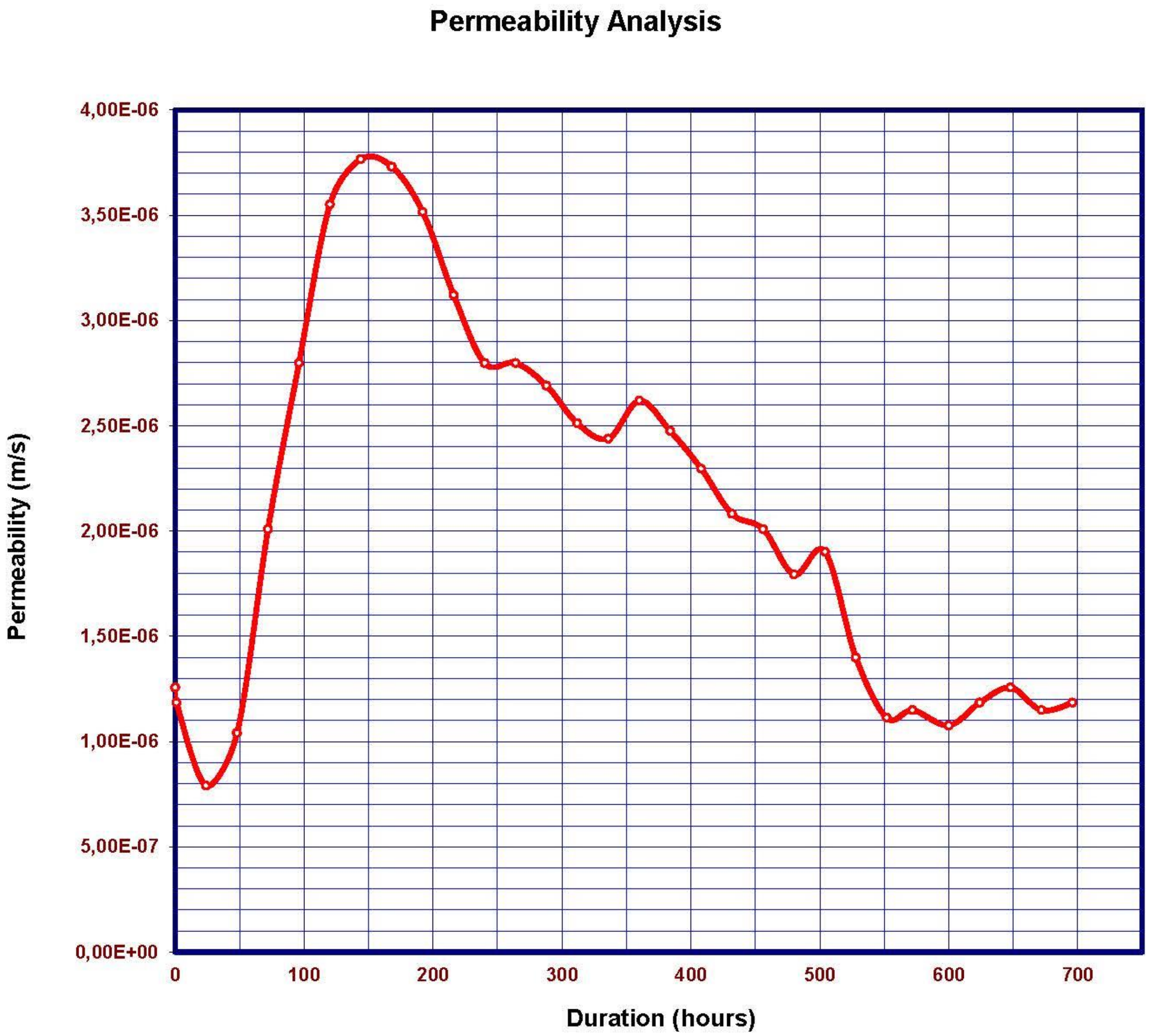
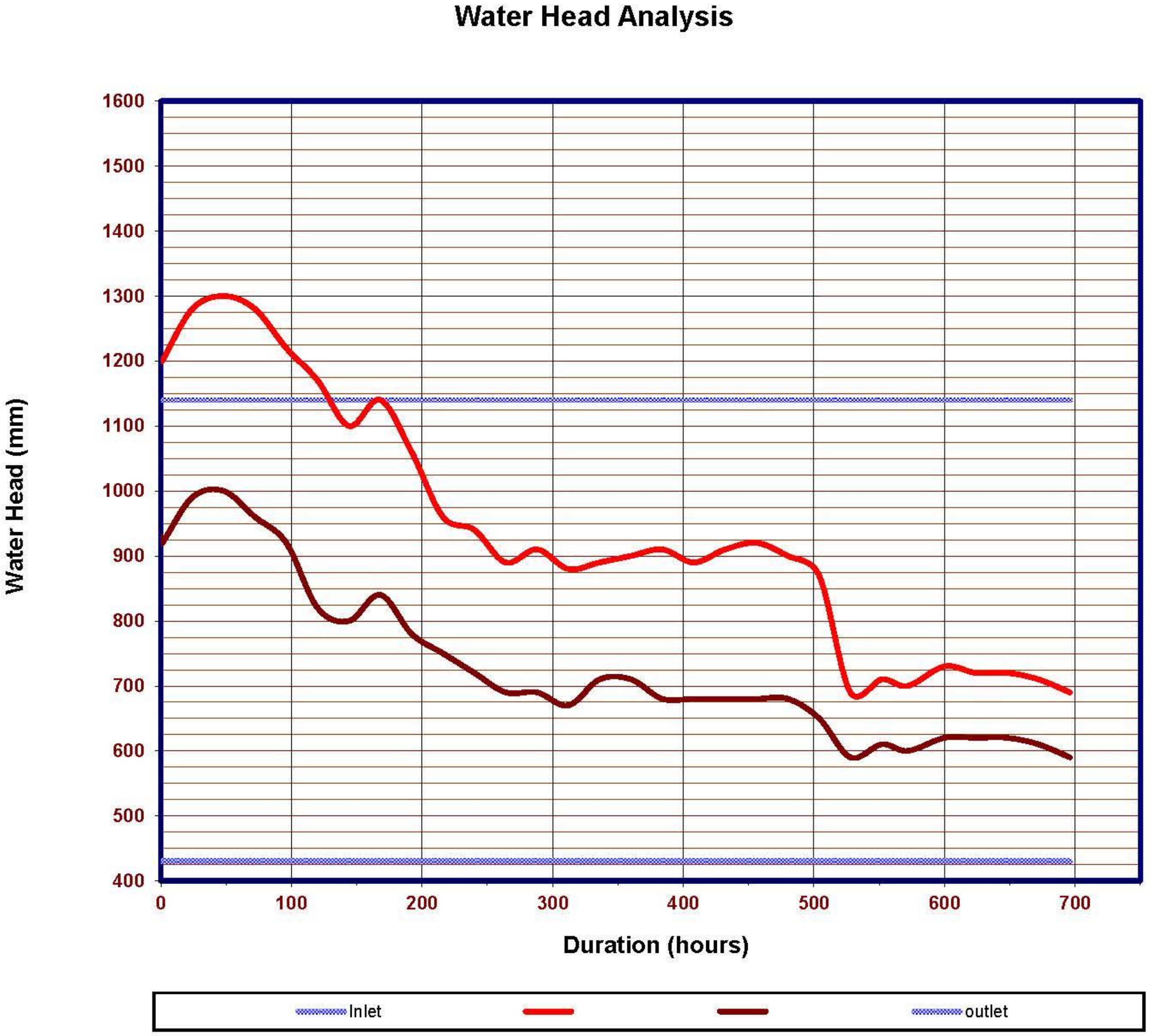
# Permeability Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S120 - Zone 2* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *18-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *S120* |
| | | **Soil Sample** | *Clayey Sand* |



# Water Head Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S120 - Zone 2* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *18-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *S120* |
| | | **Soil Sample** | *Clayey Sand* |



## Hydraulic Gradients and Gradient Ratios of the System

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S120 - Zone 2* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *18-Jul-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *16-Aug-21* |
| **Project** | *Masters Thesis* | **Product** | *S120* |
| | | **Soil Sample** | *Clayey Sand* |

| Date | Test Accummulative Hours | | | Hydraulic Gradient | Sample Height | Standpipe Readings - mm | | | | Gradient Ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 300 | 100 | 50 | 0 | |
| | | *L* | *Δh* | (*i*) | mm | Inlet | h75 | h25 | h0 | |
| **18-Jul-21** | 0 | 120 | 270 | 2,250 | 120 | 1140 | 1200 | 930 | 430 | 3,7 |
| **18-Jul-21** | 1 | 120 | 280 | 2,333 | 120 | 1140 | 1200 | 920 | 430 | 3,5 |
| **19-Jul-21** | 24 | 120 | 290 | 2,417 | 120 | 1140 | 1280 | 990 | 430 | 3,9 |
| **20-Jul-21** | 48 | 120 | 300 | 2,500 | 120 | 1140 | 1300 | 1000 | 430 | 3,8 |
| **21-Jul-21** | 72 | 120 | 320 | 2,667 | 120 | 1140 | 1280 | 960 | 430 | 3,3 |
| **22-Jul-21** | 96 | 120 | 300 | 2,500 | 120 | 1140 | 1220 | 920 | 430 | 3,3 |
| **23-Jul-21** | 120 | 120 | 350 | 2,917 | 120 | 1140 | 1170 | 820 | 430 | 2,2 |
| **24-Jul-21** | 144 | 120 | 300 | 2,500 | 120 | 1140 | 1100 | 800 | 430 | 2,5 |
| **25-Jul-21** | 168 | 120 | 300 | 2,500 | 120 | 1140 | 1140 | 840 | 430 | 2,7 |
| **26-Jul-21** | 192 | 120 | 280 | 2,333 | 120 | 1140 | 1060 | 780 | 430 | 2,5 |
| **27-Jul-21** | 216 | 120 | 210 | 1,750 | 120 | 1140 | 960 | 750 | 430 | 3,0 |
| **28-Jul-21** | 240 | 120 | 220 | 1,833 | 120 | 1140 | 940 | 720 | 430 | 2,6 |
| **29-Jul-21** | 264 | 120 | 200 | 1,667 | 120 | 1140 | 890 | 690 | 430 | 2,6 |
| **30-Jul-21** | 288 | 120 | 220 | 1,833 | 120 | 1140 | 910 | 690 | 430 | 2,4 |
| **31-Jul-21** | 312 | 120 | 210 | 1,750 | 120 | 1140 | 880 | 670 | 430 | 2,3 |
| **01-Aug-21** | 336 | 120 | 180 | 1,500 | 120 | 1140 | 890 | 710 | 430 | 3,1 |
| **02-Aug-21** | 360 | 120 | 190 | 1,583 | 120 | 1140 | 900 | 710 | 430 | 2,9 |
| **03-Aug-21** | 384 | 120 | 230 | 1,917 | 120 | 1140 | 910 | 680 | 430 | 2,2 |
| **04-Aug-21** | 408 | 120 | 210 | 1,750 | 120 | 1140 | 890 | 680 | 430 | 2,4 |
| **05-Aug-21** | 432 | 120 | 230 | 1,917 | 120 | 1140 | 910 | 680 | 430 | 2,2 |
| **06-Aug-21** | 456 | 120 | 240 | 2,000 | 120 | 1140 | 920 | 680 | 430 | 2,1 |
| **07-Aug-21** | 480 | 120 | 220 | 1,833 | 120 | 1140 | 900 | 680 | 430 | 2,3 |
| **08-Aug-21** | 504 | 120 | 220 | 1,833 | 120 | 1140 | 870 | 650 | 430 | 2,0 |
| **09-Aug-21** | 528 | 120 | 100 | 0,833 | 120 | 1140 | 690 | 590 | 430 | 3,2 |
| **10-Aug-21** | 552 | 120 | 100 | 0,833 | 120 | 1140 | 710 | 610 | 430 | 3,6 |
| **11-Aug-21** | 572 | 120 | 100 | 0,833 | 120 | 1140 | 700 | 600 | 430 | 3,4 |
| **12-Aug-21** | 600 | 120 | 110 | 0,917 | 120 | 1140 | 730 | 620 | 430 | 3,5 |
| **13-Aug-21** | 624 | 120 | 100 | 0,833 | 120 | 1140 | 720 | 620 | 430 | 3,8 |
| **14-Aug-21** | 648 | 120 | 100 | 0,833 | 120 | 1140 | 720 | 620 | 430 | 3,8 |
| **15-Aug-21** | 672 | 120 | 100 | 0,833 | 120 | 1140 | 710 | 610 | 430 | 3,6 |
| **16-Aug-21** | 696 | 120 | 100 | 0,833 | 120 | 1140 | 690 | 590 | 430 | 3,2 |
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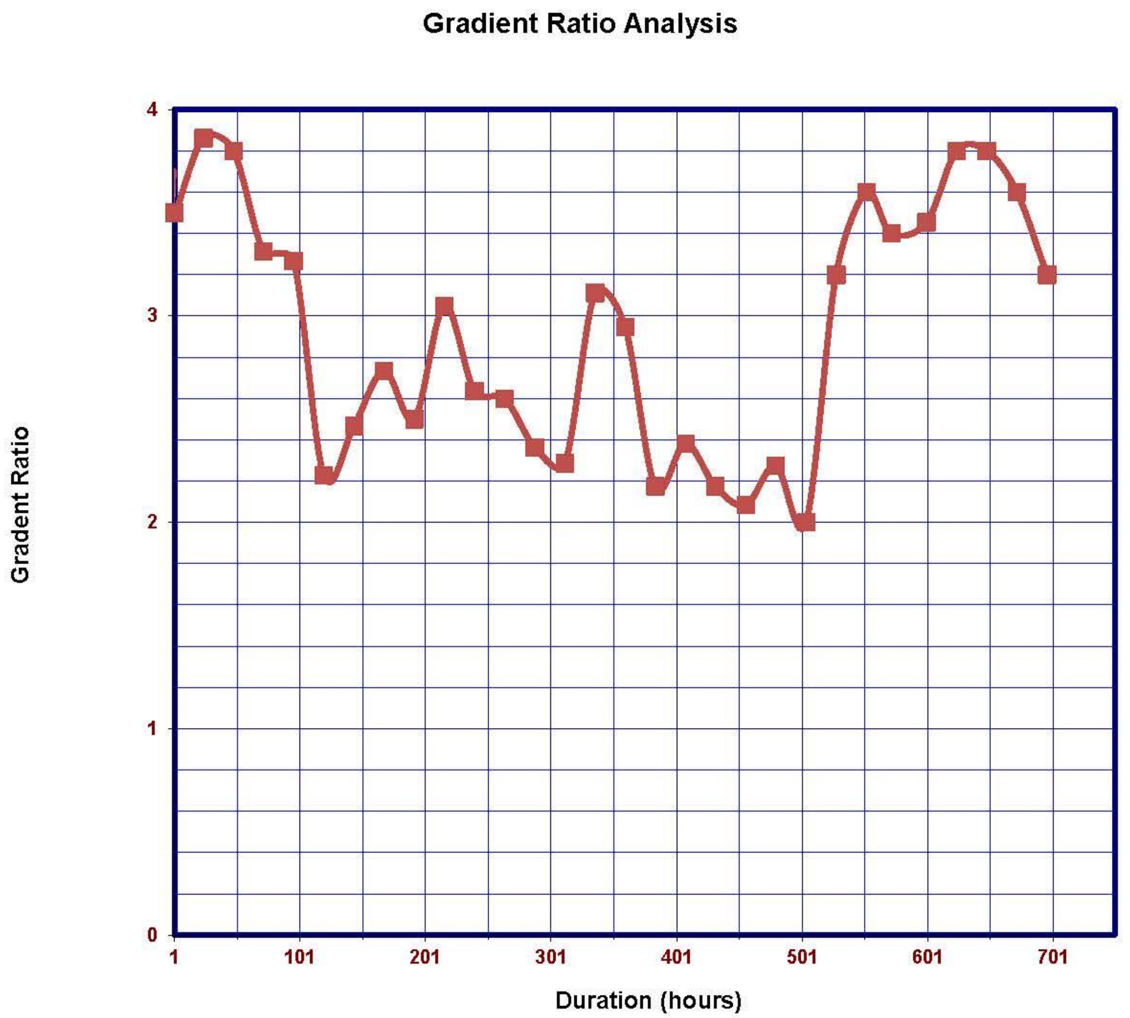
# Gradient Ratio

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S120 - Zone 2* |
| **Consultant** | *Vincent Mukwevho* | **Date** | *16-Aug-21* |
| **Project** | *Masters Thesis* | **Product** | *S120* |
| | | **Soil Sample** | *Clayey Sand* |



# APPENDIX J

## Laboratory Results – Zone 2 Soil (Clayey Sand Vs S120)

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# LONG TERM GRADIENT RATIO TEST REPORT

## Permeameter Summary

### GL Test Method 1 (Adapted from Kaytech Engineerred Fabrics)

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S270 - Zone 2* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *18-Jul-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *10-Aug-21* |
| **Project** | *Masters Thesis* | **Product** | *S270* |
| | | **Soil Sample** | *Clayey Sand* |

| | | | | |
|---|---|---|---|---|
| **Equipment** | *GL MK1 Permeameter* | | **Support Above** | *none* |
| **Internal Diameter** | *100mm* | | **Support Below** | *wire mesh* |
| **Wetting Up** | *Below* | | **Preparation** | *Oven Dried* |
| | **Mass @ Start (g)** | **Mass @ Finish (g)** | **Thickness (mm)** | **k estimate** |
| **Geosynthetic** | *4,00* | *4.41* | *1.0* | |
| **Soil Sample** | *1042.90* | *1039.40* | *120* | |

| Date Start 31-03-2016 11h00 | Test Accummulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| **18-Jul-21** | *0* | *32* | *10* | *1,148E-06* | *120* | *1140* | | *1300* | | *1350* | *970* | *430* |
| **18-Jul-21** | *1* | *31* | *10* | *1,112E-06* | *120* | *1140* | | *1300* | | *1350* | *980* | *430* |
| **19-Jul-21** | *24* | *19* | *10* | *6,815E-07* | *120* | *1140* | | *1300* | | *1400* | *1020* | *430* |
| **20-Jul-21** | *48* | *8* | *10* | *2,869E-07* | *120* | *1140* | | *1300* | | *1400* | *1050* | *430* |
| **21-Jul-21** | *72* | *18* | *10* | *6,456E-07* | *120* | *1140* | | *1300* | | *1400* | *1030* | *430* |
| **22-Jul-21** | *96* | *24* | *10* | *8,608E-07* | *120* | *1140* | | *1300* | | *1400* | *1020* | *430* |
| **23-Jul-21** | *120* | *46* | *10* | *1,650E-06* | *120* | *1140* | | *1300* | | *1380* | *960* | *430* |
| **24-Jul-21** | *144* | *53* | *10* | *1,901E-06* | *120* | *1140* | | *1300* | | *1370* | *950* | *430* |
| **25-Jul-21** | *168* | *54* | *10* | *1,937E-06* | *120* | *1140* | | *1300* | | *1370* | *955* | *430* |
| **26-Jul-21** | *192* | *56* | *10* | *2,008E-06* | *120* | *1140* | | *1300* | | *1350* | *950* | *430* |
| **27-Jul-21** | *216* | *102* | *10* | *3,658E-06* | *120* | *1140* | | *1300* | | *1220* | *720* | *430* |
| **28-Jul-21** | *240* | *133* | *10* | *4,770E-06* | *120* | *1140* | | *1300* | | *1160* | *700* | *430* |
| **29-Jul-21** | *264* | *119* | *10* | *4,268E-06* | *120* | *1140* | | *1300* | | *1110* | *700* | *430* |
| **30-Jul-21** | *288* | *100* | *10* | *3,587E-06* | *120* | *1140* | | *1300* | | *1100* | *700* | *430* |
| **31-Jul-21** | *312* | *105* | *10* | *3,766E-06* | *120* | *1140* | | *1300* | | *1090* | *680* | *430* |
| **01-Aug-21** | *336* | *98* | *10* | *3,515E-06* | *120* | *1140* | | *1300* | | *1115* | *670* | *430* |
| **02-Aug-21** | *360* | *77* | *10* | *2,762E-06* | *120* | *1140* | | *1300* | | *1080* | *730* | *430* |
| **03-Aug-21** | *384* | *70* | *10* | *2,511E-06* | *120* | *1140* | | *1300* | | *1020* | *730* | *430* |
| **04-Aug-21** | *408* | *73* | *10* | *2,618E-06* | *120* | *1140* | | *1300* | | *990* | *700* | *430* |
| **05-Aug-21** | *432* | *65* | *10* | *2,331E-06* | *120* | *1140* | | *1300* | | *1000* | *760* | *430* |
| **06-Aug-21** | *456* | *63* | *10* | *2,260E-06* | *120* | *1140* | | *1300* | | *950* | *700* | *430* |
| **07-Aug-21** | *480* | *60* | *10* | *2,152E-06* | *120* | *1140* | | *1300* | | *900* | *690* | *430* |
| **08-Aug-21** | *504* | *53* | *10* | *1,901E-06* | *120* | *1140* | | *1300* | | *850* | *670* | *430* |
| **09-Aug-21** | *528* | *35* | *10* | *1,255E-06* | *120* | *1140* | | *1300* | | *900* | *670* | *430* |
| **10-Aug-21** | *552* | *31* | *10* | *1,112E-06* | *120* | *1140* | | *1300* | | *880* | *670* | *430* |
| **11-Aug-21** | *576* | *32* | *10* | *1,148E-06* | *120* | *1140* | | *1300* | | *890* | *660* | *430* |
| **12-Aug-21** | *600* | *32* | *10* | *1,148E-06* | *120* | *1140* | | *1300* | | *880* | *670* | *430* |
| **13-Aug-21** | *624* | *31* | *10* | *1,112E-06* | *120* | *1140* | | *1300* | | *900* | *680* | *430* |
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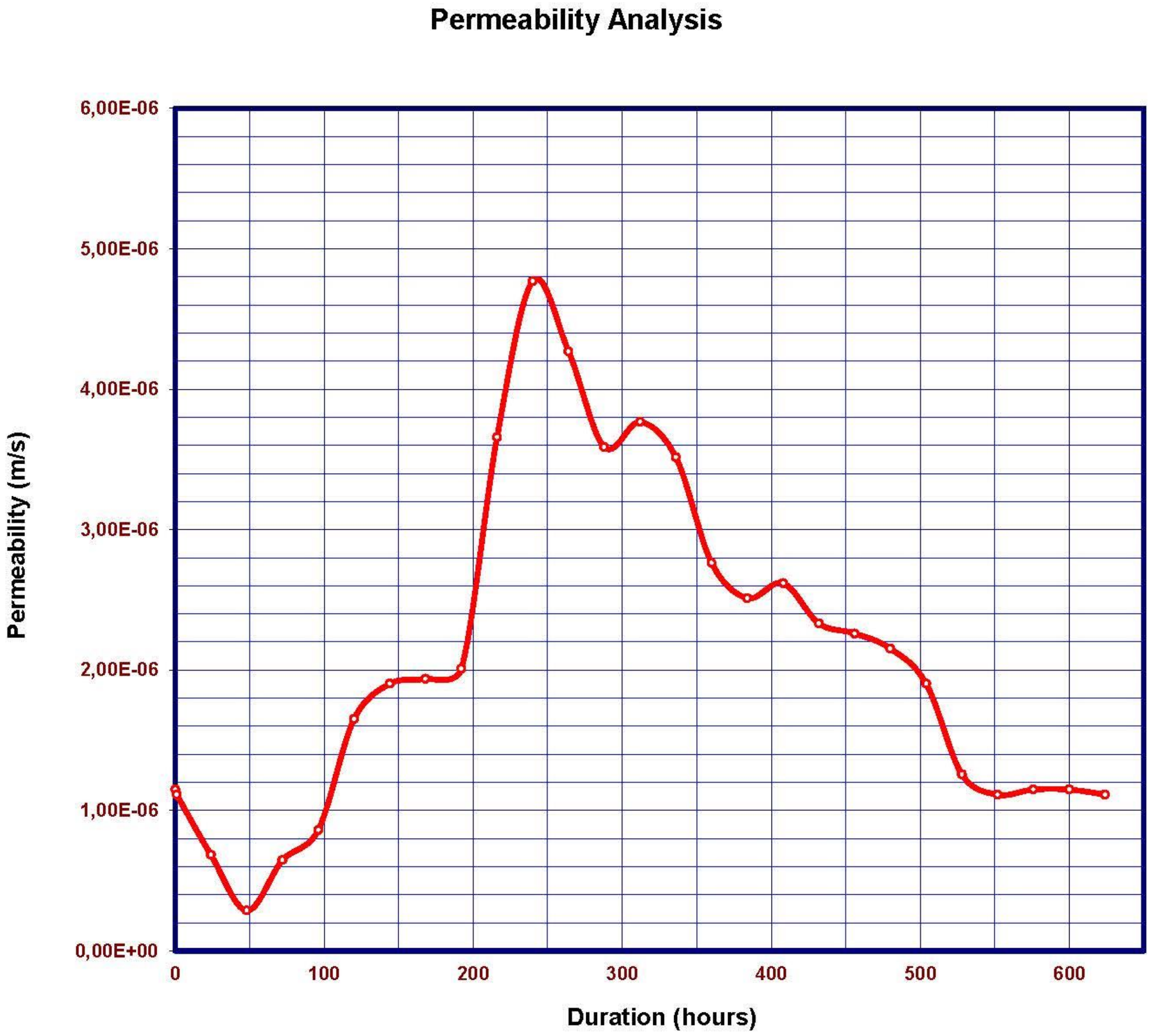
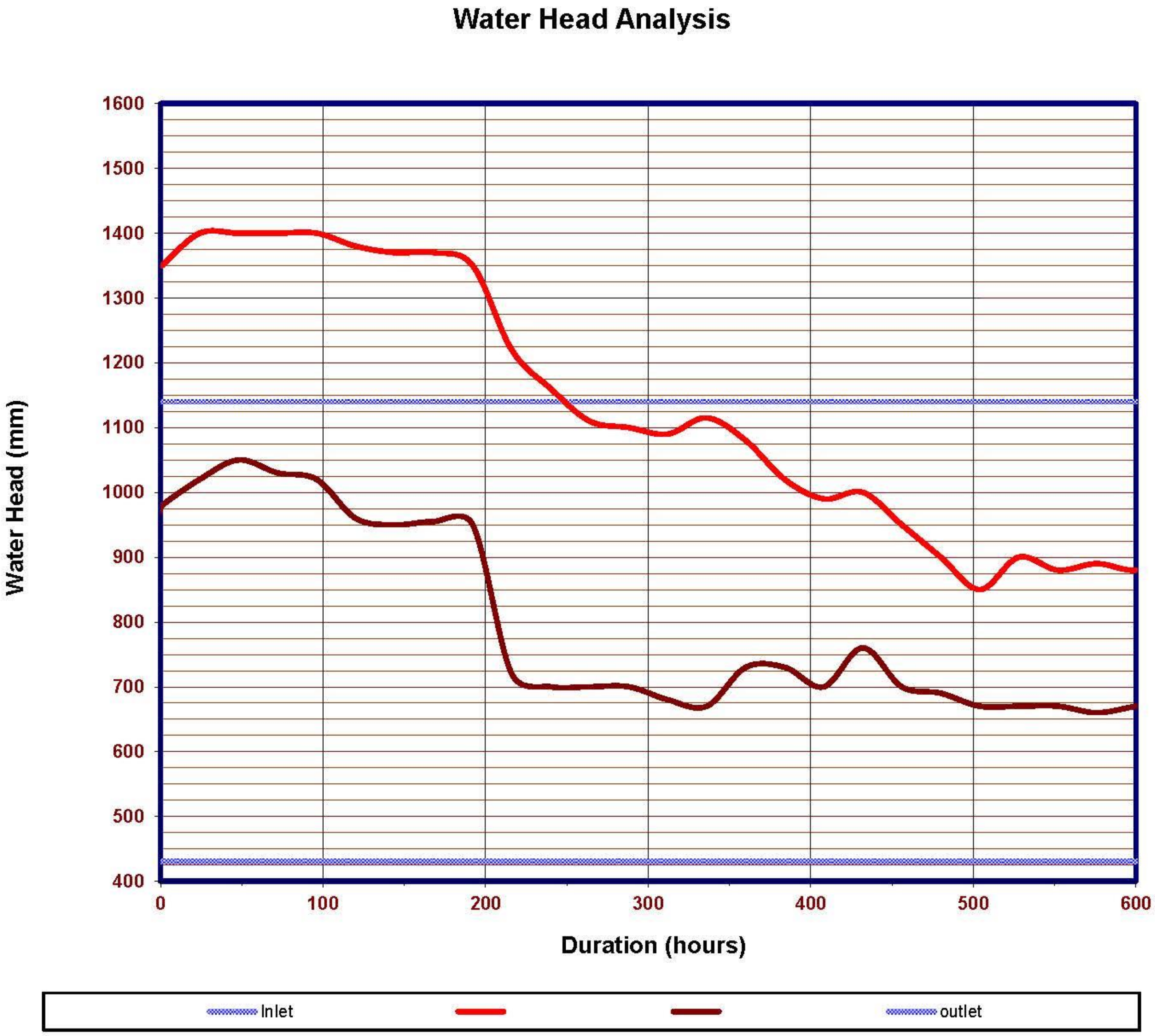
# Permeability Analysis

| | | | |
|---|---|---|---|
| Client | *Vincent Mukwevho* | Test Number | *S270 - Zone 2* |
| Consultant | *230 Albertus Street, La Montagne, Silverton, 0184* | Date | *18-Jul-21* |
| Project | *Masters Thesis* | Product | *S270* |
| | | Soil Sample | *Clayey Sand* |



# Water Head Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S270 - Zone 2* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *18-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *S270* |
| | | **Soil Sample** | *Clayey Sand* |



## Hydraulic Gradients and Gradient Ratios of the System

| | | | |
|---|---|---|---|
| **Client** | Vincent Mukwevho | **Test Number** | S270 - Zone 2 |
| **Address** | 230 Albertus Street, La Montagne, Silverton, 0184 | **Date Start** | 18-Jul-21 |
| **Contact** | Vincent Mukwevho | **Date Fin** | 10-Aug-21 |
| **Project** | Masters Thesis | **Product** | S270 |
| | | **Soil Sample** | Clayey Sand |

| Date | Test Accummulative Hours | | | Hydraulic Gradient | Sample Height | Standpipe Readings - mm | | | | Gradient Ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 300 | 100 | 50 | 0 | |
| | | L | Δh | (i) | mm | Inlet | h75 | h25 | h0 | |
| **18-Jul-21** | 0 | 120 | 380 | 3,167 | 120 | 1140 | 1350 | 970 | 430 | 2,8 |
| **18-Jul-21** | 1 | 120 | 370 | 3,083 | 120 | 1140 | 1350 | 980 | 430 | 3,0 |
| **19-Jul-21** | 24 | 120 | 380 | 3,167 | 120 | 1140 | 1400 | 1020 | 430 | 3,1 |
| **20-Jul-21** | 48 | 120 | 350 | 2,917 | 120 | 1140 | 1400 | 1050 | 430 | 3,5 |
| **21-Jul-21** | 72 | 120 | 370 | 3,083 | 120 | 1140 | 1400 | 1030 | 430 | 3,2 |
| **22-Jul-21** | 96 | 120 | 380 | 3,167 | 120 | 1140 | 1400 | 1020 | 430 | 3,1 |
| **23-Jul-21** | 120 | 120 | 420 | 3,500 | 120 | 1140 | 1380 | 960 | 430 | 2,5 |
| **24-Jul-21** | 144 | 120 | 420 | 3,500 | 120 | 1140 | 1370 | 950 | 430 | 2,5 |
| **25-Jul-21** | 168 | 120 | 415 | 3,458 | 120 | 1140 | 1370 | 955 | 430 | 2,5 |
| **26-Jul-21** | 192 | 120 | 400 | 3,333 | 120 | 1140 | 1350 | 950 | 430 | 2,6 |
| **27-Jul-21** | 216 | 120 | 500 | 4,167 | 120 | 1140 | 1220 | 720 | 430 | 1,2 |
| **28-Jul-21** | 240 | 120 | 460 | 3,833 | 120 | 1140 | 1160 | 700 | 430 | 1,2 |
| **29-Jul-21** | 264 | 120 | 410 | 3,417 | 120 | 1140 | 1110 | 700 | 430 | 1,3 |
| **30-Jul-21** | 288 | 120 | 400 | 3,333 | 120 | 1140 | 1100 | 700 | 430 | 1,4 |
| **31-Jul-21** | 312 | 120 | 410 | 3,417 | 120 | 1140 | 1090 | 680 | 430 | 1,2 |
| **01-Aug-21** | 336 | 120 | 445 | 3,708 | 120 | 1140 | 1115 | 670 | 430 | 1,1 |
| **02-Aug-21** | 360 | 120 | 350 | 2,917 | 120 | 1140 | 1080 | 730 | 430 | 1,7 |
| **03-Aug-21** | 384 | 120 | 290 | 2,417 | 120 | 1140 | 1020 | 730 | 430 | 2,1 |
| **04-Aug-21** | 408 | 120 | 290 | 2,417 | 120 | 1140 | 990 | 700 | 430 | 1,9 |
| **05-Aug-21** | 432 | 120 | 240 | 2,000 | 120 | 1140 | 1000 | 760 | 430 | 2,8 |
| **06-Aug-21** | 456 | 120 | 250 | 2,083 | 120 | 1140 | 950 | 700 | 430 | 2,2 |
| **07-Aug-21** | 480 | 120 | 210 | 1,750 | 120 | 1140 | 900 | 690 | 430 | 2,5 |
| **08-Aug-21** | 504 | 120 | 180 | 1,500 | 120 | 1140 | 850 | 670 | 430 | 2,7 |
| **09-Aug-21** | 528 | 120 | 230 | 1,917 | 120 | 1140 | 900 | 670 | 430 | 2,1 |
| **10-Aug-21** | 552 | 120 | 210 | 1,750 | 120 | 1140 | 880 | 670 | 430 | 2,3 |
| **11-Aug-21** | 576 | 120 | 230 | 1,917 | 120 | 1140 | 890 | 660 | 430 | 2,0 |
| **12-Aug-21** | 600 | 120 | 210 | 1,750 | 120 | 1140 | 880 | 670 | 430 | 2,3 |
| **13-Aug-21** | 624 | 120 | 220 | 1,833 | 120 | 1140 | 900 | 680 | 430 | 2,3 |
| | | | | | | | | | | |
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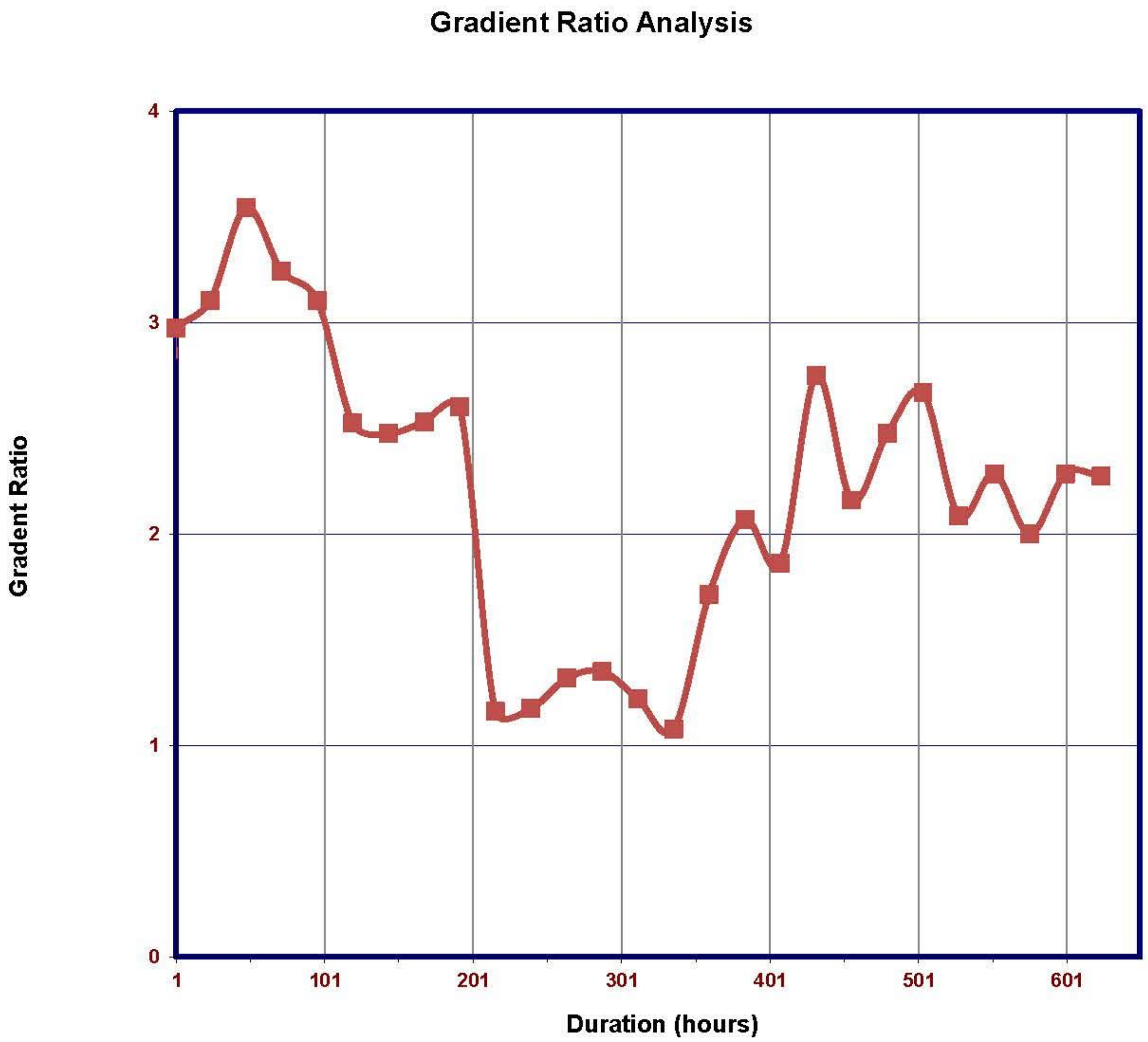
# Gradient Ratio

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S270 - Zone 2* |
| **Consultant** | *Vincent Mukwevho* | **Date** | *10-Aug-21* |
| **Project** | *Masters Thesis* | **Product** | *S270* |
| | | **Soil Sample** | *Clayey Sand* |



# APPENDIX K

## Laboratory Results – Zone 3 Soil (Sandy Gravel Vs A2)

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# LONG TERM GRADIENT RATIO TEST REPORT

## Permeameter Summary

### GL Test Method 1 (Adapted from Kaytech Engineerred Fabrics)

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A2-Zone 3* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *15-May-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *26-Jun-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A2* |
| | | **Soil Sample** | *Sandy Gravel* |

| | | | | |
|---|---|---|---|---|
| **Equipment** | *GL MK1 Permeameter* | | **Support Above** | *none* |
| **Internal Diameter** | *100mm* | | **Support Below** | *wire mesh* |
| **Wetting Up** | *Below* | | **Preparation** | *Oven Dried* |
| | **Mass @ Start (g)** | **Mass @ Finish (g)** | **Thickness (mm)** | **k estimate** |
| **Geosynthetic** | *2.70* | *5.80* | *1.69* | |
| **Soil Sample** | *1181.20* | *1174.72* | *100* | |

| Date<br>Start 31-03-2016<br>11h00 | Test Accummulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| ***15-May-21*** | *0* | *380* | *10* | *1,120E-05* | *100* | *1150* | | *1290* | | *1290* | *600* | *430* |
| ***15-May-21*** | *1* | *840* | *10* | *2,476E-05* | *100* | *1150* | | *1290* | | *1390* | *630* | *430* |
| ***16-May-21*** | *24* | *970* | *10* | *2,859E-05* | *100* | *1150* | | *1290* | | *1390* | *600* | *430* |
| ***17-May-21*** | *48* | *1030* | *10* | *3,036E-05* | *100* | *1150* | | *1290* | | *1390* | *570* | *430* |
| ***18-May-21*** | *72* | *1470* | *10* | *4,333E-05* | *100* | *1150* | | *1290* | | *1390* | *550* | *430* |
| ***19-May-21*** | *96* | *1350* | *10* | *3,979E-05* | *100* | *1150* | | *1290* | | *1390* | *590* | *430* |
| ***20-May-21*** | *120* | *890* | *10* | *2,623E-05* | *100* | *1150* | | *1290* | | *1390* | *600* | *430* |
| ***21-May-21*** | *144* | *725* | *10* | *2,137E-05* | *100* | *1150* | | *1290* | | *1390* | *610* | *430* |
| ***22-May-21*** | *168* | *545* | *10* | *1,606E-05* | *100* | *1150* | | *1290* | | *1390* | *680* | *430* |
| ***23-May-21*** | *192* | *430* | *10* | *1,362E-05* | *100* | *1100* | | *1240* | | *1340* | *720* | *430* |
| ***24-May-21*** | *216* | *410* | *10* | *1,299E-05* | *100* | *1100* | | *1240* | | *1340* | *680* | *430* |
| ***25-May-21*** | *240* | *440* | *10* | *1,482E-05* | *100* | *1060* | | *1240* | | *1340* | *615* | *430* |
| ***26-May-21*** | *264* | *260* | *10* | *8,488E-06* | *100* | *1080* | | *1220* | | *1360* | *600* | *430* |
| ***27-May-21*** | *288* | *285* | *10* | *9,027E-06* | *100* | *1100* | | *1240* | | *1360* | *620* | *430* |
| ***28-May-21*** | *312* | *565* | *10* | *1,689E-05* | *100* | *1140* | | *1270* | | *1360* | *600* | *430* |
| ***29-May-21*** | *336* | *480* | *10* | *1,435E-05* | *100* | *1140* | | *1270* | | *1360* | *600* | *430* |
| ***30-May-21*** | *360* | *450* | *10* | *1,345E-05* | *100* | *1140* | | *1250* | | *1360* | *650* | *430* |
| ***31-May-21*** | *384* | *430* | *10* | *1,285E-05* | *100* | *1140* | | *1270* | | *1350* | *660* | *430* |
| ***01-Jun-21*** | *408* | *410* | *10* | *1,225E-05* | *100* | *1140* | | *1260* | | *1360* | *650* | *430* |
| ***02-Jun-21*** | *432* | *320* | *10* | *9,841E-06* | *100* | *1120* | | *1260* | | *1380* | *675* | *430* |
| ***03-Jun-21*** | *456* | *430* | *10* | *1,322E-05* | *100* | *1120* | | *1260* | | *1380* | *680* | *430* |
| ***04-Jun-21*** | *480* | *271* | *10* | *8,713E-06* | *100* | *1090* | | *1230* | | *1350* | *700* | *430* |
| ***05-Jun-21*** | *504* | *275* | *10* | *8,582E-06* | *100* | *1110* | | *1260* | | *1360* | *690* | *430* |
| ***06-Jun-21*** | *528* | *277* | *10* | *8,644E-06* | *100* | *1110* | | *1260* | | *1360* | *650* | *430* |
| ***07-Jun-21*** | *552* | *233* | *10* | *7,380E-06* | *100* | *1100* | | *1260* | | *1330* | *675* | *430* |
| ***08-Jun-21*** | *572* | *374* | *10* | *1,102E-05* | *100* | *1150* | | *1290* | | *1400* | *650* | *430* |
| ***09-Jun-21*** | *600* | *283* | *10* | *8,518E-06* | *100* | *1135* | | *1290* | | *1390* | *660* | *430* |
| ***10-Jun-21*** | *624* | *277* | *10* | *8,338E-06* | *100* | *1135* | | *1290* | | *1400* | *650* | *430* |
| ***11-Jun-21*** | *648* | *280* | *10* | *8,428E-06* | *100* | *1135* | | *1290* | | *1390* | *640* | *430* |
| ***12-Jun-21*** | *672* | *260* | *10* | *7,826E-06* | *100* | *1135* | | *1290* | | *1380* | *620* | *430* |
| ***13-Jun-21*** | *696* | *256* | *10* | *7,706E-06* | *100* | *1135* | | *1290* | | *1400* | *630* | *430* |
| ***14-Jun-21*** | *720* | *246* | *10* | *7,405E-06* | *100* | *1135* | | *1290* | | *1400* | *650* | *430* |
| ***15-Jun-21*** | *744* | *218* | *10* | *6,337E-06* | *100* | *1160* | | *1320* | | *1420* | *680* | *430* |
| ***16-Jun-21*** | *768* | *235* | *10* | *6,831E-06* | *100* | *1160* | | *1320* | | *1410* | *690* | *430* |
| ***17-Jun-21*** | *792* | *227* | *10* | *6,599E-06* | *100* | *1160* | | *1320* | | *1400* | *730* | *430* |
| ***18-Jun-21*** | *816* | *240* | *10* | *7,224E-06* | *100* | *1135* | | *1295* | | *1400* | *700* | *430* |
| ***19-Jun-21*** | *840* | *450* | *10* | *1,326E-05* | *100* | *1150* | | *1290* | | *1400* | *800* | *430* |
| ***20-Jun-21*** | *864* | *243* | *10* | *7,212E-06* | *100* | *1145* | | *1290* | | *1400* | *750* | *430* |
| ***21-Jun-21*** | *888* | *237* | *10* | *6,985E-06* | *100* | *1150* | | *1295* | | *1390* | *720* | *430* |
| ***22-Jun-21*** | *912* | *240* | *10* | *7,074E-06* | *100* | *1150* | | *1290* | | *1390* | *690* | *430* |
| ***23-Jun-21*** | *936* | *243* | *10* | *7,212E-06* | *100* | *1145* | | *1295* | | *1400* | *650* | *430* |
| ***24-Jun-21*** | *960* | *238* | *10* | *7,015E-06* | *100* | *1150* | | *1290* | | *1390* | *680* | *430* |
| ***25-Jun-21*** | *984* | *235* | *10* | *6,926E-06* | *100* | *1150* | | *1295* | | *1390* | *670* | *430* |
| ***26-Jun-21*** | *1008* | *237* | *10* | *7,034E-06* | *100* | *1145* | | *1295* | | *1390* | *650* | *430* |

***Disclaimer:***

*The test results contained herein refers only to the specific product tested as per the referenced test standard and should not be compared to any similar product not tested. The Laboratory does not imply suitability of this product to be used in any particular application, nor does it imply approval of the quality of the product. This test report shall not be reproduced except in full, and only with written approval of the Laboratory.*

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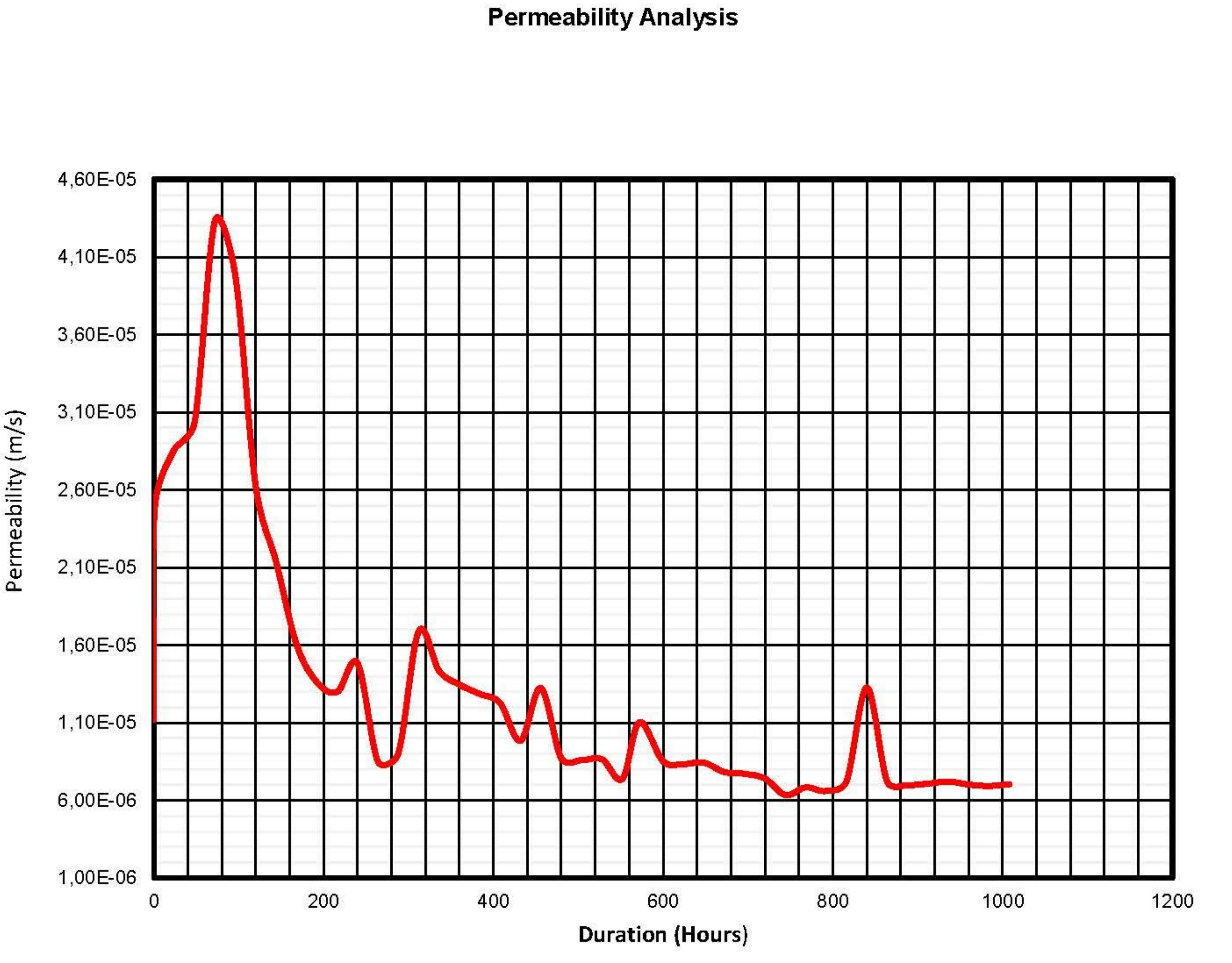
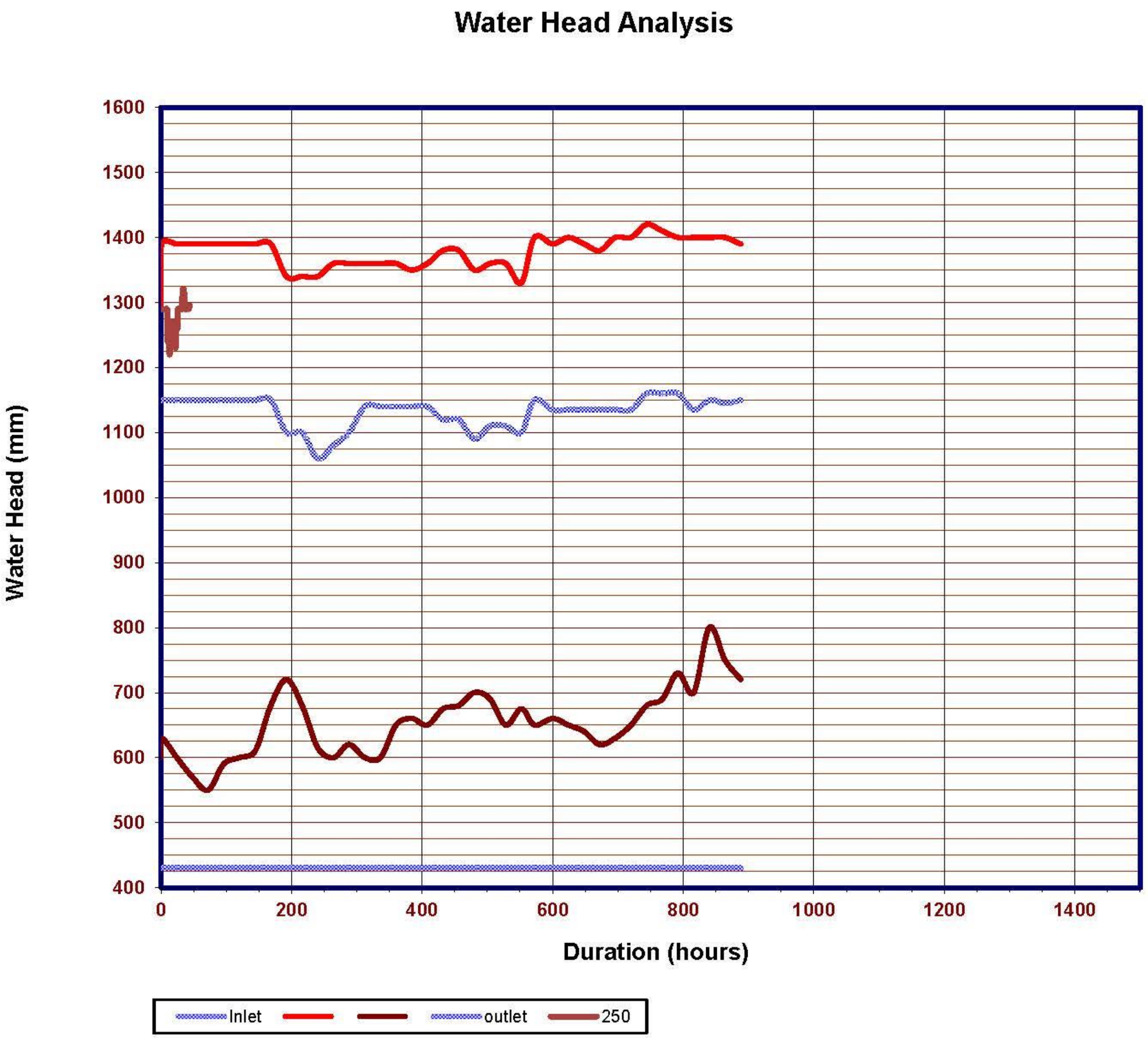
# Permeability Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A2-Zone 3* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *15-May-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A2* |
| | | **Soil Sample** | *Sandy Gravel* |



# Water Head Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A2-Zone 3* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *15-May-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A2* |
| | | **Soil Sample** | *Sandy Gravel* |



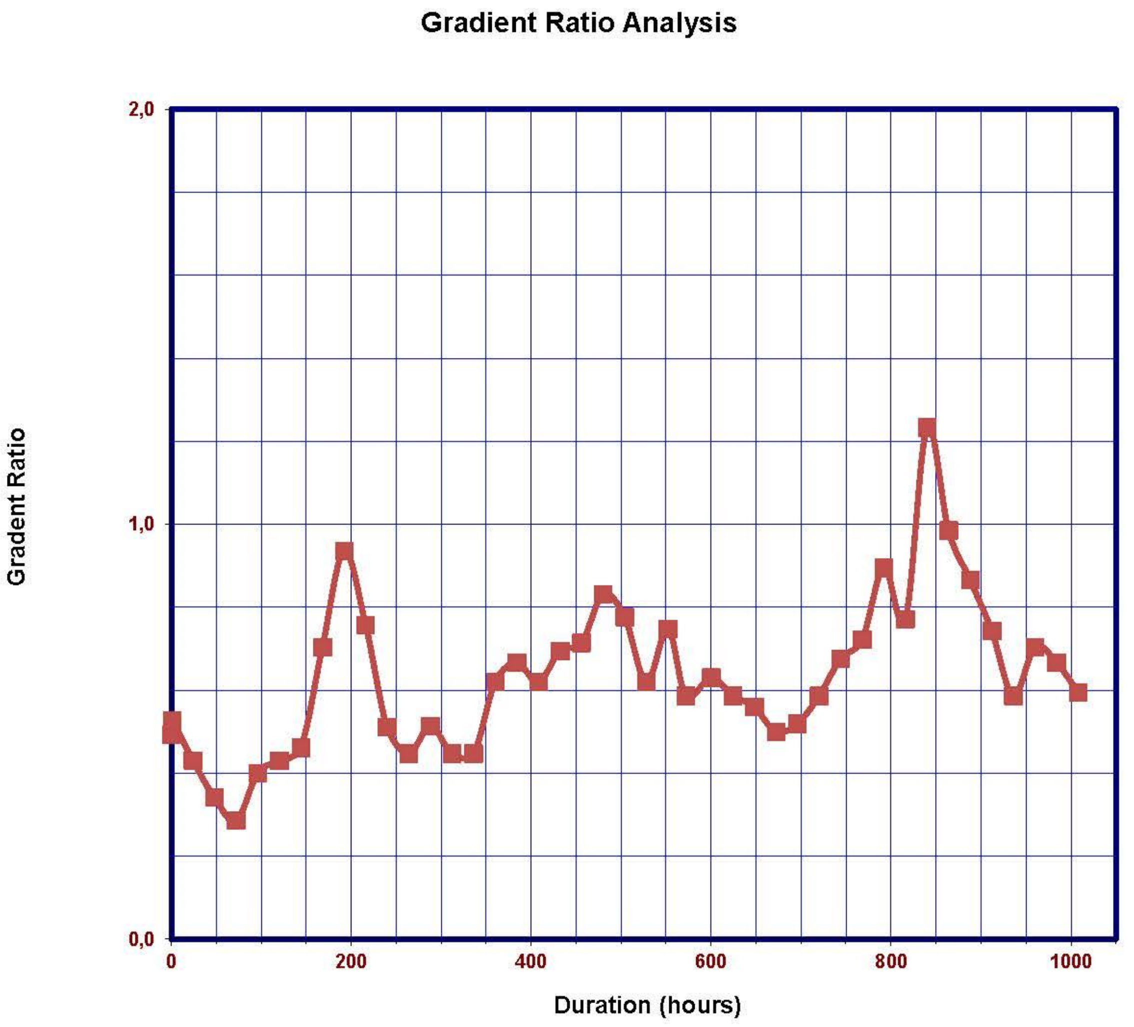
## Hydraulic Gradients and Gradient Ratios of the System

| | | | |
|---|---|---|---|
| **Client** | Vincent Mukwevho | **Test Number** | A2-Zone 3 |
| **Address** | 230 Albertus Street, La Montagne, Silverton, 0184 | **Date Start** | 15-May-21 |
| **Contact** | Vincent Mukwevho | **Date Fin** | 26-Jun-21 |
| **Project** | Masters Thesis | **Product** | Bidim A2 |
| | | **Soil Sample** | Sandy Gravel |

| Date | Test Accummulative Hours | L | Δh | Hydraulic Gradient (i) | Sample Height mm | Standpipe Readings - mm | | | | Gradient Ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 300 | 100 | 50 | 0 | |
| | | | | | | Inlet | h75 | h25 | h0 | |
| 15-May-21 | 0 | 100 | 690 | 6,900 | 100 | 1150 | 1290 | 600 | 430 | 0,5 |
| 15-May-21 | 1 | 100 | 760 | 7,600 | 100 | 1150 | 1390 | 630 | 430 | 0,5 |
| 16-May-21 | 24 | 100 | 790 | 7,900 | 100 | 1150 | 1390 | 600 | 430 | 0,4 |
| 17-May-21 | 48 | 100 | 820 | 8,200 | 100 | 1150 | 1390 | 570 | 430 | 0,3 |
| 18-May-21 | 72 | 100 | 840 | 8,400 | 100 | 1150 | 1390 | 550 | 430 | 0,3 |
| 19-May-21 | 96 | 100 | 800 | 8,000 | 100 | 1150 | 1390 | 590 | 430 | 0,4 |
| 20-May-21 | 120 | 100 | 790 | 7,900 | 100 | 1150 | 1390 | 600 | 430 | 0,4 |
| 21-May-21 | 144 | 100 | 780 | 7,800 | 100 | 1150 | 1390 | 610 | 430 | 0,5 |
| 22-May-21 | 168 | 100 | 710 | 7,100 | 100 | 1150 | 1390 | 680 | 430 | 0,7 |
| 23-May-21 | 192 | 100 | 620 | 6,200 | 100 | 1100 | 1340 | 720 | 430 | 0,9 |
| 24-May-21 | 216 | 100 | 660 | 6,600 | 100 | 1100 | 1340 | 680 | 430 | 0,8 |
| 25-May-21 | 240 | 100 | 725 | 7,250 | 100 | 1060 | 1340 | 615 | 430 | 0,5 |
| 26-May-21 | 264 | 100 | 760 | 7,600 | 100 | 1080 | 1360 | 600 | 430 | 0,4 |
| 27-May-21 | 288 | 100 | 740 | 7,400 | 100 | 1100 | 1360 | 620 | 430 | 0,5 |
| 28-May-21 | 312 | 100 | 760 | 7,600 | 100 | 1140 | 1360 | 600 | 430 | 0,4 |
| 29-May-21 | 336 | 100 | 760 | 7,600 | 100 | 1140 | 1360 | 600 | 430 | 0,4 |
| 30-May-21 | 360 | 100 | 710 | 7,100 | 100 | 1140 | 1360 | 650 | 430 | 0,6 |
| 31-May-21 | 384 | 100 | 690 | 6,900 | 100 | 1140 | 1350 | 660 | 430 | 0,7 |
| 01-Jun-21 | 408 | 100 | 710 | 7,100 | 100 | 1140 | 1360 | 650 | 430 | 0,6 |
| 02-Jun-21 | 432 | 100 | 705 | 7,050 | 100 | 1120 | 1380 | 675 | 430 | 0,7 |
| 03-Jun-21 | 456 | 100 | 700 | 7,000 | 100 | 1120 | 1380 | 680 | 430 | 0,7 |
| 04-Jun-21 | 480 | 100 | 650 | 6,500 | 100 | 1090 | 1350 | 700 | 430 | 0,8 |
| 05-Jun-21 | 504 | 100 | 670 | 6,700 | 100 | 1110 | 1360 | 690 | 430 | 0,8 |
| 06-Jun-21 | 528 | 100 | 710 | 7,100 | 100 | 1110 | 1360 | 650 | 430 | 0,6 |
| 07-Jun-21 | 552 | 100 | 655 | 6,550 | 100 | 1100 | 1330 | 675 | 430 | 0,7 |
| 08-Jun-21 | 572 | 100 | 750 | 7,500 | 100 | 1150 | 1400 | 650 | 430 | 0,6 |
| 09-Jun-21 | 600 | 100 | 730 | 7,300 | 100 | 1135 | 1390 | 660 | 430 | 0,6 |
| 10-Jun-21 | 624 | 100 | 750 | 7,500 | 100 | 1135 | 1400 | 650 | 430 | 0,6 |
| 11-Jun-21 | 648 | 100 | 750 | 7,500 | 100 | 1135 | 1390 | 640 | 430 | 0,6 |
| 12-Jun-21 | 672 | 100 | 760 | 7,600 | 100 | 1135 | 1380 | 620 | 430 | 0,5 |
| 13-Jun-21 | 696 | 100 | 770 | 7,700 | 100 | 1135 | 1400 | 630 | 430 | 0,5 |
| 14-Jun-21 | 720 | 100 | 750 | 7,500 | 100 | 1135 | 1400 | 650 | 430 | 0,6 |
| 15-Jun-21 | 744 | 100 | 740 | 7,400 | 100 | 1160 | 1420 | 680 | 430 | 0,7 |
| 16-Jun-21 | 768 | 100 | 720 | 7,200 | 100 | 1160 | 1410 | 690 | 430 | 0,7 |
| 17-Jun-21 | 792 | 100 | 670 | 6,700 | 100 | 1160 | 1400 | 730 | 430 | 0,9 |
| 18-Jun-21 | 816 | 100 | 700 | 7,000 | 100 | 1135 | 1400 | 700 | 430 | 0,8 |
| 19-Jun-21 | 840 | 100 | 600 | 6,000 | 100 | 1150 | 1400 | 800 | 430 | 1,2 |
| 20-Jun-21 | 864 | 100 | 650 | 6,500 | 100 | 1145 | 1400 | 750 | 430 | 1,0 |
| 21-Jun-21 | 888 | 100 | 670 | 6,700 | 100 | 1150 | 1390 | 720 | 430 | 0,9 |
| 22-Jun-21 | 912 | 100 | 700 | 7,000 | 100 | 1150 | 1390 | 690 | 430 | 0,7 |
| 23-Jun-21 | 936 | 100 | 750 | 7,500 | 100 | 1145 | 1400 | 650 | 430 | 0,6 |
| 24-Jun-21 | 960 | 100 | 710 | 7,100 | 100 | 1150 | 1390 | 680 | 430 | 0,7 |
| 25-Jun-21 | 984 | 100 | 720 | 7,200 | 100 | 1150 | 1390 | 670 | 430 | 0,7 |
| 26-Jun-21 | 1008 | 100 | 740 | 7,400 | 100 | 1145 | 1390 | 650 | 430 | 0,6 |

# Gradient Ratio

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A2-Zone 3* |
| **Consultant** | *Vincent Mukwevho* | **Date** | *15-May-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A2* |
| | | **Soil Sample** | *Sandy Gravel* |



# APPENDIX L

## Laboratory Results – Zone 3 Soil (Sandy Gravel Vs A4)

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# LONG TERM GRADIENT RATIO TEST REPORT

## Permeameter Summary

### GL Test Method 1

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A4 - Zone 3* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *15-May-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *26-Jun-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A4* |
| | | **Soil Sample** | *Sandy Gravel* |

| | | | | |
|---|---|---|---|---|
| **Equipment** | *GL MK1 Permeameter* | | **Support Above** | *none* |
| **Internal Diameter** | *100mm* | | **Support Below** | *wire mesh* |
| **Wetting Up** | *Below* | | **Preparation** | *Oven Dried* |
| | **Mass @ Start (g)** | **Mass @ Finish (g)** | **Thickness (mm)** | **k estimate** |
| **Geosynthetic** | *3,65* | *5.85* | *2.37* | |
| **Soil Sample** | *1157,60* | *1146.07* | *100* | |

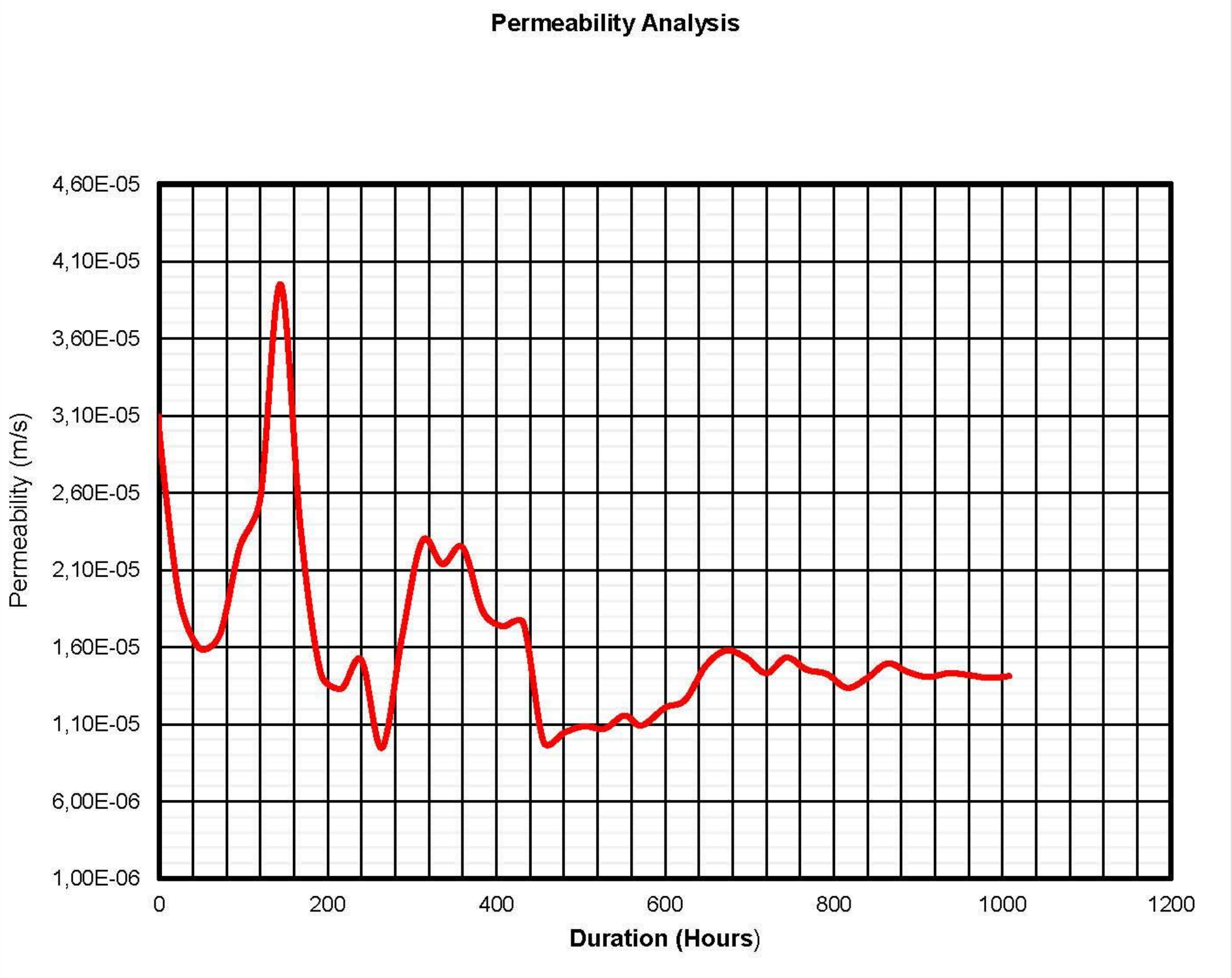
| Date Start 31-03-2016 11h00 | Test Accummulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| ***15-May-21*** | *0* | *1050* | *10* | *3,095E-05* | *100* | *1150* | | *1290* | | *1200* | *590* | *430* |
| ***15-May-21*** | *1* | *1000* | *10* | *2,947E-05* | *100* | *1150* | | *1290* | | *1250* | *600* | *430* |
| ***16-May-21*** | *24* | *650* | *10* | *1,916E-05* | *100* | *1150* | | *1290* | | *1250* | *650* | *430* |
| ***17-May-21*** | *48* | *540* | *10* | *1,592E-05* | *100* | *1150* | | *1290* | | *1300* | *640* | *430* |
| ***18-May-21*** | *72* | *570* | *10* | *1,680E-05* | *100* | *1150* | | *1290* | | *1300* | *650* | *430* |
| ***19-May-21*** | *96* | *765* | *10* | *2,255E-05* | *100* | *1150* | | *1290* | | *1300* | *650* | *430* |
| ***20-May-21*** | *120* | *870* | *10* | *2,564E-05* | *100* | *1150* | | *1290* | | *1300* | *650* | *430* |
| ***21-May-21*** | *144* | *1340* | *10* | *3,949E-05* | *100* | *1150* | | *1290* | | *1300* | *580* | *430* |
| ***22-May-21*** | *168* | *800* | *10* | *2,358E-05* | *100* | *1150* | | *1290* | | *1300* | *650* | *430* |
| ***23-May-21*** | *192* | *450* | *10* | *1,425E-05* | *100* | *1100* | | *1240* | | *1300* | *640* | *430* |
| ***24-May-21*** | *216* | *420* | *10* | *1,330E-05* | *100* | *1100* | | *1240* | | *1290* | *660* | *430* |
| ***25-May-21*** | *240* | *450* | *10* | *1,516E-05* | *100* | *1060* | | *1200* | | *1240* | *650* | *430* |
| ***26-May-21*** | *264* | *290* | *10* | *9,468E-06* | *100* | *1080* | | *1230* | | *1260* | *670* | *430* |
| ***27-May-21*** | *288* | *525* | *10* | *1,663E-05* | *100* | *1100* | | *1260* | | *1300* | *630* | *430* |
| ***28-May-21*** | *312* | *765* | *10* | *2,286E-05* | *100* | *1140* | | *1270* | | *1320* | *620* | *430* |
| ***29-May-21*** | *336* | *695* | *10* | *2,137E-05* | *100* | *1120* | | *1250* | | *1280* | *640* | *430* |
| ***30-May-21*** | *360* | *730* | *10* | *2,245E-05* | *100* | *1120* | | *1250* | | *1280* | *650* | *430* |
| ***31-May-21*** | *384* | *595* | *10* | *1,830E-05* | *100* | *1120* | | *1250* | | *1240* | *660* | *430* |
| ***01-Jun-21*** | *408* | *580* | *10* | *1,734E-05* | *100* | *1140* | | *1270* | | *1240* | *650* | *430* |
| ***02-Jun-21*** | *432* | *570* | *10* | *1,753E-05* | *100* | *1120* | | *1260* | | *1280* | *630* | *430* |
| ***03-Jun-21*** | *456* | *320* | *10* | *9,841E-06* | *100* | *1120* | | *1260* | | *1280* | *610* | *430* |
| ***04-Jun-21*** | *480* | *325* | *10* | *1,045E-05* | *100* | *1090* | | *1230* | | *1260* | *640* | *430* |
| ***05-Jun-21*** | *504* | *343* | *10* | *1,086E-05* | *100* | *1100* | | *1260* | | *1260* | *650* | *430* |
| ***06-Jun-21*** | *528* | *338* | *10* | *1,071E-05* | *100* | *1100* | | *1250* | | *1260* | *660* | *430* |
| ***07-Jun-21*** | *552* | *365* | *10* | *1,156E-05* | *100* | *1100* | | *1250* | | *1260* | *670* | *430* |
| ***08-Jun-21*** | *572* | *355* | *10* | *1,092E-05* | *100* | *1120* | | *1280* | | *1290* | *650* | *430* |
| ***09-Jun-21*** | *600* | *398* | *10* | *1,207E-05* | *100* | *1130* | | *1270* | | *1290* | *610* | *430* |
| ***10-Jun-21*** | *624* | *415* | *10* | *1,258E-05* | *100* | *1130* | | *1270* | | *1290* | *650* | *430* |
| ***11-Jun-21*** | *648* | *487* | *10* | *1,476E-05* | *100* | *1130* | | *1270* | | *1290* | *650* | *430* |
| ***12-Jun-21*** | *672* | *520* | *10* | *1,576E-05* | *100* | *1130* | | *1270* | | *1290* | *660* | *430* |
| ***13-Jun-21*** | *696* | *505* | *10* | *1,531E-05* | *100* | *1130* | | *1270* | | *1290* | *640* | *430* |
| ***14-Jun-21*** | *720* | *472* | *10* | *1,431E-05* | *100* | *1130* | | *1270* | | *1300* | *650* | *430* |
| ***15-Jun-21*** | *744* | *527* | *10* | *1,532E-05* | *100* | *1160* | | *1320* | | *1300* | *670* | *430* |
| ***16-Jun-21*** | *768* | *500* | *10* | *1,453E-05* | *100* | *1160* | | *1320* | | *1330* | *660* | *430* |
| ***17-Jun-21*** | *792* | *490* | *10* | *1,424E-05* | *100* | *1160* | | *1320* | | *1320* | *640* | *430* |
| ***18-Jun-21*** | *816* | *450* | *10* | *1,336E-05* | *100* | *1145* | | *1310* | | *1300* | *650* | *430* |
| ***19-Jun-21*** | *840* | *475* | *10* | *1,400E-05* | *100* | *1150* | | *1310* | | *1300* | *650* | *430* |
| ***20-Jun-21*** | *864* | *507* | *10* | *1,494E-05* | *100* | *1150* | | *1320* | | *1320* | *630* | *430* |
| ***21-Jun-21*** | *888* | *488* | *10* | *1,438E-05* | *100* | *1150* | | *1320* | | *1320* | *640* | *430* |
| ***22-Jun-21*** | *912* | *477* | *10* | *1,406E-05* | *100* | *1150* | | *1320* | | *1320* | *650* | *430* |
| ***23-Jun-21*** | *936* | *482* | *10* | *1,431E-05* | *100* | *1145* | | *1310* | | *1320* | *660* | *430* |
| ***24-Jun-21*** | *960* | *478* | *10* | *1,419E-05* | *100* | *1145* | | *1320* | | *1320* | *650* | *430* |
| ***25-Jun-21*** | *984* | *475* | *10* | *1,400E-05* | *100* | *1150* | | *1320* | | *1320* | *640* | *430* |
| ***26-Jun-21*** | *1008* | *479* | *10* | *1,412E-05* | *100* | *1150* | | *1320* | | *1320* | *650* | *430* |

***Disclaimer:***

*The test results contained herein refers only to the specific product tested as per the referenced test standard and should not be compared to any similar product not tested. The Laboratory does not imply suitability of this product to be used in any particular application, nor does it imply approval of the quality of the product. This test report shall not be reproduced except in full, and only with written approval of the Laboratory.*

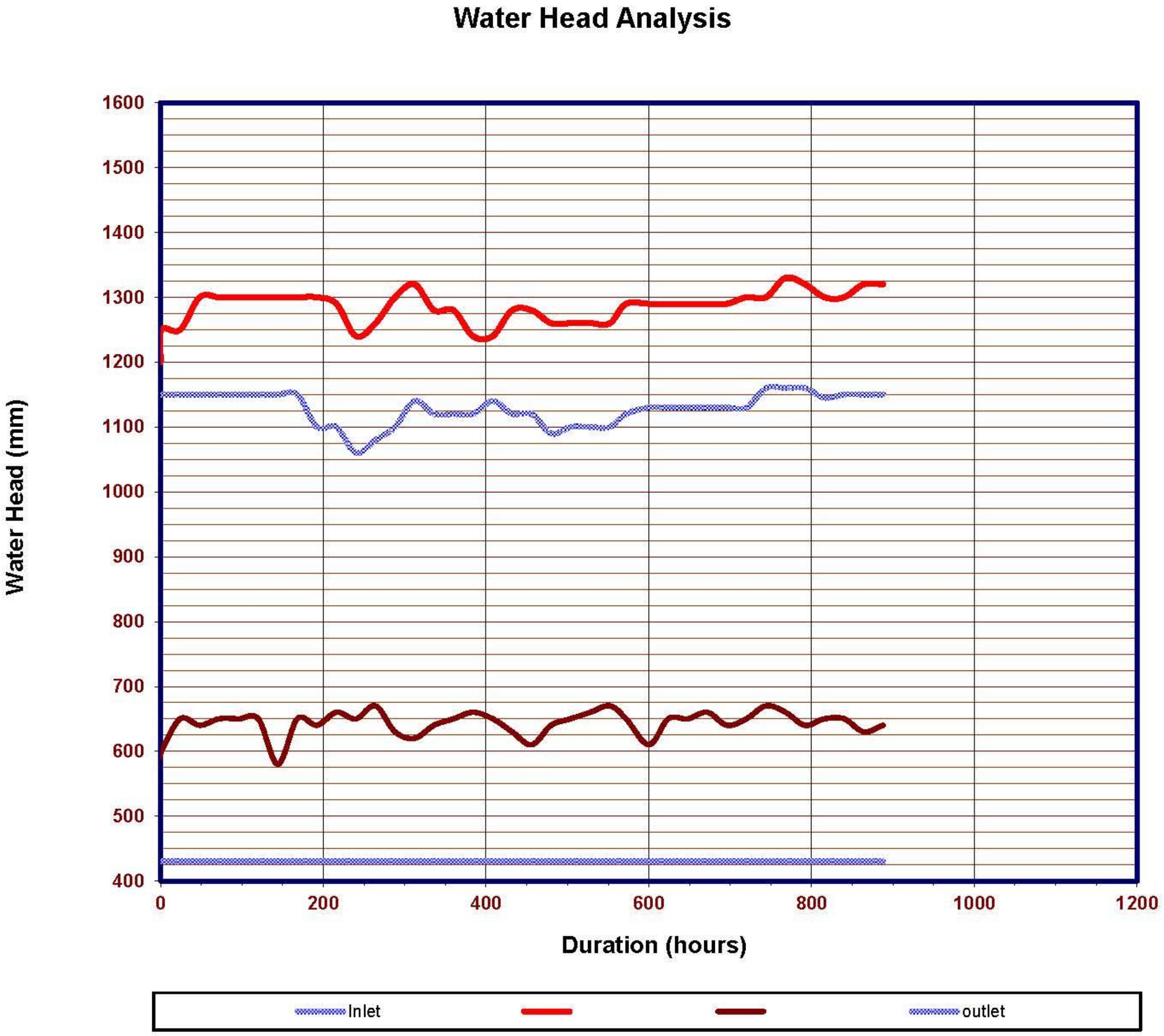
# Permeability Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A4 - Zone 3* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *15-May-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A4* |
| | | **Soil Sample** | *Sandy Gravel* |



# Water Head Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A4 - Zone 3* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *15-May-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A4* |
| | | **Soil Sample** | *Sandy Gravel* |



## Hydraulic Gradients and Gradient Ratios of the System

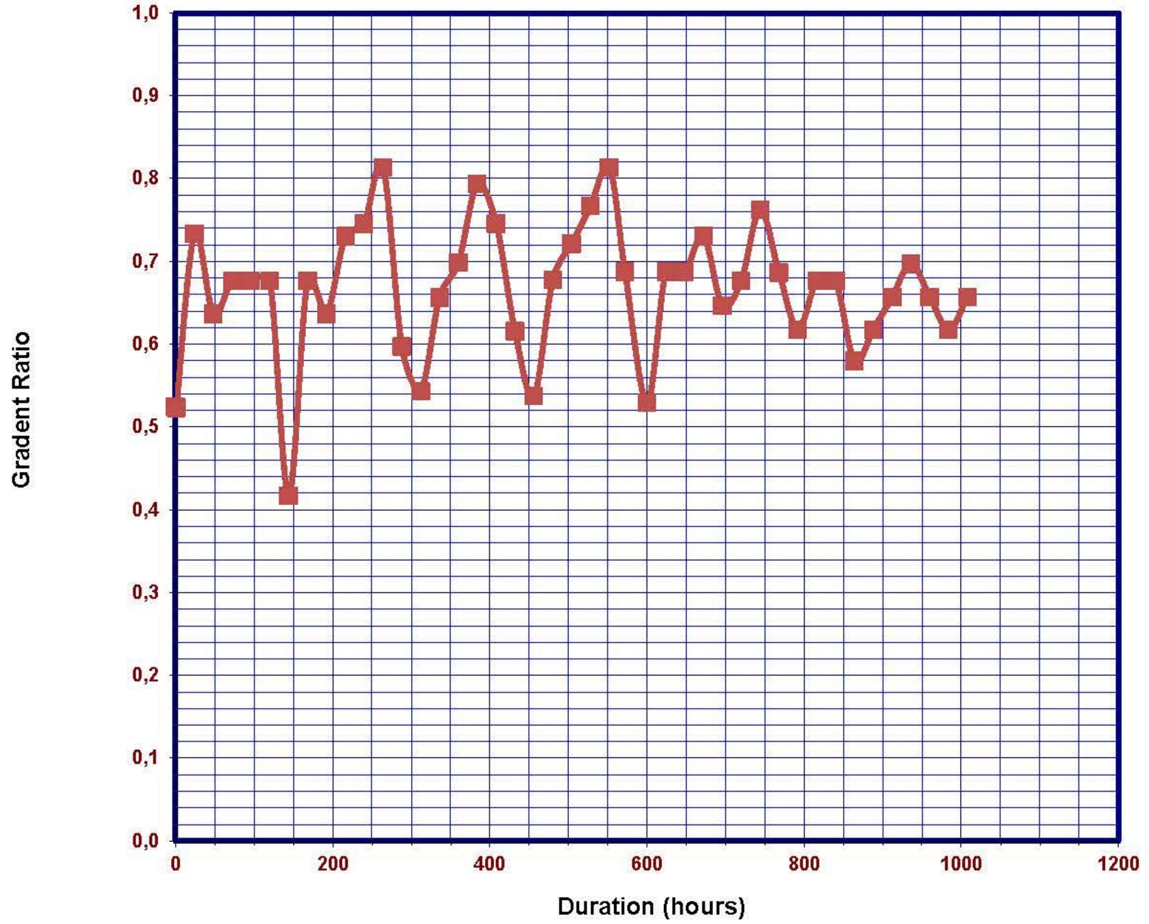
| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A4 - Zone 3* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *15-May-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *26-Jun-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A4* |
| | | **Soil Sample** | *Sandy Gravel* |

| Date | Test Accummulative Hours | *L* | *Δh* | Hydraulic Gradient (*i*) | Sample Height mm | Standpipe Readings - mm | | | | Gradient Ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 300 | 100 | 50 | 0 | |
| | | | | | | Inlet | h75 | h25 | h0 | |
| **15-May-21** | 0 | 100 | 610 | 6,100 | 100 | 1150 | 1200 | 590 | 430 | **0,5** |
| **15-May-21** | 1 | 100 | 650 | 6,500 | 100 | 1150 | 1250 | 600 | 430 | **0,5** |
| **16-May-21** | 24 | 100 | 600 | 6,000 | 100 | 1150 | 1250 | 650 | 430 | **0,7** |
| **17-May-21** | 48 | 100 | 660 | 6,600 | 100 | 1150 | 1300 | 640 | 430 | **0,6** |
| **18-May-21** | 72 | 100 | 650 | 6,500 | 100 | 1150 | 1300 | 650 | 430 | **0,7** |
| **19-May-21** | 96 | 100 | 650 | 6,500 | 100 | 1150 | 1300 | 650 | 430 | **0,7** |
| **20-May-21** | 120 | 100 | 650 | 6,500 | 100 | 1150 | 1300 | 650 | 430 | **0,7** |
| **21-May-21** | 144 | 100 | 720 | 7,200 | 100 | 1150 | 1300 | 580 | 430 | **0,4** |
| **22-May-21** | 168 | 100 | 650 | 6,500 | 100 | 1150 | 1300 | 650 | 430 | **0,7** |
| **23-May-21** | 192 | 100 | 660 | 6,600 | 100 | 1100 | 1300 | 640 | 430 | **0,6** |
| **24-May-21** | 216 | 100 | 630 | 6,300 | 100 | 1100 | 1290 | 660 | 430 | **0,7** |
| **25-May-21** | 240 | 100 | 590 | 5,900 | 100 | 1060 | 1240 | 650 | 430 | **0,7** |
| **26-May-21** | 264 | 100 | 590 | 5,900 | 100 | 1080 | 1260 | 670 | 430 | **0,8** |
| **27-May-21** | 288 | 100 | 670 | 6,700 | 100 | 1100 | 1300 | 630 | 430 | **0,6** |
| **28-May-21** | 312 | 100 | 700 | 7,000 | 100 | 1140 | 1320 | 620 | 430 | **0,5** |
| **29-May-21** | 336 | 100 | 640 | 6,400 | 100 | 1120 | 1280 | 640 | 430 | **0,7** |
| **30-May-21** | 360 | 100 | 630 | 6,300 | 100 | 1120 | 1280 | 650 | 430 | **0,7** |
| **31-May-21** | 384 | 100 | 580 | 5,800 | 100 | 1120 | 1240 | 660 | 430 | **0,8** |
| **01-Jun-21** | 408 | 100 | 590 | 5,900 | 100 | 1140 | 1240 | 650 | 430 | **0,7** |
| **02-Jun-21** | 432 | 100 | 650 | 6,500 | 100 | 1120 | 1280 | 630 | 430 | **0,6** |
| **03-Jun-21** | 456 | 100 | 670 | 6,700 | 100 | 1120 | 1280 | 610 | 430 | **0,5** |
| **04-Jun-21** | 480 | 100 | 620 | 6,200 | 100 | 1090 | 1260 | 640 | 430 | **0,7** |
| **05-Jun-21** | 504 | 100 | 610 | 6,100 | 100 | 1100 | 1260 | 650 | 430 | **0,7** |
| **06-Jun-21** | 528 | 100 | 600 | 6,000 | 100 | 1100 | 1260 | 660 | 430 | **0,8** |
| **07-Jun-21** | 552 | 100 | 590 | 5,900 | 100 | 1100 | 1260 | 670 | 430 | **0,8** |
| **08-Jun-21** | 572 | 100 | 640 | 6,400 | 100 | 1120 | 1290 | 650 | 430 | **0,7** |
| **09-Jun-21** | 600 | 100 | 680 | 6,800 | 100 | 1130 | 1290 | 610 | 430 | **0,5** |
| **10-Jun-21** | 624 | 100 | 640 | 6,400 | 100 | 1130 | 1290 | 650 | 430 | **0,7** |
| **11-Jun-21** | 648 | 100 | 640 | 6,400 | 100 | 1130 | 1290 | 650 | 430 | **0,7** |
| **12-Jun-21** | 672 | 100 | 630 | 6,300 | 100 | 1130 | 1290 | 660 | 430 | **0,7** |
| **13-Jun-21** | 696 | 100 | 650 | 6,500 | 100 | 1130 | 1290 | 640 | 430 | **0,6** |
| **14-Jun-21** | 720 | 100 | 650 | 6,500 | 100 | 1130 | 1300 | 650 | 430 | **0,7** |
| **15-Jun-21** | 744 | 100 | 630 | 6,300 | 100 | 1160 | 1300 | 670 | 430 | **0,8** |
| **16-Jun-21** | 768 | 100 | 670 | 6,700 | 100 | 1160 | 1330 | 660 | 430 | **0,7** |
| **17-Jun-21** | 792 | 100 | 680 | 6,800 | 100 | 1160 | 1320 | 640 | 430 | **0,6** |
| **18-Jun-21** | 816 | 100 | 650 | 6,500 | 100 | 1145 | 1300 | 650 | 430 | **0,7** |
| **19-Jun-21** | 840 | 100 | 650 | 6,500 | 100 | 1150 | 1300 | 650 | 430 | **0,7** |
| **20-Jun-21** | 864 | 100 | 690 | 6,900 | 100 | 1150 | 1320 | 630 | 430 | **0,6** |
| **21-Jun-21** | 888 | 100 | 680 | 6,800 | 100 | 1150 | 1320 | 640 | 430 | **0,6** |
| **22-Jun-21** | 912 | 100 | 670 | 6,700 | 100 | 1150 | 1320 | 650 | 430 | **0,7** |
| **23-Jun-21** | 936 | 100 | 660 | 6,600 | 100 | 1145 | 1320 | 660 | 430 | **0,7** |
| **24-Jun-21** | 960 | 100 | 670 | 6,700 | 100 | 1145 | 1320 | 650 | 430 | **0,7** |
| **25-Jun-21** | 984 | 100 | 680 | 6,800 | 100 | 1150 | 1320 | 640 | 430 | **0,6** |
| **26-Jun-21** | 1008 | 100 | 670 | 6,700 | 100 | 1150 | 1320 | 650 | 430 | **0,7** |

# Gradient Ratio

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A4 - Zone 3* |
| **Consultant** | *Vincent Mukwevho* | **Date** | *15-May-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A4* |
| | | **Soil Sample** | *Sandy Gravel* |

## Gradient Ratio Analysis



# APPENDIX M

## Laboratory Results – Zone 3 Soil (Sandy Gravel Vs A6)

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# LONG TERM GRADIENT RATIO TEST REPORT

## Permeameter Summary

### GL Test Method 1

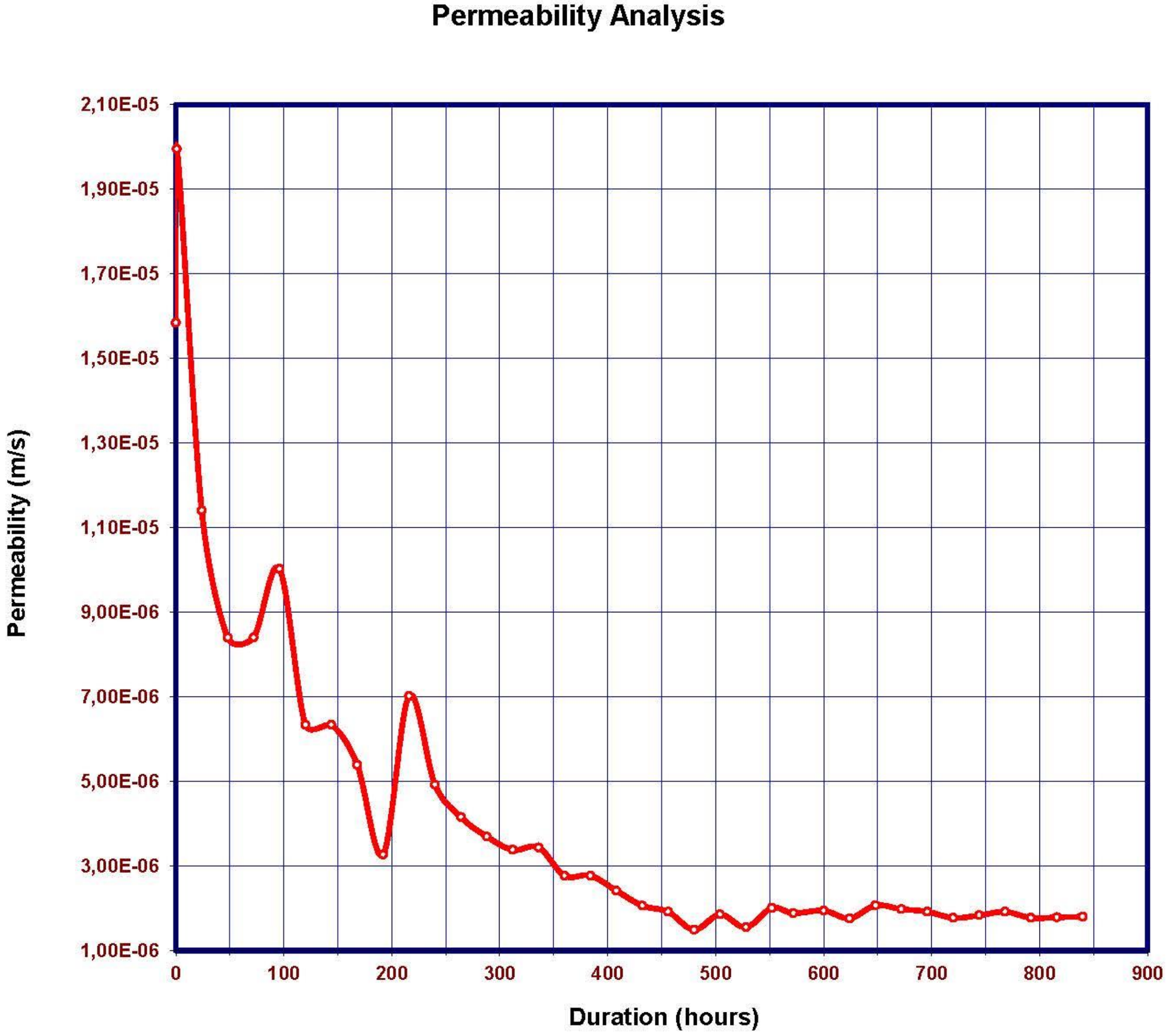
| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A6 - Zone 3* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *18-May-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *22-Jun-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A6* |
| | | **Soil Sample** | *Sandy Gravel* |

| | | | | |
|---|---|---|---|---|
| **Equipment** | *GL MK1 Permeameter* | | **Support Above** | *none* |
| **Internal Diameter** | *100mm* | | **Support Below** | *wire mesh* |
| **Wetting Up** | *Below* | | **Preparation** | *Oven Dried* |
| | **Mass @ Start (g)** | **Mass @ Finish (g)** | **Thickness (mm)** | **k estimate** |
| **Geosynthetic** | *5,34* | *7,60* | *3.36* | |
| **Soil Sample** | *1168,50* | *1163.46* | *100* | |

| Date Start 31-03-2016 11h00 | Test Accummulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| **18-May-21** | 0 | 500 | 10 | 1,584E-05 | 100 | 1100 | | 1290 | | 600 | 480 | 430 |
| **18-May-21** | 1 | 630 | 10 | 1,995E-05 | 100 | 1100 | | 1290 | | 800 | 560 | 430 |
| **19-May-21** | 24 | 360 | 10 | 1,140E-05 | 100 | 1100 | | 1290 | | 900 | 600 | 430 |
| **20-May-21** | 48 | 285 | 10 | 8,400E-06 | 100 | 1150 | | 1290 | | 1150 | 720 | 430 |
| **21-May-21** | 72 | 285 | 10 | 8,400E-06 | 100 | 1150 | | 1290 | | 1220 | 740 | 430 |
| **22-May-21** | 96 | 340 | 10 | 1,002E-05 | 100 | 1150 | | 1290 | | 1350 | 790 | 430 |
| **23-May-21** | 120 | 200 | 10 | 6,335E-06 | 100 | 1100 | | 1240 | | 1360 | 800 | 430 |
| **24-May-21** | 144 | 200 | 10 | 6,335E-06 | 100 | 1100 | | 1240 | | 1360 | 810 | 430 |
| **25-May-21** | 168 | 160 | 10 | 5,389E-06 | 100 | 1060 | | 1200 | | 1320 | 810 | 430 |
| **26-May-21** | 192 | 100 | 10 | 3,265E-06 | 100 | 1080 | | 1240 | | 1240 | 780 | 430 |
| **27-May-21** | 216 | 215 | 10 | 7,019E-06 | 100 | 1080 | | 1260 | | 1270 | 780 | 430 |
| **28-May-21** | 240 | 160 | 10 | 4,921E-06 | 100 | 1120 | | 1280 | | 1300 | 800 | 430 |
| **29-May-21** | 264 | 135 | 10 | 4,152E-06 | 100 | 1120 | | 1280 | | 1270 | 810 | 430 |
| **30-May-21** | 288 | 120 | 10 | 3,691E-06 | 100 | 1120 | | 1280 | | 1270 | 800 | 430 |
| **31-May-21** | 312 | 105 | 10 | 3,376E-06 | 100 | 1090 | | 1250 | | 1260 | 690 | 430 |
| **01-Jun-21** | 336 | 110 | 10 | 3,433E-06 | 100 | 1110 | | 1270 | | 1270 | 770 | 430 |
| **02-Jun-21** | 360 | 90 | 10 | 2,768E-06 | 100 | 1120 | | 1280 | | 1280 | 810 | 430 |
| **03-Jun-21** | 384 | 90 | 10 | 2,768E-06 | 100 | 1120 | | 1280 | | 1280 | 790 | 430 |
| **04-Jun-21** | 408 | 75 | 10 | 2,411E-06 | 100 | 1090 | | 1250 | | 1260 | 820 | 430 |
| **05-Jun-21** | 432 | 65 | 10 | 2,059E-06 | 100 | 1100 | | 1260 | | 1280 | 850 | 430 |
| **06-Jun-21** | 456 | 63 | 10 | 1,910E-06 | 100 | 1130 | | 1270 | | 1280 | 840 | 430 |
| **07-Jun-21** | 480 | 47 | 10 | 1,489E-06 | 100 | 1100 | | 1240 | | 1240 | 830 | 430 |
| **08-Jun-21** | 504 | 61 | 10 | 1,849E-06 | 100 | 1130 | | 1300 | | 1260 | 850 | 430 |
| **09-Jun-21** | 528 | 51 | 10 | 1,546E-06 | 100 | 1130 | | 1300 | | 1265 | 830 | 430 |
| **10-Jun-21** | 552 | 66 | 10 | 2,001E-06 | 100 | 1130 | | 1300 | | 1260 | 820 | 430 |
| **11-Jun-21** | 572 | 62 | 10 | 1,880E-06 | 100 | 1130 | | 1300 | | 1250 | 810 | 430 |
| **12-Jun-21** | 600 | 64 | 10 | 1,940E-06 | 100 | 1130 | | 1300 | | 1290 | 800 | 430 |
| **13-Jun-21** | 624 | 58 | 10 | 1,758E-06 | 100 | 1130 | | 1300 | | 1260 | 800 | 430 |
| **14-Jun-21** | 648 | 68 | 10 | 2,061E-06 | 100 | 1130 | | 1300 | | 1270 | 850 | 430 |
| **15-Jun-21** | 672 | 67 | 10 | 1,975E-06 | 100 | 1150 | | 1300 | | 1280 | 830 | 430 |
| **16-Jun-21** | 696 | 65 | 10 | 1,916E-06 | 100 | 1150 | | 1300 | | 1320 | 850 | 430 |
| **17-Jun-21** | 720 | 60 | 10 | 1,768E-06 | 100 | 1150 | | 1300 | | 1330 | 840 | 430 |
| **18-Jun-21** | 744 | 62 | 10 | 1,827E-06 | 100 | 1150 | | 1300 | | 1310 | 880 | 430 |
| **19-Jun-21** | 768 | 64 | 10 | 1,913E-06 | 100 | 1140 | | 1300 | | 1320 | 870 | 430 |
| **20-Jun-21** | 792 | 60 | 10 | 1,768E-06 | 100 | 1150 | | 1300 | | 1330 | 860 | 430 |
| **21-Jun-21** | 816 | 60 | 10 | 1,781E-06 | 100 | 1145 | | 1300 | | 1310 | 880 | 430 |
| **22-Jun-21** | 840 | 61 | 10 | 1,798E-06 | 100 | 1150 | | 1300 | | 1320 | 900 | 430 |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |

# Permeability Analysis

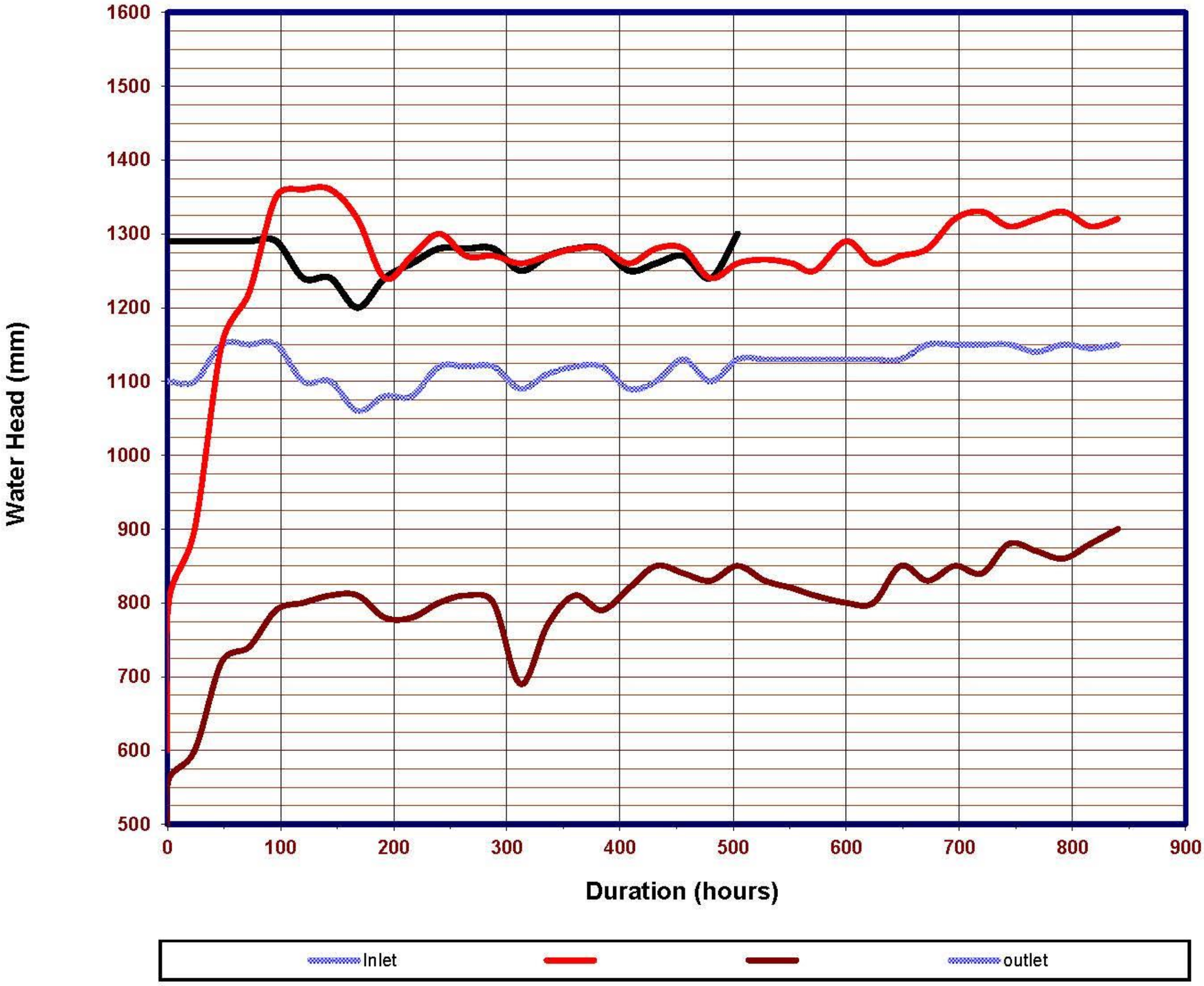
| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A6 - Zone 3* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *18-May-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A6* |
| | | **Soil Sample** | *Sandy Gravel* |



# Water Head Analysis

|  |  |  |  |
|---|---|---|---|
| Client | Vincent Mukwevho | Test Number | A6 - Zone 3 |
| Consultant | 230 Albertus Street, La Montagne, Silverton, 0184 | Date | 18-May-21 |
| Project | Masters Thesis | Product | Bidim A6 |
|  |  | Soil Sample | Sandy Gravel |

## Water Head Analysis



## Hydraulic Gradients and Gradient Ratios of the System

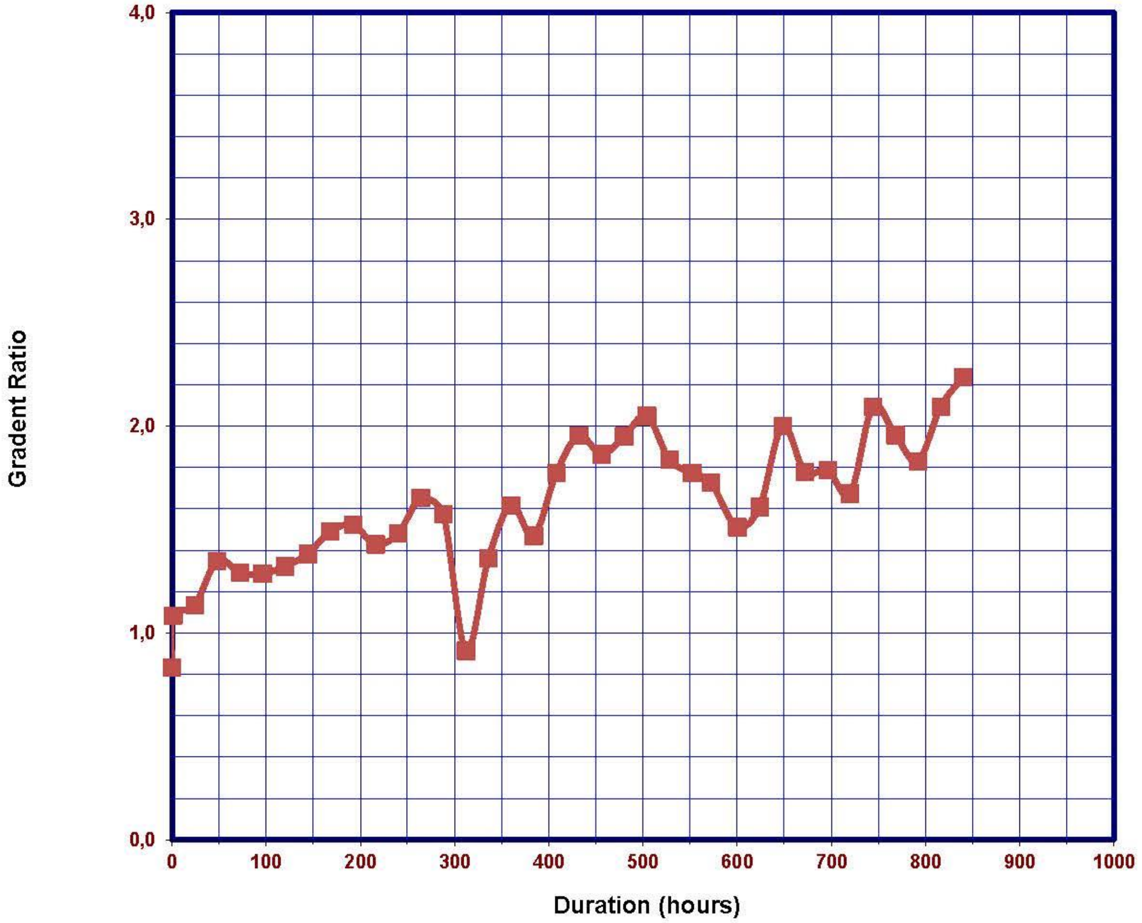
| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A6 - Zone 3* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *18-May-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *22-Jun-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A6* |
| | | **Soil Sample** | *Sandy Gravel* |

| Date | Test Accummulative Hours | *L* | Δ*h* | Hydraulic Gradient (*i*) | Sample Height mm | Standpipe Readings - mm | | | | Gradient Ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 300 | 100 | 50 | 0 | |
| | | | | | | Inlet | h75 | h25 | h0 | |
| **18-May-21** | 0 | 100 | 120 | 1,200 | 100 | 1100 | 600 | 480 | 430 | 0,8 |
| **18-May-21** | 1 | 100 | 240 | 2,400 | 100 | 1100 | 800 | 560 | 430 | 1,1 |
| **19-May-21** | 24 | 100 | 300 | 3,000 | 100 | 1100 | 900 | 600 | 430 | 1,1 |
| **20-May-21** | 48 | 100 | 430 | 4,300 | 100 | 1150 | 1150 | 720 | 430 | 1,3 |
| **21-May-21** | 72 | 100 | 480 | 4,800 | 100 | 1150 | 1220 | 740 | 430 | 1,3 |
| **22-May-21** | 96 | 100 | 560 | 5,600 | 100 | 1150 | 1350 | 790 | 430 | 1,3 |
| **23-May-21** | 120 | 100 | 560 | 5,600 | 100 | 1100 | 1360 | 800 | 430 | 1,3 |
| **24-May-21** | 144 | 100 | 550 | 5,500 | 100 | 1100 | 1360 | 810 | 430 | 1,4 |
| **25-May-21** | 168 | 100 | 510 | 5,100 | 100 | 1060 | 1320 | 810 | 430 | 1,5 |
| **26-May-21** | 192 | 100 | 460 | 4,600 | 100 | 1080 | 1240 | 780 | 430 | 1,5 |
| **27-May-21** | 216 | 100 | 490 | 4,900 | 100 | 1080 | 1270 | 780 | 430 | 1,4 |
| **28-May-21** | 240 | 100 | 500 | 5,000 | 100 | 1120 | 1300 | 800 | 430 | 1,5 |
| **29-May-21** | 264 | 100 | 460 | 4,600 | 100 | 1120 | 1270 | 810 | 430 | 1,7 |
| **30-May-21** | 288 | 100 | 470 | 4,700 | 100 | 1120 | 1270 | 800 | 430 | 1,6 |
| **31-May-21** | 312 | 100 | 570 | 5,700 | 100 | 1090 | 1260 | 690 | 430 | 0,9 |
| **01-Jun-21** | 336 | 100 | 500 | 5,000 | 100 | 1110 | 1270 | 770 | 430 | 1,4 |
| **02-Jun-21** | 360 | 100 | 470 | 4,700 | 100 | 1120 | 1280 | 810 | 430 | 1,6 |
| **03-Jun-21** | 384 | 100 | 490 | 4,900 | 100 | 1120 | 1280 | 790 | 430 | 1,5 |
| **04-Jun-21** | 408 | 100 | 440 | 4,400 | 100 | 1090 | 1260 | 820 | 430 | 1,8 |
| **05-Jun-21** | 432 | 100 | 430 | 4,300 | 100 | 1100 | 1280 | 850 | 430 | 2,0 |
| **06-Jun-21** | 456 | 100 | 440 | 4,400 | 100 | 1130 | 1280 | 840 | 430 | 1,9 |
| **07-Jun-21** | 480 | 100 | 410 | 4,100 | 100 | 1100 | 1240 | 830 | 430 | 2,0 |
| **08-Jun-21** | 504 | 100 | 410 | 4,100 | 100 | 1130 | 1260 | 850 | 430 | 2,0 |
| **09-Jun-21** | 528 | 100 | 435 | 4,350 | 100 | 1130 | 1265 | 830 | 430 | 1,8 |
| **10-Jun-21** | 552 | 100 | 440 | 4,400 | 100 | 1130 | 1260 | 820 | 430 | 1,8 |
| **11-Jun-21** | 572 | 100 | 440 | 4,400 | 100 | 1130 | 1250 | 810 | 430 | 1,7 |
| **12-Jun-21** | 600 | 100 | 490 | 4,900 | 100 | 1130 | 1290 | 800 | 430 | 1,5 |
| **13-Jun-21** | 624 | 100 | 460 | 4,600 | 100 | 1130 | 1260 | 800 | 430 | 1,6 |
| **14-Jun-21** | 648 | 100 | 420 | 4,200 | 100 | 1130 | 1270 | 850 | 430 | 2,0 |
| **15-Jun-21** | 672 | 100 | 450 | 4,500 | 100 | 1150 | 1280 | 830 | 430 | 1,8 |
| **16-Jun-21** | 696 | 100 | 470 | 4,700 | 100 | 1150 | 1320 | 850 | 430 | 1,8 |
| **17-Jun-21** | 720 | 100 | 490 | 4,900 | 100 | 1150 | 1330 | 840 | 430 | 1,7 |
| **18-Jun-21** | 744 | 100 | 430 | 4,300 | 100 | 1150 | 1310 | 880 | 430 | 2,1 |
| **19-Jun-21** | 768 | 100 | 450 | 4,500 | 100 | 1140 | 1320 | 870 | 430 | 2,0 |
| **20-Jun-21** | 792 | 100 | 470 | 4,700 | 100 | 1150 | 1330 | 860 | 430 | 1,8 |
| **21-Jun-21** | 816 | 100 | 430 | 4,300 | 100 | 1145 | 1310 | 880 | 430 | 2,1 |
| **22-Jun-21** | 840 | 100 | 420 | 4,200 | 100 | 1150 | 1320 | 900 | 430 | 2,2 |
| | | | | | | | | | | |
| | | | | | | | | | | |

## Gradient Ratio

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *A6 - Zone 3* |
| **Consultant** | *Vincent Mukwevho* | **Date** | *22-Jun-21* |
| **Project** | *Masters Thesis* | **Product** | *Bidim A6* |
| | | **Soil Sample** | *Sandy Gravel* |

### Gradient Ratio Analysis



# APPENDIX N

## Laboratory Results – Zone 3 Soil (Sandy Gravel Vs S120)

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# LONG TERM GRADIENT RATIO TEST REPORT

## Permeameter Summary

### GL Test Method 1

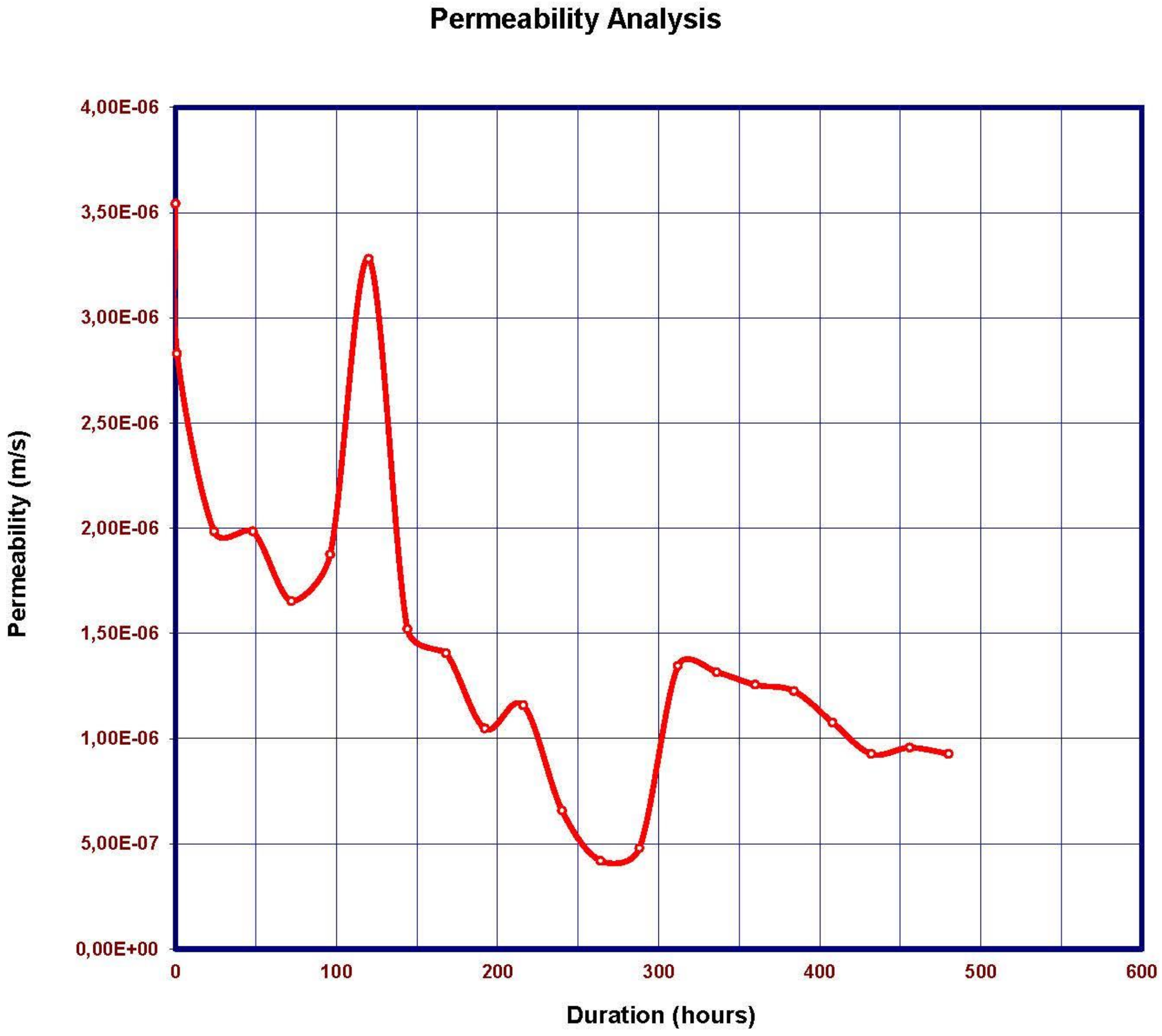
| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S120 - Zone 3* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *23-Jun-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *13-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *S120* |
| | | **Soil Sample** | *Sandy Gravel* |

| | | | | |
|---|---|---|---|---|
| **Equipment** | *GL MK1 Permeameter* | | **Support Above** | *none* |
| **Internal Diameter** | *100mm* | | **Support Below** | *wire mesh* |
| **Wetting Up** | *Below* | | **Preparation** | *Oven Dried* |
| | **Mass @ Start (g)** | **Mass @ Finish (g)** | **Thickness (mm)** | **k estimate** |
| **Geosynthetic** | *3,60* | *4,10* | *0.75* | |
| **Soil Sample** | *1227,50* | *1224.48* | *100* | |

| Date Start 31-03-2016 11h00 | Test Accummulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| **23-Jun-21** | *0* | *121* | *10* | *3,542E-06* | *100* | *1155* | | *1310* | | *770* | *500* | *430* |
| **23-Jun-21** | *1* | *98* | *10* | *2,829E-06* | *100* | *1165* | | *1320* | | *1260* | *660* | *430* |
| **24-Jun-21** | *24* | *72* | *10* | *1,984E-06* | *100* | *1200* | | *1340* | | *1330* | *890* | *430* |
| **25-Jun-21** | *48* | *72* | *10* | *1,984E-06* | *100* | *1200* | | *1340* | | *1330* | *910* | *430* |
| **26-Jun-21** | *72* | *60* | *10* | *1,654E-06* | *100* | *1200* | | *1340* | | *1330* | *900* | *430* |
| **27-Jun-21** | *96* | *68* | *10* | *1,874E-06* | *100* | *1200* | | *1340* | | *1320* | *910* | *430* |
| **28-Jun-21** | *120* | *119* | *10* | *3,280E-06* | *100* | *1200* | | *1340* | | *1330* | *700* | *430* |
| **29-Jun-21** | *144* | *53* | *10* | *1,520E-06* | *100* | *1170* | | *1310* | | *1320* | *980* | *430* |
| **30-Jun-21** | *168* | *51* | *10* | *1,406E-06* | *100* | *1200* | | *1340* | | *1320* | *1000* | *430* |
| **01-Jul-21** | *192* | *38* | *10* | *1,047E-06* | *100* | *1200* | | *1340* | | *1340* | *970* | *430* |
| **02-Jul-21** | *216* | *42* | *10* | *1,157E-06* | *100* | *1200* | | *1340* | | *1320* | *1000* | *430* |
| **03-Jul-21** | *240* | *22* | *10* | *6,575E-07* | *100* | *1140* | | *1290* | | *1330* | *930* | *430* |
| **04-Jul-21** | *264* | *14* | *10* | *4,184E-07* | *100* | *1140* | | *1290* | | *1330* | *980* | *430* |
| **05-Jul-21** | *288* | *16* | *10* | *4,782E-07* | *100* | *1140* | | *1290* | | *1340* | *960* | *430* |
| **06-Jul-21** | *312* | *45* | *10* | *1,345E-06* | *100* | *1140* | | *1290* | | *1320* | *860* | *430* |
| **07-Jul-21** | *336* | *44* | *10* | *1,315E-06* | *100* | *1140* | | *1300* | | *1250* | *850* | *430* |
| **08-Jul-21** | *360* | *42* | *10* | *1,255E-06* | *100* | *1140* | | *1300* | | *1240* | *830* | *430* |
| **09-Jul-21** | *384* | *41* | *10* | *1,225E-06* | *100* | *1140* | | *1300* | | *1220* | *880* | *430* |
| **10-Jul-21** | *408* | *36* | *10* | *1,076E-06* | *100* | *1140* | | *1300* | | *1210* | *850* | *430* |
| **11-Jul-21** | *432* | *31* | *10* | *9,265E-07* | *100* | *1140* | | *1300* | | *1200* | *850* | *430* |
| **12-Jul-21** | *456* | *32* | *10* | *9,564E-07* | *100* | *1140* | | *1300* | | *1200* | *850* | *430* |
| **13-Jul-21** | *480* | *31* | *10* | *9,265E-07* | *100* | *1140* | | *1300* | | *1220* | *850* | *430* |

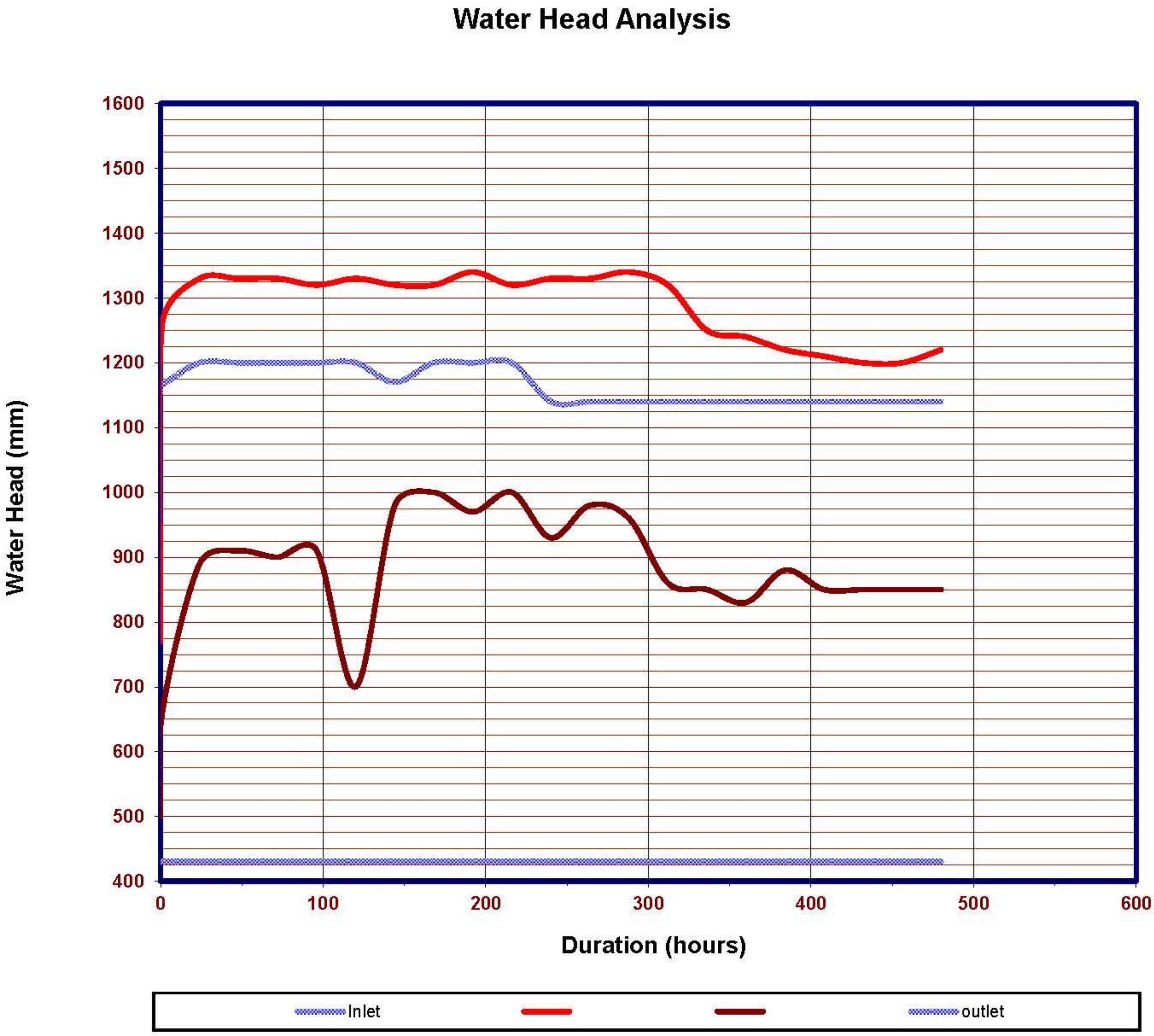
# Permeability Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S120 - Zone 3* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *23-Jun-21* |
| **Project** | *Masters Thesis* | **Product** | *S120* |
| | | **Soil Sample** | *Sandy Gravel* |



# Water Head Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S120 - Zone 3* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *23-Jun-21* |
| **Project** | *Masters Thesis* | **Product** | *S120* |
| | | **Soil Sample** | *Sandy Gravel* |



## Hydraulic Gradients and Gradient Ratios of the System

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S120 - Zone 3* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *23-Jun-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *13-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *S120* |
| | | **Soil Sample** | *Sandy Gravel* |

| Date | Test Accummulative Hours | *L* | *Δh* | Hydraulic Gradient (*i*) | Sample Height mm | Standpipe Readings - mm | | | | Gradient Ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 300 | 100 | 50 | 0 | |
| | | | | | | Inlet | h75 | h25 | h0 | |
| **23-Jun-21** | 0 | 100 | 270 | 2,700 | 100 | 1155 | 770 | 500 | 430 | 0,5 |
| **23-Jun-21** | 1 | 100 | 600 | 6,000 | 100 | 1165 | 1260 | 660 | 430 | 0,8 |
| **24-Jun-21** | 24 | 100 | 440 | 4,400 | 100 | 1200 | 1330 | 890 | 430 | 2,1 |
| **25-Jun-21** | 48 | 100 | 420 | 4,200 | 100 | 1200 | 1330 | 910 | 430 | 2,3 |
| **26-Jun-21** | 72 | 100 | 430 | 4,300 | 100 | 1200 | 1330 | 900 | 430 | 2,2 |
| **27-Jun-21** | 96 | 100 | 410 | 4,100 | 100 | 1200 | 1320 | 910 | 430 | 2,3 |
| **28-Jun-21** | 120 | 100 | 630 | 6,300 | 100 | 1200 | 1330 | 700 | 430 | 0,9 |
| **29-Jun-21** | 144 | 100 | 340 | 3,400 | 100 | 1170 | 1320 | 980 | 430 | 3,2 |
| **30-Jun-21** | 168 | 100 | 320 | 3,200 | 100 | 1200 | 1320 | 1000 | 430 | 3,6 |
| **01-Jul-21** | 192 | 100 | 370 | 3,700 | 100 | 1200 | 1340 | 970 | 430 | 2,9 |
| **02-Jul-21** | 216 | 100 | 320 | 3,200 | 100 | 1200 | 1320 | 1000 | 430 | 3,6 |
| **03-Jul-21** | 240 | 100 | 400 | 4,000 | 100 | 1140 | 1330 | 930 | 430 | 2,5 |
| **04-Jul-21** | 264 | 100 | 350 | 3,500 | 100 | 1140 | 1330 | 980 | 430 | 3,1 |
| **05-Jul-21** | 288 | 100 | 380 | 3,800 | 100 | 1140 | 1340 | 960 | 430 | 2,8 |
| **06-Jul-21** | 312 | 100 | 460 | 4,600 | 100 | 1140 | 1320 | 860 | 430 | 1,9 |
| **07-Jul-21** | 336 | 100 | 400 | 4,000 | 100 | 1140 | 1250 | 850 | 430 | 2,1 |
| **08-Jul-21** | 360 | 100 | 410 | 4,100 | 100 | 1140 | 1240 | 830 | 430 | 2,0 |
| **09-Jul-21** | 384 | 100 | 340 | 3,400 | 100 | 1140 | 1220 | 880 | 430 | 2,6 |
| **10-Jul-21** | 408 | 100 | 360 | 3,600 | 100 | 1140 | 1210 | 850 | 430 | 2,3 |
| **11-Jul-21** | 432 | 100 | 350 | 3,500 | 100 | 1140 | 1200 | 850 | 430 | 2,4 |
| **12-Jul-21** | 456 | 100 | 350 | 3,500 | 100 | 1140 | 1200 | 850 | 430 | 2,4 |
| **13-Jul-21** | 480 | 100 | 370 | 3,700 | 100 | 1140 | 1220 | 850 | 430 | 2,3 |
| | | | | | | | | | | |
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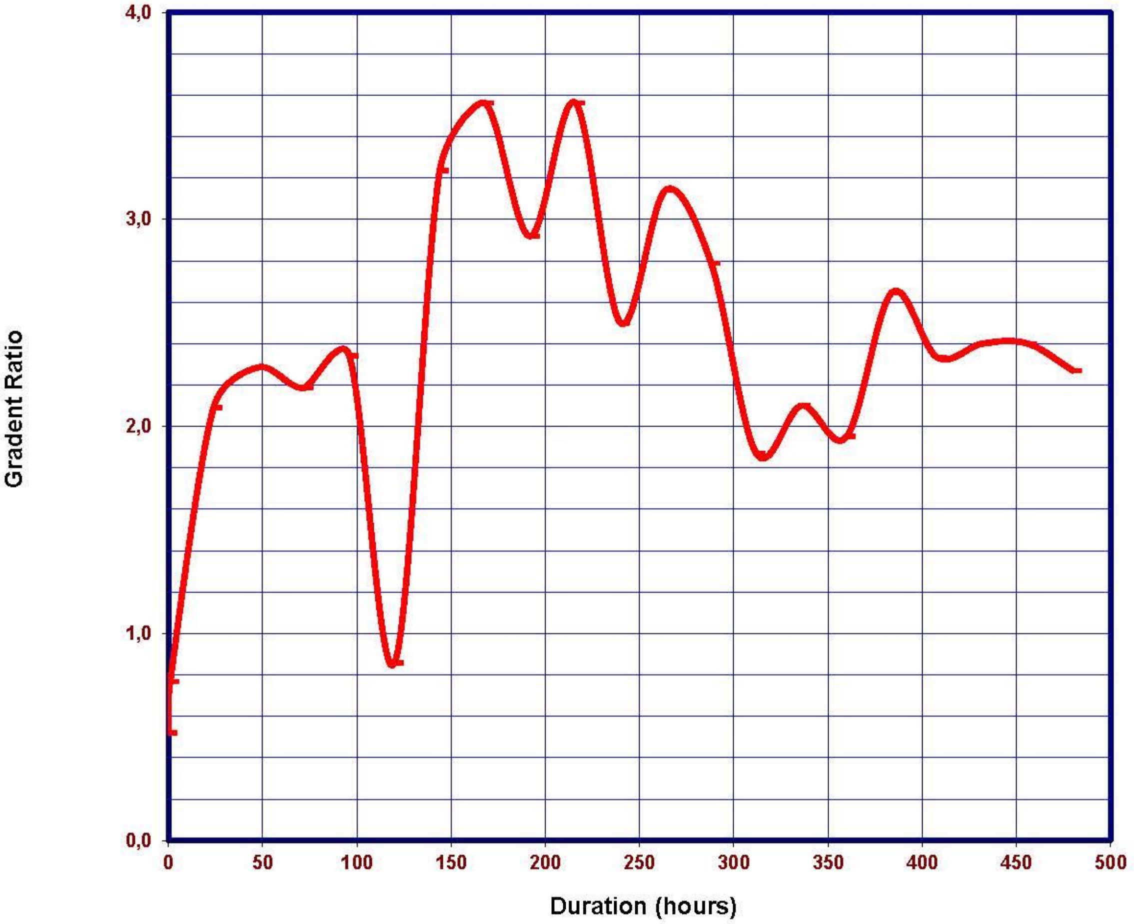
# Gradient Ratio

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S120 - Zone 3* |
| **Consultant** | *Vincent Mukwevho* | **Date** | *13-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *S120* |
| | | **Soil Sample** | *Sandy Gravel* |

## Gradient Ratio Analysis



# APPENDIX O

## Laboratory Results – Zone 3 Soil (Sandy Gravel Vs S120)

SOILLAB
Part of the SMEC Group

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# LONG TERM GRADIENT RATIO TEST REPORT

## Permeameter Summary

### GL Test Method 1 (Adapted from Kaytech Engineerred Fabrics)

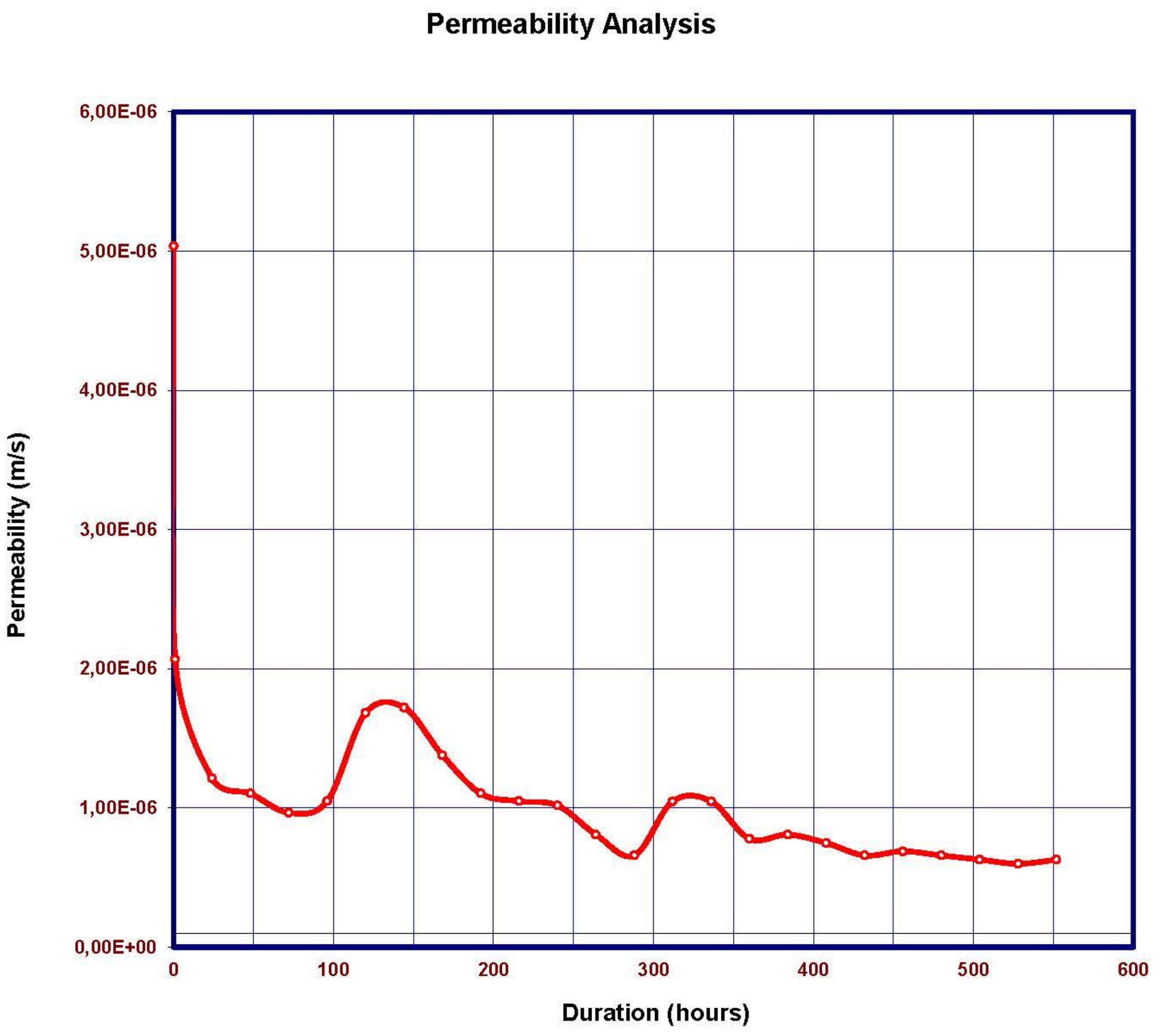
| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S270 - Zone 3* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *23-Jun-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *30-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *S270* |
| | | **Soil Sample** | *Sandy Gravel* |

| | | | | |
|---|---|---|---|---|
| **Equipment** | *GL MK1 Permeameter* | | **Support Above** | *none* |
| **Internal Diameter** | *100mm* | | **Support Below** | *wire mesh* |
| **Wetting Up** | *Below* | | **Preparation** | *Oven Dried* |
| | **Mass @ Start (g)** | **Mass @ Finish (g)** | **Thickness (mm)** | **k estimate** |
| **Geosynthetic** | *3.90* | *4.30* | *1.0* | |
| **Soil Sample** | *1205.70* | *1201.96* | *100* | |

| Date Start 31-03-2016 11h00 | Test Accummulative Hours | Quantity ml | Duration min | Permeability k m/s | Sample Height mm | Standpipe Readings - mm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | | 2 | | 3 | 4 | 5 |
| | | | | | | 300 | 250 | 200 | 150 | 100 | 50 | 0 |
| | | | | | | Inlet | | | | Soil Sample | | Outlet |
| **23-Jun-21** | *0* | *178* | *10* | *5,036E-06* | *100* | *1180* | | *320* | | *600* | *480* | *430* |
| **23-Jun-21** | *1* | *75* | *10* | *2,067E-06* | *100* | *1200* | | *650* | | *650* | *520* | *430* |
| **24-Jun-21** | *24* | *44* | *10* | *1,213E-06* | *100* | *1200* | | *1340* | | *670* | *550* | *430* |
| **25-Jun-21** | *48* | *40* | *10* | *1,102E-06* | *100* | *1200* | | *1340* | | *700* | *590* | *430* |
| **26-Jun-21** | *72* | *35* | *10* | *9,646E-07* | *100* | *1200* | | *1340* | | *720* | *610* | *430* |
| **27-Jun-21** | *96* | *38* | *10* | *1,047E-06* | *100* | *1200* | | *1340* | | *730* | *600* | *430* |
| **28-Jun-21** | *120* | *61* | *10* | *1,681E-06* | *100* | *1200* | | *1340* | | *750* | *630* | *430* |
| **29-Jun-21** | *144* | *60* | *10* | *1,721E-06* | *100* | *1170* | | *1310* | | *800* | *680* | *430* |
| **30-Jun-21** | *168* | *50* | *10* | *1,378E-06* | *100* | *1200* | | *1340* | | *780* | *660* | *430* |
| **01-Jul-21** | *192* | *40* | *10* | *1,102E-06* | *100* | *1200* | | *1340* | | *750* | *630* | *430* |
| **02-Jul-21** | *216* | *38* | *10* | *1,047E-06* | *100* | *1200* | | *1340* | | *800* | *650* | *430* |
| **03-Jul-21** | *240* | *34* | *10* | *1,016E-06* | *100* | *1140* | | *1290* | | *900* | *700* | *430* |
| **04-Jul-21** | *264* | *27* | *10* | *8,070E-07* | *100* | *1140* | | *1290* | | *1000* | *760* | *430* |
| **05-Jul-21** | *288* | *22* | *10* | *6,575E-07* | *100* | *1140* | | *1290* | | *1020* | *760* | *430* |
| **06-Jul-21** | *312* | *35* | *10* | *1,046E-06* | *100* | *1140* | | *1290* | | *1010* | *760* | *430* |
| **07-Jul-21** | *336* | *35* | *10* | *1,046E-06* | *100* | *1140* | | *1300* | | *990* | *760* | *430* |
| **08-Jul-21** | *360* | *26* | *10* | *7,771E-07* | *100* | *1140* | | *1300* | | *970* | *760* | *430* |
| **09-Jul-21** | *384* | *27* | *10* | *8,070E-07* | *100* | *1140* | | *1300* | | *955* | *760* | *430* |
| **10-Jul-21** | *408* | *25* | *10* | *7,472E-07* | *100* | *1140* | | *1300* | | *930* | *760* | *430* |
| **11-Jul-21** | *432* | *22* | *10* | *6,575E-07* | *100* | *1140* | | *1300* | | *940* | *760* | *430* |
| **12-Jul-21** | *456* | *23* | *10* | *6,874E-07* | *100* | *1140* | | *1300* | | *950* | *760* | *430* |
| **13-Jul-21** | *480* | *22* | *10* | *6,575E-07* | *100* | *1140* | | *1300* | | *930* | *760* | *430* |
| **14-Jul-21** | *504* | *21* | *10* | *6,277E-07* | *100* | *1140* | | *1300* | | *940* | *760* | *430* |
| **15-Jul-21** | *528* | *20* | *10* | *5,978E-07* | *100* | *1140* | | *1300* | | *950* | *760* | *430* |
| **16-Jul-21** | *552* | *21* | *10* | *6,277E-07* | *100* | *1140* | | *1300* | | *940* | *760* | *430* |

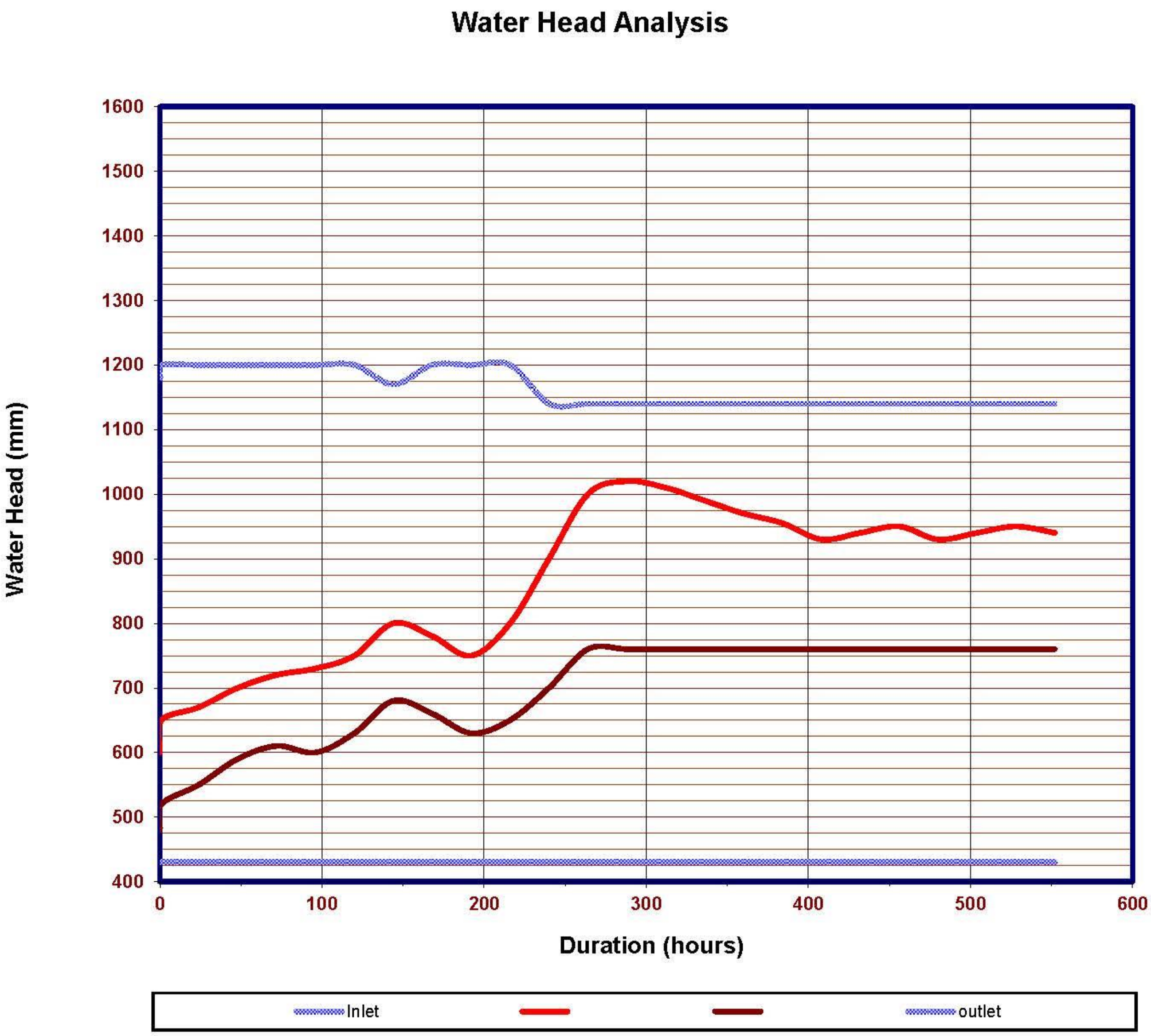
# Permeability Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S270 - Zone 3* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *23-Jun-21* |
| **Project** | *Masters Thesis* | **Product** | *S270* |
| | | **Soil Sample** | *Sandy Gravel* |



# Water Head Analysis

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S270 - Zone 3* |
| **Consultant** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date** | *23-Jun-21* |
| **Project** | *Masters Thesis* | **Product** | *S270* |
| | | **Soil Sample** | *Sandy Gravel* |



## Hydraulic Gradients and Gradient Ratios of the System

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S270 - Zone 3* |
| **Address** | *230 Albertus Street, La Montagne, Silverton, 0184* | **Date Start** | *23-Jun-21* |
| **Contact** | *Vincent Mukwevho* | **Date Fin** | *30-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *S270* |
| | | **Soil Sample** | *Sandy Gravel* |

| Date | Test | | | Hydraulic | Sample | Standpipe Readings - mm | | | | Gradient |
|---|---|---|---|---|---|---|---|---|---|---|
| | 3.90 | | | Gradient | Height | 300 | 100 | 50 | 0 | Ratio |
| | 1205.70 | *L* | Δ*h* | (*i*) | mm | Inlet | h75 | h25 | h0 | |
| **23-Jun-21** | *0* | *100* | *120* | *1,200* | *100* | *1180* | *600* | *480* | *430* | 0,8 |
| **23-Jun-21** | *1* | *100* | *130* | *1,300* | *100* | *1200* | *650* | *520* | *430* | 1,4 |
| **24-Jun-21** | *24* | *100* | *120* | *1,200* | *100* | *1200* | *670* | *550* | *430* | 2,0 |
| **25-Jun-21** | *48* | *100* | *110* | *1,100* | *100* | *1200* | *700* | *590* | *430* | 2,9 |
| **26-Jun-21** | *72* | *100* | *110* | *1,100* | *100* | *1200* | *720* | *610* | *430* | 3,3 |
| **27-Jun-21** | *96* | *100* | *130* | *1,300* | *100* | *1200* | *730* | *600* | *430* | 2,6 |
| **28-Jun-21** | *120* | *100* | *120* | *1,200* | *100* | *1200* | *750* | *630* | *430* | 3,3 |
| **29-Jun-21** | *144* | *100* | *120* | *1,200* | *100* | *1170* | *800* | *680* | *430* | 4,2 |
| **30-Jun-21** | *168* | *100* | *120* | *1,200* | *100* | *1200* | *780* | *660* | *430* | 3,8 |
| **01-Jul-21** | *192* | *100* | *120* | *1,200* | *100* | *1200* | *750* | *630* | *430* | 3,3 |
| **02-Jul-21** | *216* | *100* | *150* | *1,500* | *100* | *1200* | *800* | *650* | *430* | 2,9 |
| **03-Jul-21** | *240* | *100* | *200* | *2,000* | *100* | *1140* | *900* | *700* | *430* | 2,7 |
| **04-Jul-21** | *264* | *100* | *240* | *2,400* | *100* | *1140* | *1000* | *760* | *430* | 2,8 |
| **05-Jul-21** | *288* | *100* | *260* | *2,600* | *100* | *1140* | *1020* | *760* | *430* | 2,5 |
| **06-Jul-21** | *312* | *100* | *250* | *2,500* | *100* | *1140* | *1010* | *760* | *430* | 2,6 |
| **07-Jul-21** | *336* | *100* | *230* | *2,300* | *100* | *1140* | *990* | *760* | *430* | 2,9 |
| **08-Jul-21** | *360* | *100* | *210* | *2,100* | *100* | *1140* | *970* | *760* | *430* | 3,1 |
| **09-Jul-21** | *384* | *100* | *195* | *1,950* | *100* | *1140* | *955* | *760* | *430* | 3,4 |
| **10-Jul-21** | *408* | *100* | *170* | *1,700* | *100* | *1140* | *930* | *760* | *430* | 3,9 |
| **11-Jul-21** | *432* | *100* | *180* | *1,800* | *100* | *1140* | *940* | *760* | *430* | 3,7 |
| **12-Jul-21** | *456* | *100* | *190* | *1,900* | *100* | *1140* | *950* | *760* | *430* | 3,5 |
| **13-Jul-21** | *480* | *100* | *170* | *1,700* | *100* | *1140* | *930* | *760* | *430* | 3,9 |
| **14-Jul-21** | *504* | *100* | *180* | *1,800* | *100* | *1140* | *940* | *760* | *430* | 3,7 |
| **15-Jul-21** | *528* | *100* | *190* | *1,900* | *100* | *1140* | *950* | *760* | *430* | 3,5 |
| **16-Jul-21** | *552* | *100* | *180* | *1,800* | *100* | *1140* | *940* | *760* | *430* | 3,7 |
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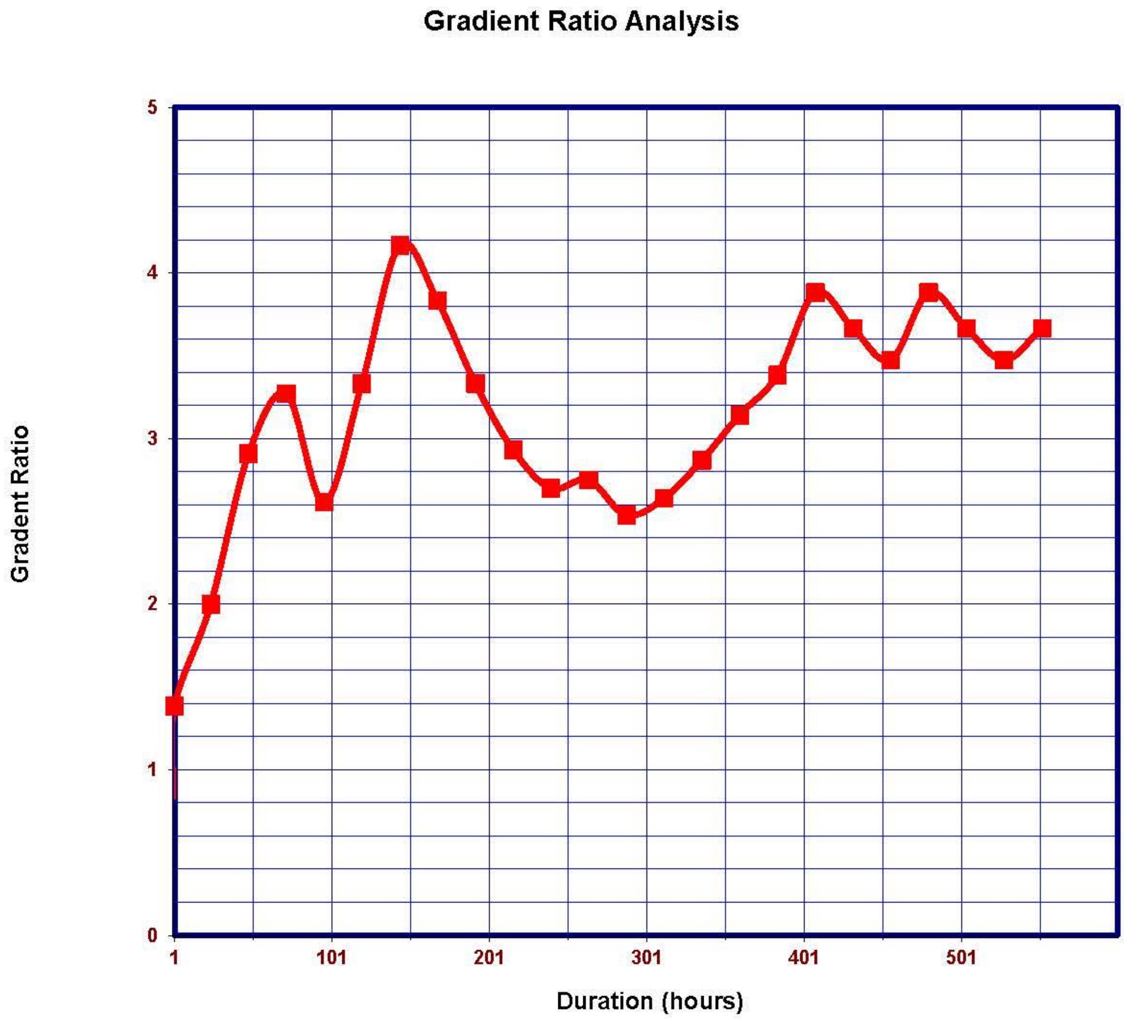
## Gradient Ratio

| | | | |
|---|---|---|---|
| **Client** | *Vincent Mukwevho* | **Test Number** | *S270 - Zone 3* |
| **Consultant** | *Vincent Mukwevho* | **Date** | *30-Jul-21* |
| **Project** | *Masters Thesis* | **Product** | *S270* |
| | | **Soil Sample** | *Sandy Gravel* |



# APPENDIX P

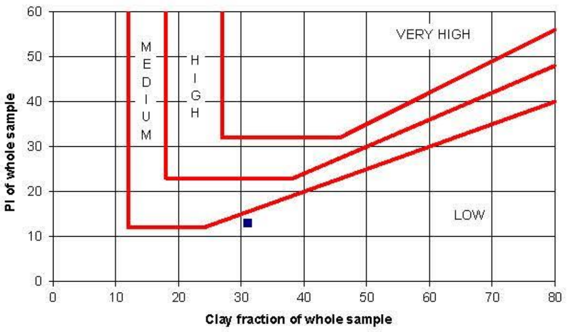
## Laboratory Results – Foundation Indicators and Permeability

# PARTICLE SIZE ANALYSIS

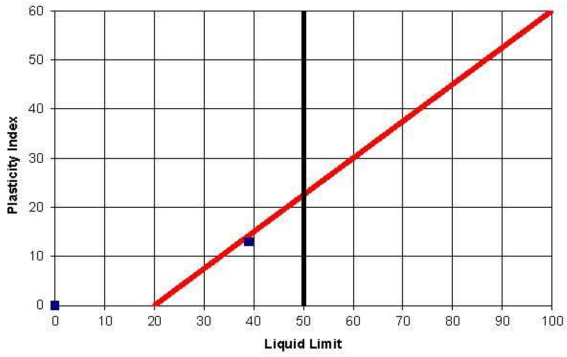
| | |
|---|---|
| Sample No. | 01 |
| Soillab Sample No. | S21-THESIS-01 |
| Depth (m) | - |
| Position | - |
| Material Description | LIGHT<br>GREY<br><br>CLAYEY<br>SILT |
| Relative density on < 2 mm **(SANS 5844)** | 2.65 |
| Organic Material | |
| Moisture (%) / Dispersion (%) | |
| SCREEN ANALYSIS (% PASSING) **(SANS 3001:GR1)** | |
| 63.0 mm | 100 |
| 50.0 mm | 100 |
| 37.5 mm | 100 |
| 28.0 mm | 100 |
| 20.0 mm | 100 |
| 14.0 mm | 100 |
| 5.0 mm | 100 |
| 2.00 mm | 100 |
| 0.425 mm | 100 |
| 0.075 mm | 100 |
| HYDROMETER ANALYSIS (% PASSING) **(SANS 3001:GR3)** | |
| 49 µm | 81 |
| 30 µm | 61 |
| 13 µm | 41 |
| 6 µm | 31 |
| 2 µm | 21 |
| | |
| % Clay | 31 |
| % Silt | 50 |
| % Sand | 19 |
| % Gravel | 0 |
| ATTERBERG LIMITS **(SANS 3001:GR10)** | |
| Liquid Limit | 39 |
| Plasticity Index | 13 |
| Linear Shrinkage (%) | 6.0 |
| Grading Modulus | |
| Classification | A-6 (15) |
| Unified Classification | ML |
| Chart Reference | |

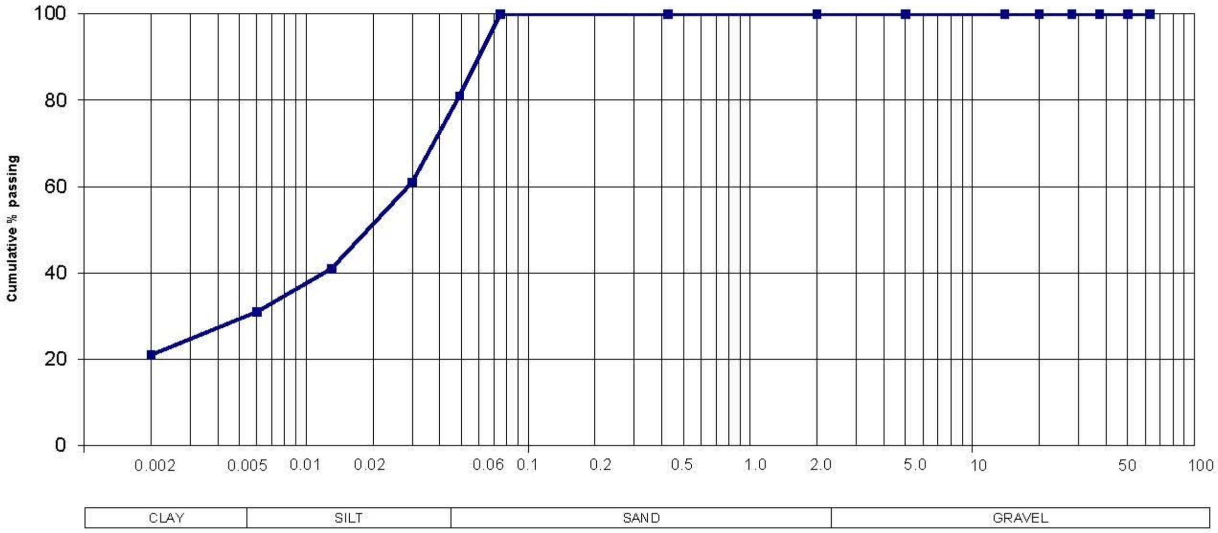
PROJECT : MASTERS PROJECT
JOB No. : S21-THESIS
DATE : 2021/08/10

## POTENTIAL EXPANSIVENESS



## PLASTICITY CHART





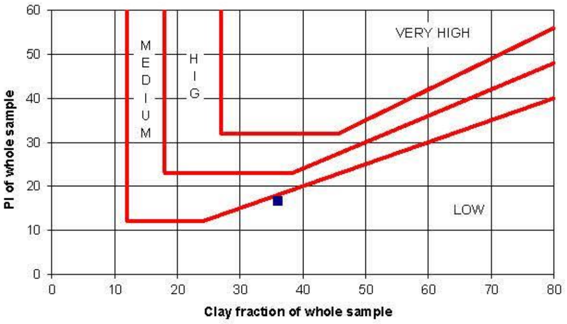
**Note: Standard Relative Density of 2.650 was used.**

# PARTICLE SIZE ANALYSIS

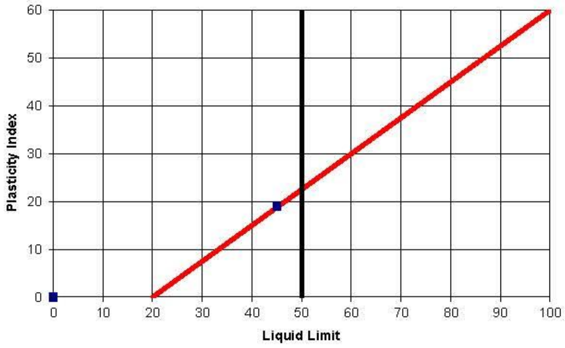
PROJECT : MASTERS THESIS
JOB No. : S21-THESIS-02
DATE : 2021/05/21

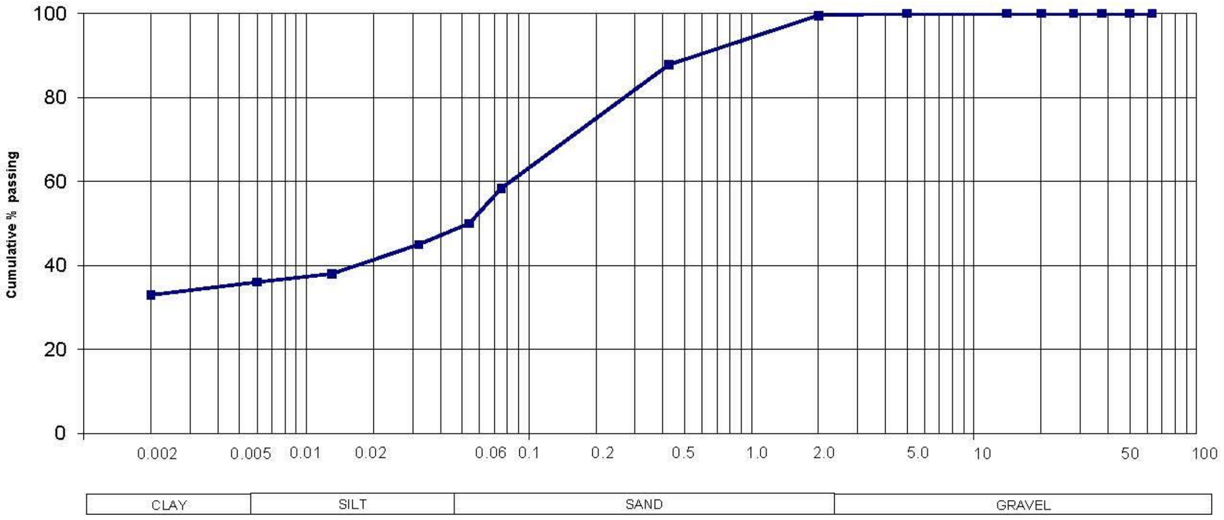
| | |
|---|---|
| Sample No. | 01 |
| Soillab Sample No. | S21-THESIS-02-01 |
| Depth (m) | 1.1 - 1.9 |
| Position | TP12 |
| Material Description | DARK<br>GREY<br>CLAYEY<br>SAND |
| Relative density on < 2 mm **(SANS 5844)** | 2,650 |
| Organic Material | |
| Moisture (%) / Dispersion (%) | |
| SCREEN ANALYSIS (% PASSING) **(SANS 3001:GR1)** | |
| 63.0 mm | 100 |
| 50.0 mm | 100 |
| 37.5 mm | 100 |
| 28.0 mm | 100 |
| 20.0 mm | 100 |
| 14.0 mm | 100 |
| 5.0 mm | 100 |
| 2.00 mm | 100 |
| 0.425 mm | 88 |
| 0.075 mm | 58 |
| HYDROMETER ANALYSIS (% PASSING) **(SANS 3001:GR3)** | |
| 54 µm | 50 |
| 32 µm | 45 |
| 13 µm | 38 |
| 6 µm | 36 |
| 2 µm | 33 |
| | |
| % Clay | 36 |
| % Silt | 14 |
| % Sand | 50 |
| % Gravel | 0 |
| ATTERBERG LIMITS **(SANS 3001:GR10)** | |
| Liquid Limit | 45 |
| Plasticity Index | 19 |
| Linear Shrinkage (%) | 8,0 |
| Grading Modulus | 0,54 |
| Classification | A-7-6 (9) |
| Unified Classification | CL |
| Chart Reference |  |

## POTENTIAL EXPANSIVENESS



## PLASTICITY CHART





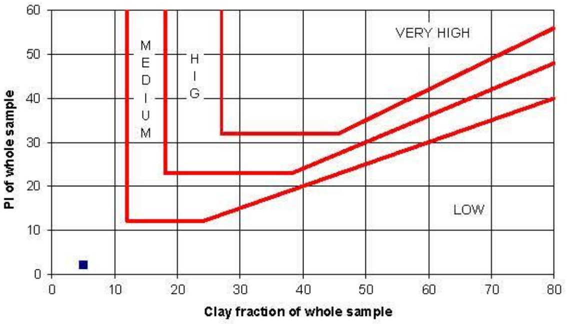
**Note: Standard Relative Density of 2.650 was used.**

# PARTICLE SIZE ANALYSIS

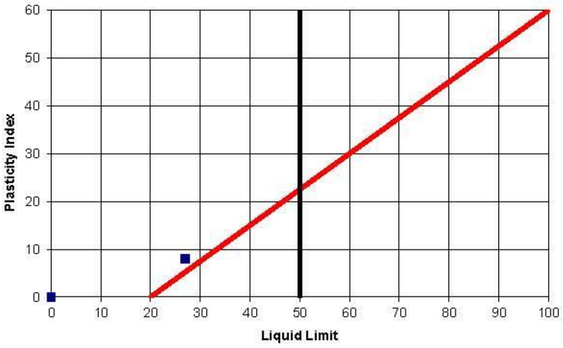
| | |
|---|---|
| Sample No. | 01 |
| Soillab Sample No. | S21-THESIS-01-01 |
| Depth (m) | 0.8 - 1.23 |
| Position | TP04 |
| Material Description | LIGHT<br>GREY<br><br>SANDY<br>GRAVEL |
| Relative density on < 2 mm **(SANS 5844)** | 2,65 |
| Organic Material | |
| Moisture (%) / Dispersion (%) | |
| SCREEN ANALYSIS (% PASSING) **(SANS 3001:GR1)** | |
| 63.0 mm | 100 |
| 50.0 mm | 100 |
| 37.5 mm | 100 |
| 28.0 mm | 95 |
| 20.0 mm | 86 |
| 14.0 mm | 77 |
| 5.0 mm | 49 |
| 2.00 mm | 38 |
| 0.425 mm | 26 |
| 0.075 mm | 19 |
| HYDROMETER ANALYSIS (% PASSING) **(SANS 3001:GR3)** | |
| 55 µm | 13 |
| 32 µm | 11 |
| 14 µm | 7 |
| 6 µm | 5 |
| 2 µm | 4 |
| | |
| % Clay | 5 |
| % Silt | 8 |
| % Sand | 25 |
| % Gravel | 62 |
| ATTERBERG LIMITS **(SANS 3001:GR10)** | |
| Liquid Limit | 27 |
| Plasticity Index | 8 |
| Linear Shrinkage (%) | 3,0 |
| Grading Modulus | 2,18 |
| Classification | A-2-4 (0) |
| Unified Classification | GC |
| Chart Reference | |

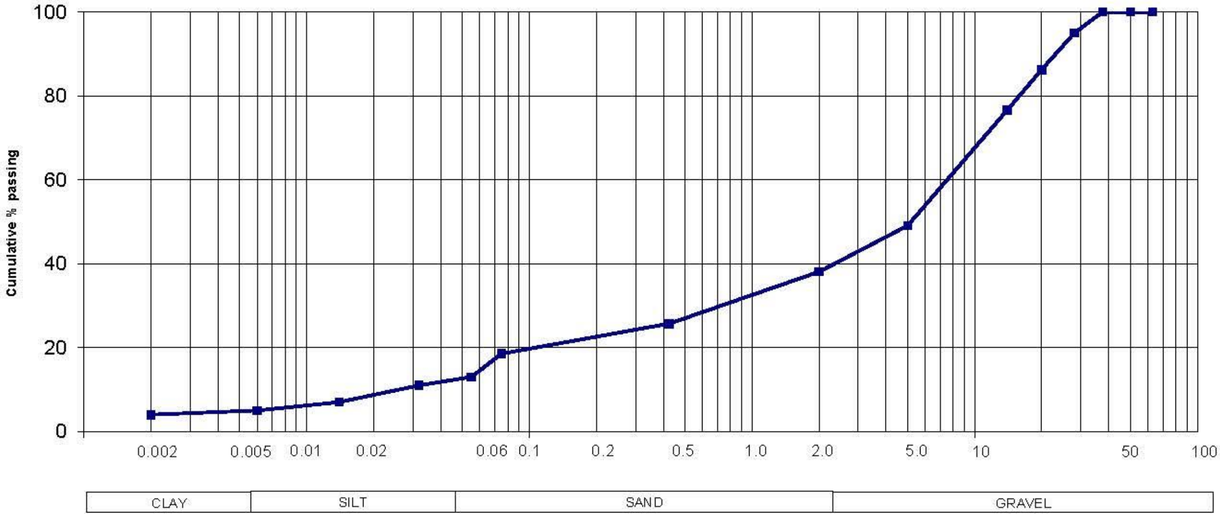
PROJECT : MASTERS THESIS
JOB No. : S21-THESIS-01
DATE : 2021/06/03

## POTENTIAL EXPANSIVENESS



## PLASTICITY CHART





**Note: Standard Relative Density of 2.650 was used.**

# Constant Head Permeability

| | |
|---|---|
| **Project:** | Master's Thesis |
| **Client:** | Vincent Mukwevho |
| **Job Number:** | S21-Thesis |
| **Date:** | 2022/03/11 |
| **Test Method:** | ASTM D2434:1974 |

| **Sample** | **Depth** | **Water Head** | **Dry Density** | **Flow (ΔV)** | **Time** | **Permeability** |
|---|---|---|---|---|---|---|
| **Number:** | **m** | **kPa** | **kg/m³** | **ml** | **h:m:s** | **cm/s** |
| Sandy Gravel | 0.8 - 1.23 | 5,0 | 1794 | 14,6 | 1:36:22 | 4,54E-06 |
| Clayey Sand | 1.1 - 1.9 | 5,0 | 1378 | 20,7 | 23:33:15 | 4,47E-07 |
| Clayey Silt | - | 5,0 | 1467 | 4,4 | 22:46:46 | 9,81E-08 |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
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| | | | | | | |
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| | | | | | | |

# APPENDIX Q

## Soil Profiles

Client: Vincent Mukwevho Date: 2020/12/12

Project: MSc Thesis

Project No: S20-1657

TP No. TP12

Ch:

Carriage way:

| Photo | Symbol | Sample | Depth (m) | Description |
|---|---|---|---|---|
|  | | | 0,00<br>0,43 | Moist, dark grayish Brown, loose, roots in layer, transported Clayey **SAND** |
| | | | 1,10 | Moist, Light Brown speckled White, medium dense, transported Clayey **SAND** |
| | | | 1,90 | Moist, dark grayish Brownish mottled White, dense to very dense Clayey **SAND, Alluvium** |

Note 1: TLB struggled digging on at 1.9m

Note 2: Side walls stable

Note 3: No water seepage

Note 4:

Coordinates: S27° 49.165'

: E26° 22.861'

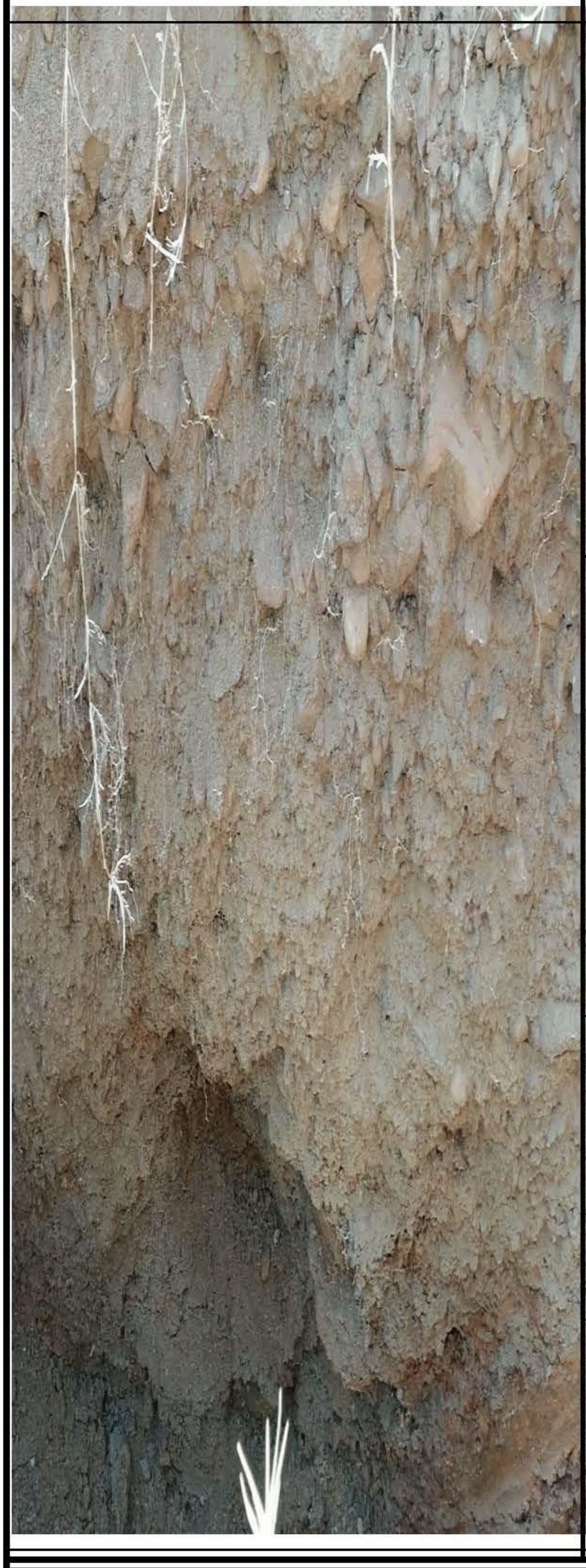
Profiled By: V Mukwevho

Excavation method: TLB

Client: Vincent Mukwevho
Date: 20/05/2021
Project: MSc Thesis
Project No: S21-0347

TP No. TP04

Ch:

| Photo | Symbol | Sample | 0,00 | Description |
|---|---|---|---|---|
|  | | | 0.0 | |
| | | | 0,43 | Dry to slightly moist, Light Brown, speckled Black, loose, quartz cobbles and boulders, Sandy **Gravel,** Fill |
| | | | 0,80 | Moist, Light Brown, speckled Black, medium dense, scattered ferricrete nodules and quartz cobles, Gravelly **SAND**, transported. |
| | | | 1,23 | Moist, Light Grey, speckled Orange, dense to very dense, Gravely SAND as matrix for ferricrete nodules, strongly cemented pedogenic ferricrete |

Note 1: Refusal on Pedogenic
Note2: Sidewalls stable
Note 3: No water seepage
Note 4:

Coordinates: S23° 52.411'
: E29°26.876'
Profiled By: V Mukwevho
Excavation method: TLB-Refusal at 1230mm

# APPENDIX R

## Laboratory Results - Bidim Results Summary (A2/A4/A6)

GEOSYNTHETIC
LABORATORY

# TEST REPORT SUMMARY

*11 Livingstone Road*
*Pinetown*
*3600*
*Tel: +2731 717 2300*
*Fax: +2731 702 4477*
info@geolaboratory.com
www.geolaboratory.com

## KAYTECH BIDIM A2 (GKB17SUL530150) 181204007 P2019008-01

Page 1 of 9
Issue no. 1

**Report reference:** *Kaytech Bidim A2 P2019008/01*
**Contact:** *V Mukwevho*
**Client details:** *V Mukwevho*
**Address:** *11 Livingstone road, Pinetown, 3600*
**Project:** *MSc Thesis*

**Sample Ref:** *Bidim A2 (GKB17SUL 530150)*
**Description:** *NW-N-CF-PET*
**Colour:** *Grey*
**Roll Number** *181204007*
**Job Number:** *P2019008*

| | | | PRODUCT | Bidim A2 | |
|---|---|---|---|---|---|
| Mass per unit area | Mass of geotextile | | gsm | 161 | ISO 9864-05 |
| Thickness of geotextile | Thickness under 2 kPa | | mm | 1,69 | ISO 9863.1-16 |
| Wide Width Tensile | MD | Strength | kN/m | 10,912 | SANS 1525-13 |
| | | Elong | % | 51 | |
| | CD | Strength | kN/m | 9,745 | |
| | | Elong | % | 55 | |
| GRAB Tensile | MD | Strength | N | 715 | ASTM D4632-15 |
| | | Elong | % | 65 | |
| | CD | Strength | N | 560 | |
| | | Elong | % | 66 | |
| TRAP TEAR | MD | Strength | N | 382 | ASTM D4533-15 |
| | | Elong | % | 178 | |
| | CD | Strength | N | 340 | |
| | | Elong | % | 199 | |
| Static Puncture | CBR | Force | N | 1692 | ISO 12236-06 |
| | 50mm probe | Elong | mm | 51 | |
| Drop Cone | | Hole diameter | mm | 24 | ISO 13433-06 |
| Permeability | Water head | 100 ml | m/s | 4,7E-03 | ISO 11058-10 |
| Pore Size | | AOS95 | microns | 175 | SANS 12956:13/ISO 12956:10 |

Authorised by V Mukwevho
Technical Signatory

Date 2019-03-29

sanas
Testing Laboratory
T 0303

GEOSYNTHETIC
LABORATORY

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## KAYTECH BIDIM A4 (GKB25SUL) 181212004 P2019008-02

Page 1 of 9
Issue no. 1

**Report reference:** *Kaytech Bidim A4 P2019008/02*
**Contact:** *V Mukwevho*
**Client details:** *V Mukwevho*
**Address:** *11 Livingstone road, Pinetown, 3600*
**Project:** *MSc Thesis*

**Sample Ref:** *Bidim A4 (GKB45SUL)*
**Job Number:** *P2019008*
**Description:** *NW-N-CF-PET*
**Colour:** *Grey*
**Roll Number** *181212004*

| | | | PRODUCT | Bidim A4 | |
|---|---|---|---|---|---|
| Mass per unit area | Mass of geotextile | | gsm | 233 | ISO 9864-05 |
| Thickness of geotextile | Thickness under 2 kPa | | mm | 2,37 | ISO 9863.1-16 |
| Wide Width Tensile | MD | Strength | kN/m | 15,668 | SANS 1525-13 |
| | | Elong | % | 57 | |
| | CD | Strength | kN/m | 13,542 | |
| | | 1,675 | 1,7 | 55 | |
| GRAB Tensile | 1,71 | 1,699 | 1,7 | 939 | ASTM D4632-15 |
| | | 1,801 | 1,8 | 59 | |
| | 1,86 | 1,922 | 1,9 | 918 | |
| | | 1,920 | 1,9 | 66 | |
| TRAP TEAR | 1,79 | 1,766 | 1,8 | 449 | ASTM D4533-15 |
| | | 1,851 | 1,8 | 161 | |
| | CD | Strength | N | 507 | |
| | | 1,958 | 2,0 | 175 | |
| Static Puncture | CBR | Force | N | 2485 | ISO 12236-06 |
| | 50mm probe | Elong | mm | 54 | |
| Drop Cone | | Hole diameter | mm | 17 | ISO 13433-06 |
| Permeability | Water head | 100 ml | m/s | 4,21E-03 | ISO 11058-10 |
| Pore Size | | AOS95 | microns | 136 | SANS 12956:13/ISO 12956:10 |

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Technical Signatory

Date 2019-03-29

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# TEST REPORT SUMMARY

## KAYTECH BIDIM A6 (GKB45SUL/530/075) 190206003 P2019008-08

Page 1 of 9
Issue no. 1

**Report reference:** *Kaytech Bidim A6 P2019008/08*
**Contact:** *Garth James*
**Client details:** *Kaytech*
**Address:** *11 Livingstone road, Pinetown, 3600*
**Project:** *MSc Thesis*

**Sample Ref:** *Bidim A6 (GKB45SUL/530/075)*
**Job Number:** *P2019008*
**Description:** *NW-N-CF-PET*
**Colour:** *Grey*
**Roll Number** *190206003*

| | | | PRODUCT | Bidim A6 | |
|---|---|---|---|---|---|
| Mass per unit area | Mass of geotextile | | gsm | 403 | ISO 9864-05 |
| Thickness of geotextile | Thickness under 2 kPa | | mm | 3,36 | ISO 9863.1-16 |
| Wide Width Tensile | MD | Strength | kN/m | **27,830** | SANS 1525-13 |
| | | Elong | % | **65** | |
| | CD | Strength | kN/m | **29,633** | |
| | | Elong | % | **58** | |
| GRAB Tensile | MD | Strength | N | **1876** | ASTM D4632-15 |
| | | Elong | % | **58** | |
| | CD | Strength | N | **1797** | |
| | | Elong | % | **62** | |
| TRAP TEAR | MD | Strength | N | **958** | ASTM D4533-15 |
| | | Elong | % | **161** | |
| | CD | Strength | N | **914** | |
| | | Elong | % | **154** | |
| Static Puncture | CBR | Force | N | **4662** | ISO 12236-06 |
| | 50mm probe | Elong | mm | **58** | |
| Drop Cone | | Hole diameter | mm | **12** | ISO 13433-06 |
| Permeability | Water head | 100 ml | m/s | **3,94E-03** | ISO 11058-10 |
| Pore Size | | AOS95 | microns | **128** | SANS 12956:13/ISO 12956:10 |

***Disclaimer :***

*The test results contained herein refers only to the specific product tested as per the referenced test standard and should not be compared to any similar product not tested. Geosynthetic Laboratory does not imply suitability of this product to be used in any particular application, nor does it imply approval of the quality of the product. This test report shall not be reproduced except in full, and only with written approval of Geosynthetic Laboratory.*

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Date 2019-03-29

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