# اقرار

انا الموقع ادناه مقدم الرسالة التي تحمل عنوان:

**Enhancement of the Efficiency of Infiltration Basins for Effluent Recharge**

**(Case Study: Northern Gaza New Infiltration Basins)**

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# Enhancement of the Efficiency of Infiltration Basins for Effluent Recharge

## (Case Study: Northern Gaza New Infiltration Basins)

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# نتيجة الحكم على أطروحة ماجستير

بناءً على موافقة الدراسات العليا بالجامعة الإسلامية بغزة على تشكيل لجنة الحكم على أطروحة الباحث/ **باسم ابراهيم جمعة سرداح** لنيل درجة الماجستير في **كلية *الهندسة* قسم الهندسة المدنية- هندسة مصادر المياه** وموضوعها:

## تحسين كفاءة أحواض الترشيح المعدة لاستخدام مياه الصرف الصحي المعالجة

**Enhancement of the Efficiency of Infiltration Basins for Effluent Recharge (Case Study: Northern Gaza New Infiltration Basins)**

وبعد المناقشة العلنية التي تمت اليوم السبت 12 محرم 1435هـ، الموافق 2013/11/16م الساعة الواحدة ظهراً بمبنى القدس، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

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***واللجنة إذ تمنحه هذه الدرجة فإنها توصيه بتقوى الله ولزوم طاعته وأن يسخر علمه في خدمة دينه ووطنه.***

والله ولي التوفيق ،،،

**مساعد نائب الرئيس للبحث العلمي وللدراسات العليا**

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# ABSTRACT

The Agricultural sector in the Gaza Strip on an average consumes around 75-80 MCM of water annually. All amounts of water used for this purpose come from groundwater wells. Wastewater reuse is envisaged primarily as a means to support the agricultural sector in Gaza Strip as addressed by Palestinian Water Authority (PWA). The artificial recharge (AR) of treated wastewater to groundwater can be achieved by means of spreading basins the commonly used methods for infiltration purposes to unconfined aquifers. The problem of the AR is the reduction of infiltration capacity in the infiltration basins resulting from using partially treated wastewater due to accumulation of suspended solids (SS) and the organic load, and the poor maintenance. The goal of this research is enhancement of the efficiency of Infiltration Basins for effluent recharge. Field experiments was performed in order to achieve the required objectives such as the quality of the soil under the infiltration basin, and quality of the effluent water to the basin. Also modeling for the unsaturated zone using the Green-Ampt model (1911) was performed in order to predict the existing and enhanced infiltration rate. The field and lab tests results showed that the soil strata in the infiltration basin IB1 consists of Sand which is non-plastic and has good permeability characteristics, Clayey Sand: which is the wide spreading layer at the top of the basin, and of low to medium plasticity, and of low permeability, and Sandy Silty Clay which is of medium plasticity, and of low permeability. The results showed that the infiltration rate is affected by the soil properties; sandy soils have the highest infiltration rates and clayey soils have the lowest infiltration rates. Also the results showed that the infiltration rate is affected by the quality of the effluent water, operation cycles and maintenance for the top surface. According to the results which have been supported by model; removing the upper 2.0 meters of soil layer at IB1 and replacing it with new sand martial with high permeability introduced an efficient solution for enhancement the infiltration rate. Also penetrating the lower soil layers with 60 piles and filling the piles with gravel fine media with high permeability, will increase the infiltration rate for the whole basin according to the study. Performing 35 cycles of wetting and drying during the year with 2 days of wetting in summer and winter and 7 days of drying in summer and 12 days of drying in winter, will help to reach the optimal infiltration rate. Soil plowing after each drying cycle for the basin is required to maintain good infiltration rate and prevent accumulation of the organic matter (OM) in the top soil layer.

## الخلاصة

يستهلك قطاع الزراعة في قطاع غزة في المتوسط حوالي 75-80 مليون متر مكعب من المياه سنويا وجميع كميات المياه المستخدمة لهذا الغرض تأتي من الآبار الجوفية. يرجع إعادة استخدام المياه العادمة في المقام الأول كوسيلة لدعم القطاع الزراعي في غزة كما هو مقرر من قبل سلطة المياه الفلسطينية. التغذية الصناعية للخزان الجوفي باستخدام مياه الصرف الصحي المعالجة يمكن تحقيقها عن طريق استخدام احواض الترشيح وهي الطرق الاكثر استخداما لأغراض الترشيح للمياه الجوفية الغير المحصورة. مشكلة التغذية الصناعية تأتي من انخفاض كفاءة الترشيح في احواض الترشيح نتيجة استخدام مياه الصرف الصحي المعالجة جزئيا بسبب تراكم المواد الصلبة والمواد العضوية بالإضافة الى سوء الصيانة. الهدف من هذا البحث هو تحسين كفاءة احواض الترشيح المعدة لاستخدام مياه الصرف الصحي المعالجة . من أجل تحقيق الأهداف المطلوبة تم إجراء التجارب الميدانية مثل فحص نوعية وجودة التربة تحت حوض الترشيح، ونوعية المياه المتدفقة إلى الحوض. كما تم عمل نمذجة للمنطقة غير المشبعة باستخدام جرين امبت (1911) من أجل التنبؤ بمعدل الترشيح للوضع القائم والوضع بعد التحسين. أظهرت النتائج أن طبقة التربة في حوض الترشيح رقم 1 تتكون من الرمل الغير لدن وله خصائص نفاذية جيدة ، ومن الرمل الطيني وهي الطبقة العلوية الاكثر انتشارا في الحوض وتعتبر طبقة منخفضة إلى متوسطة اللدونة ، مع نفاذية منخفضة، وطبقة من الرمل والطين والطمي ذات لدونة متوسطة ، و نفاذية منخفضة . أظهرت النتائج أن معدل التسرب يتأثر بخصائص التربة؛ حيث ان التربة الرملية لديها أعلى معدلات ترشيح والتربة الطينية لديها أدنى معدلات ترشيح . كما أظهرت النتائج أن معدل الترشيح يتأثر بنوعية المياه المتدفقة ، ودورات التشغيل والصيانة للطبقة العلوية . وفقا للنتائج والتي تم تدعيمها بالنموذج تبين ان إزالة الجزء العلوي من التربة في حوض الترشيح رقم 1 وبسمك 2 متر واستبدالها بطبقة رمل جديدة ذات نفاذية عالية حسنت معدل الترشيح. أيضا اختراق طبقات التربة السفلى بعدد 60 بئر مع ملئ هذه الابار بحصمه ناعمة ذات نفاذية عالية ، سوف يزيد من معدل الترشيح لكل الحوض حسب الدراسة. اجراء عدد 35 دورة من الترطيب والتجفيف خلال السنه بمعدل 2 يوم من الترطيب خلال الصيف والشتاء و 7 ايام تجفيف في الصيف و12 يوم تجفيف في الشتاء سوف يساعد في الوصول الى المعدل الامثل للترشيح. حرث التربة بعد كل دورة تجفيف للحوض يحفاظ على معدل ترشيح جيد ويحد من تراكم المادة العضوية على طبقة التربة السطحية.

**QURAN**

{رَبِّ أَوْزِعْنِي أَنْ أَشْكُرَ نِعْمَتَكَ الَّتِي أَنْعَمْتَ عَلَيَّ وَعَلَى وَالِدَيَّ وَأَنْ أَعْمَلَ صَالِحًا تَرْضَاهُ

وَأَدْخِلْنِي بِرَحْمَتِكَ فِي عِبَادِكَ الصَّالِحِينَ} النمل (19).

All praises and glory are due to **ALLAH** for all the bounty and support granted to me. This work would not be done without **ALLAH** endless guidance and support.

## DEDICATION

*This research is dedicated:*

*To My Father and Mother*

*To my wife Majda and my daughters, Enaya, Dana, Rimas, and Sama*

*To all of my brothers, Mohammed and Ahmed and all of my sisters.*

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| | |
|---|---|
| **AR** | Artificial Recharge |
| **ASTM** | American Society for Testing and Material |
| **BH** | Bore Hole |
| **BLWWT** | Beit Lahia Waste Water Treatment Plant |
| **BOD** | Biological Oxygen Demand |
| **BS** | British Standard |
| **CA** | Calcium |
| **CMWU** | Coastal Municipalities Water Utility |
| **COD** | Chemical  Oxygen Demand |
| **EC** | Electrical Conductivity |
| **ERRC** | Environmental and Rural Research Center |
| **FC** | Fecal Coliform |
| **GA** | Green and Ampt |
| **GS** | Gaza Strip |
| **H** | Hardness |
| **IB** | Infiltration Basin |
| **IR** | Infiltration Rate |
| **K** | Hydraulic Conductivity |
| **Mg** | Magnesium |
| **Na** | Sodium |

| | |
|---|---|
| **NGSWSP** | Northern Gaza Storm Water and Sewerage Project |
| **NWP** | National Water Plan |
| **OM** | Organic Matter |
| **PCBS** | Palestinian Central Bureau of Statistics |
| **pH** | Hydrogen Ion Concentration |
| **PMU** | Project Management Unit |
| **PNA** | Palestinian National Authority |
| **PWA** | Palestinian Water Authority |
| **SAR** | Sodium Adsorption Ratio |
| **SAT** | Soil Aquifer Treatment |
| **T** | Temperature |
| **TC** | Total Coliform |
| **TSS** | Total Suspended Solids |
| **TWW** | Treated Wastewater |
| **Uc** | Uniformity coefficient |
| **USCS** | Unified Soil Classification System |
| **WC** | Water Content |
| **WW** | Wastewater |

# LIST OF UNITS

| | |
|---|---|
| **°C** | Celsius |
| **cm/hr** | Centimeter per Hour |
| **Ds/m** | Deci Siemens per meter |
| **ft/d** | feet per day |
| **Hr** | Hour |
| **m/d** | Meter per day |
| **$m^2$** | Meter square |
| **$m^3$/d** | Cubic Meter per day |
| **$m^3$/hr** | Cubic Meter per hour |
| **meq/kg** | Milli equivalent per kilogram |
| **meq/l** | Milli equivalent per liter |
| **mg/l** | Milligrams per Liter |
| **m/day** | Meter per Day |
| **MCM** | Million Cubic Meters |

# CAHPTER 1 : Introduction

## 1.1 Background

Water is essential to sustain life, and it is considered a scarce resource in Palestine. Sustainable water management calls not only for careful use of freshwater but also for reuse of treated wastewater **(Aish, 2004).** Indications of the need for changing the current (and historical) management are seen in the lowering of the water table and the increasing chloride and nitrate concentrations in the groundwater **(SWECO, 2003).**

The abstraction rates have increased remarkably over the last three decades, due to a combination of inadequate available water imports to Gaza; the expanding population; and the drilling and use of unlicensed wells (especially to provide irrigation for agricultural activities). The over-abstraction has caused saline intrusion (i.e. the entry of sea water to the aquifer from the Mediterranean Sea to the west, and also from deep groundwater in Israel to the south-east of Gaza) **(PWA, 2011).**

The Gaza Strip suffers from high pressure imposed on its water resources. There is a deficit of about 50 MCM (million cubic meters) every year, which has led to a declination of groundwater level and deterioration of groundwater quality. New water resources are sought to fulfill the water deficit; among them is the artificial recharge of treated wastewater to groundwater **(Hamdan, et al., 2011).**
The Gaza Strip has high population density accompanied with growing water demands that are met by groundwater as the one and only local resource. The Agricultural sector in the Gaza Strip on an average consumes around 75-80 MCM of water annually. All amounts of water used for this purpose come from groundwater wells **(PWA, 2012).**

Upon the fact that the entire existing agricultural water demand is taken from the groundwater aquifer, of which a large proportion is brackish, Palestinian Water Authority (PWA) addressed that the long-term target is that only minimal fresh water will be provided for soil flushing and specific high value crops. Other low quality water and conservation practices, including brackish water, storm water harvest, blending of water and conjunctive use of saline and non-saline water, will be utilized to optimal economic and practical effect in accordance with the following targets. Ultimately, by 2020 the utilization of wastewater is planned to provide 50 % of the total required by agriculture **(PWA, 2012).**

Wastewater reuse is envisaged primarily as a means to support the agricultural sector in Gaza **(PWA, 2011).** The agricultural demand is almost constant since the agricultural areas are limited or even decreasing. However, the domestic demand increases due to the rapid growth of the population. This increases the amount of wastewater produced and the treated effluent becomes a significant resource of water that could improve the water balance in the region **(Hamdan, et al., 2011).**

Artificial recharge is one such idea that has emerged over the past 20 years as a major water management tool for meeting water supply challenges. The concept of artificial recharge is simple: return water to aquifers and increase groundwater supplies **(Arroyo, 2007).** Where sewage effluent is used for ground water recharge, the quality improvement of the sewage water as it moves through the vadose zone and aquifer becomes very significant **(Bouwer, 2002)**.

Reclaiming waste water involves management of groundwater recharge by introducing treated waste water into the aquifer and taking advantage of either the raised groundwater levels or the actual water volume or a combination of the two. Artificial recharge is a process by which surface water is directed into the ground to replenish the aquifer either by spreading on the surface in basins, by using recharge wells, or by altering natural conditions to increase infiltration. The objectives of infiltration includes the quantity aspect which aimed at breaking the trend of decreasing groundwater table (and the increasing chloride concentrations connected to that) and allowing for a water abstraction from the aquifer for water supply **(SWECO, 2003).**

### 1.2 Problem Statement

Water scarcity is likely to become more problematic in the near future due to rapid population growth, increasing per capita water consumption, and the draught conditions of the world. These have forced various countries and communities to look towards alternative water resources to meet the growing needs and to be as long term water supplies. The artificially recharge of the groundwater is one option with extremely good future, since the underground storage is becoming a major alternative for overcoming short-term and long-term seasonal differences between water supply and demand (**Abushbak**, **2004).**

Artificial recharge facilities or projects are constructed to control the movement and rate of infiltration, with the purpose of adding water to the aquifer. Constructed recharge projects require maintenance to maintain infiltration rates and ensure smooth operations **(Arroyo, 2007)**.

The problem of the artificial recharge is the reduction of infiltration capacity in the infiltration basins resulting from using partially treated wastewater due to accumulation of suspended solids and biological oxygen demand loading (BOD) in addition to poor maintenance. The current infiltration system at Northern Gaza Storm Water and Sewerage Project consists of nine basins distributed from (1-9). The infiltration rate for all the basins began to deteriorate significantly since December, 2011, and infiltration basin (1) mainly has the lowest infiltration rate since the operation of the infiltration system. Figure (1-1) shows the average infiltration rate for the all basins with time since July, 2009 up to March, 2013.

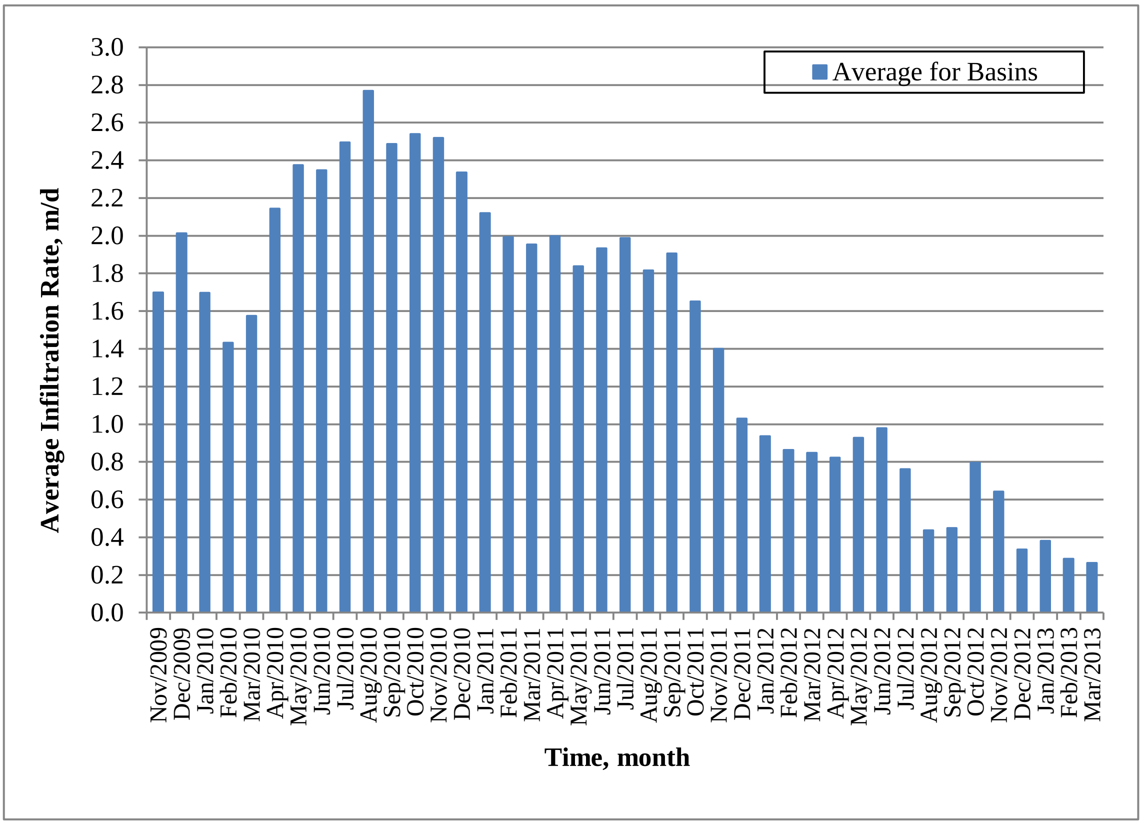


**Figure (1-1):** Average Infiltration Rate for All Basins with Time

### 1.3 Goals

The goal of this research is **Enhancement of the Efficiency of Infiltration Basins for Effluent Recharge.**

### 1.4 Objectives

The main objectives of this research are:

- Study the soil profile underneath the infiltration basin (IB1).
- Study the performance of the infiltration basin (IB1) under different conditions.
- Modeling the flow in the unsaturated zone.
- Propose enhancement methods and assess the impact of each method.

### 1.5 Methodology

It is intended to achieve the objectives of the study by the following steps:

#### a. Literature review

Revision of accessible references as books, studies and researches relative to the topic of the research which may include: Artificial Recharge, Quality of soil, Quality of Effluent, ..etc.

#### b. Data collection

Collecting of relevant data mainly from the Palestinian Water Authority (PWA), and from any relevant authorities were detailed information is needed.

#### c. Field Experiment

Field experiments was performed at infiltration basin (IB1) in order to achieve the required objectives such as:

- Quality of the soil under the infiltration basins was tested and the following tests was performed:
    - Soil tests for the layers under the basin bed in different locations was tested to a depth of 12m (five boreholes was performed and the soil samples was taken each 30 cm until depth of 2.10 m, after that from 2.10m to 3.0m and each one meter from the depth 3.0m until reaching the end of borehole). After collecting all the samples, grain size analysis (sieve analysis), water

content($\theta_i$), and hydraulic conductivity (K) for the different layers of the soil was performed.

  - Soil quality tests beneath the basin bed to a depth of 2.10m, and samples were taken each 30cm (from the same five boreholes) to test the effect of Organic Matter (OM), and Sodium Adsorption Ration (SAR) .

- Quality of the influent to the basin was tested.

**d. Modeling for ground water in the unsaturated zone**

For the infiltration basin (IB1) a lump-parameter model was developed based on the Green-Ampt Model (1911) in order to predict the model which describing the real infiltration rate, and to introduce the proposed model for infiltration after enhancement.

**e. Data analysis, assessment and discussion**

Determining the factors that influence the efficiency of the infiltration basins capacity, and how to enhance the capacity of the infiltration after enhancement in order to reach a reasonable infiltration rate.

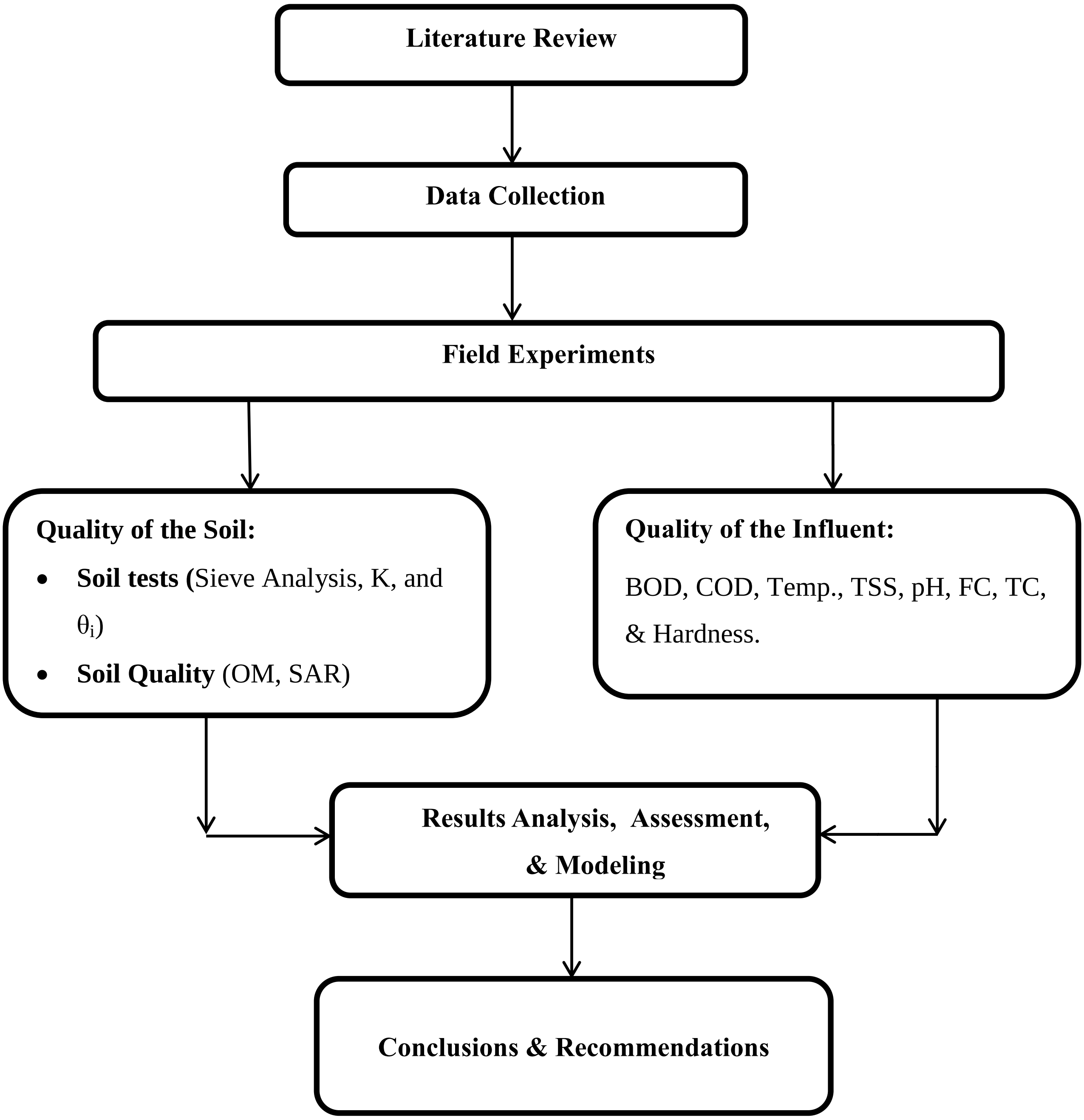


**Figure (1-2):** Methodology Flow Chart

### 1.6 Thesis Outline

This study consists of the following seven chapters:

1. **Chapter One (Introduction)**: A general background illustrating the water situation in Gaza Strip (GS) followed by the problem statement, goals and study objectives, methodology used in order to achieve the objectives and finally the thesis outline.

2. **Chapter Two (Literature Review)**: It covers a general literature review concerning the artificial recharge, infiltration, methods of enhancement the infiltration rate, and finally the literature review presents modeling of unsaturated zone.
3. **Chapter Three (Study Area):** Chapter three describes the location of the Gaza Strip, climate, rainfall status, geology, study area with respect to its location and topography, the existing situation of the infiltration basins and the related information about the operation.
4. **Chapter Four (Methodology):** Chapter four discusses the methodology of study including data collection, filed experiments, data analysis and preparation.
5. **Chapter Five (Results and Discussion):**

Chapter five will presents the field experiments results for the soil profile, the soil quality parameters and the effluent quality parameters of the recharged water, also factors that influence the efficiency of the infiltration basins capacity, behavior of infiltration capacity under different loading conditions, and finally how to enhance the capacity of the infiltration. Also this chapter will presents modeling for the unsaturated zone and its applicability in the field of infiltration basins.

6. **Chapter Six (Conclusions and Recommendations):** The conclusions and recommendations of the study are stated in this chapter.

# CAHPTER 2 : Literature Review

## 2.1 Introduction

Fresh water shortage is becoming an increasingly acute problem facing many nations in the world. Groundwater recharge with treated wastewater is becoming more valuable with time in developing countries because of the scarcity of water resources (**Deepa, and Krishnaveni, 2012)**.

Water demand in Palestine, in general and in the Gaza strip, in particular is rapidly increasing **(PWA, 1998).** The Gaza Strip suffers from a disastrous situation due to poor water quality with the Coastal Aquifer as the sole water source shared with Israel. The aquifer is being over pumped with annual quantities that double that of the safe pumping rate (50-60 MCM/ year); this has led to seawater and surrounding saline aquifers intruding into this fresh water source causing salination. The Agricultural sector in the Gaza Strip on an average consumes around 75-80 million cubic meters of water annually. All amounts of water used for this purpose come from groundwater wells **(PWA, 2012).** It is stated in the National Water Plan (NWP) that wastewater investment costs represents about 37% of overall Palestinian investment plan for Gaza Strip overall the period time to achieve strategies and targets outlined in the NWP. Wastewater reuse schemes are indispensable for Palestinian in general and Gaza strip in particular **(Nassar, et al., 2009).** Wastewater (WW) reuse will provide an alternative to groundwater (GW) for irrigation when well treated wastewater (TWW) can be used for irrigation as it is planned in the NWP by year 2000. Reuse of TWW in irrigation is considered a priority in the GS due to a number of factors including the depletion of GW resources and fact that reuse would increase the availability of fresh water resources for domestic and industrial use **(Nassar, et al., 2009).**

The reuse of the effluent could be accomplished in two ways: either by direct irrigation to farms and/or through artificial recharge to groundwater, which is then pumped to irrigate farms with reclaimed wastewater **(Hamdan et al., 2011).**

### 2.2 Artificial Recharge (AR)

Groundwater recharge with reclaimed municipal wastewater presents a wide spectrum of technical and health challenges that must be carefully evaluated. Natural replenishment of the vast supply of underground water occurs very slowly; therefore, excessive continued exploitation of groundwater at a rate greater than this replenishment causes declining groundwater levels in the long term and if not corrected, leads to eventual mining of groundwater. To increase the natural supply of groundwater, artificial recharge of groundwater basins is becoming increasingly important in groundwater management and particularly in situations where the conjunctive use of surface water and groundwater resources is being considered. **(Asano and Cotruvo, 2004).**

Artificial recharge is one means of conserving water by allowing storage and future use of reclaimed water **(Toze, et al., 2004).** AR and water reuse are important aspects of integrated water management where water resources management problems are solved by considering all aspects **(Bouwer, 2002)**. Thus moving towards attaining sustainable water management in addition, artificial recharge can significantly contribute to water quality improvement by natural attenuation of contaminants via passage of the water through the aquifer. The ability to obtain an improvement in water quality would be a major benefit of artificial recharge in less arid parts of the world where water scarcity and quality issues are prevalent **(Toze, et al., 2004). Mohammedjemal, 2006 R5** stated that artificial recharge can be used for a number of reasons: Integrated water management, seasonal storage and recovery of water, long-term storage or water banking, emergency storage or strategic water reserve, short term storage, enhance well field production, restore groundwater level, replace over draft, raise water levels, reduce pumping cost, stop or reduce rate of land surface subsidence, improve groundwater quality to agriculture or municipal standards.

Artificial recharge of groundwater is achieved by putting surface water in basins (Figure 2-1), furrows, ditches, or other facilities where it infiltrates into the soil and moves downward to recharge aquifers. Artificial recharge is increasingly used for short-or long-term underground storage, where it has several advantages over surface storage, and in water reuse **(Bouwer, 2002)**.

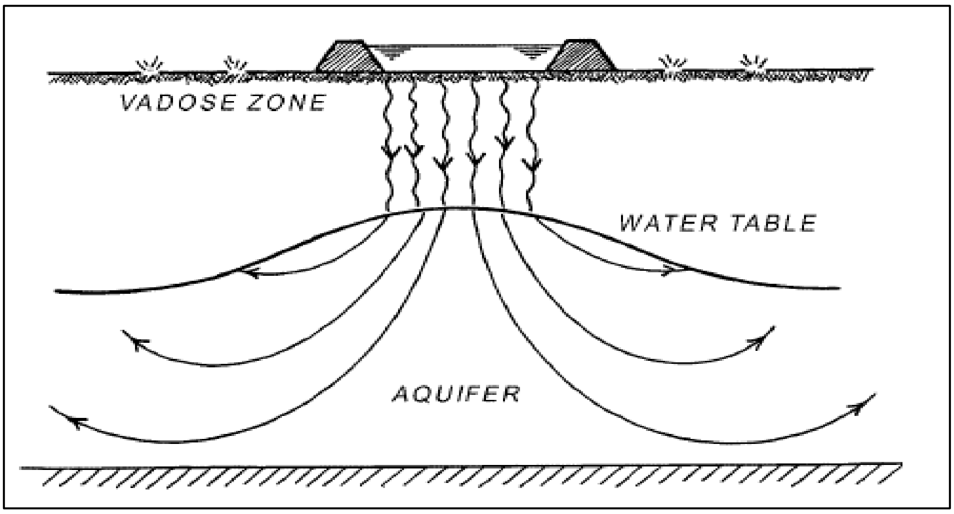


**Figure (2-1):** Typical groundwater recharge system, (Bouwer, 2002)

### 2.2.1 Advantages and Disadvantages of Artificial Recharge

Artificial recharge has several potential advantages, namely (**Bhattacharya, 2010):**

- The use of aquifers for storage and distribution of water and removal of contaminants by natural cleansing processes.
- Groundwater recharge stores water during the wet season for use in the dry season, when demand is the highest.
- Recharge can significantly increase the sustainable yield of an aquifer.
- Recharge methods are environmentally attractive, particularly in arid regions.
- Most aquifer recharge systems are easy to operate.
- Recharge with less-saline surface waters or a treated effluent improves the quality of saline aquifers, facilitating the use of the water for agriculture.

Artificial Recharge has some disadvantages, namely (**Bhattacharya, 2010):**

- Recharge can degrade the aquifer unless quality control of the injected water is adequate.
- Unless significant volumes of water are injected in an aquifer, groundwater recharge may not be economically feasible.
- The hydrogeology of an aquifer should be investigated and understood before any future full-scale recharge project is implemented.

- There is a potential for contamination of the groundwater from injected surface-water. In most cases, the surface-water is not pre-treated before injection.

### 2.2.2 Methods of Artificial Recharge

There are two methods of artificial recharge in general: Direct and Indirect **(Mohammedjemal, 2006)**.

**A. Direct method**

Direct methods can be divided into surface recharge techniques and subsurface recharge techniques. In surface recharge, water moves from the land surface to the aquifer by means of infiltration through the soil. The surface is usually excavated and water is added to spreading basins, ditches, pits, and shafts and allowed to infiltrate.

**B. Indirect methods**

Indirect method include installing groundwater pumping facilities near connected surface water bodies to lower groundwater levels and induce infiltration elsewhere in the drainage basin. Indirect methods include modifying aquifers to enhance groundwater reserves.

**Mohammedjemal, 2006** stated that there is a third method for artificial recharge, which is the Combination system. The mixed recharge is the combination of infiltration and recharge wells. The advantage of this system is that the water has been pre filtered through the soil and the perched groundwater zone, so that its clogging potential is significantly reduced. In this way the risk of aquifer obstruction is reduced.

Table (2-1) summaries the major characteristics for various technologies used for artificial_recharge **(El Arabi, 2012)**

### 2.2.3 Influence of Recharge Factors

Not all aquifers can be artificially recharged. The hydraulic characteristics of the aquifer, the nature of the existing groundwater, and the characteristics of the recharge water can have a major influence on the outcome of a recharge operation **(Spandre R., 1999).**

**Table 2-1:** Characteristics for Various Technologies Used for Artificial Recharge (El Arabi, 2012).

| Parameter | Recharge Basin | Vadose Zone Injection Wells | Direct Injection Wells |
|---|---|---|---|
| Aquifer Type | Unconfined | Unconfined | Confined/Unconfined |
| Pre-Treatment Requirements | Low Technology | Removal of Solids | High Technology |
| Capacity | 1000-20,000 $m^3$/ha/day | 1000-2000 $m^3$/ha/day | 2000-6000 $m^3$/ha/day |
| Maintenance Requirements | Drying and Scraping | Drying and Disinfection | Disinfection and Flow Recovery |
| Soil-Aquifer Treatment | Vadose Zone and Saturated Zone | Vadose Zone and Saturated Zone | Saturated Zone |

#### 2.2.3.1 Geological and Hydrogeological Factors

The receiving aquifer must be homogeneous and isotropic as possible. One of the main factors affecting recharge is aquifer porosity. Porosity must be as high as possible, and this factor depends on a uniformity coefficient: where the coefficient is small, porosity is high. Another factor is the hydraulic conductivity of an aquifer: when the hydraulic conductivity is high, recharge is very quick. Hydraulic conductivity values tend to be high when the aquifer grain size is large. The artificial recharge depends on transmissivity and porosity values, and the uniformity of these parameters is very important.

#### 2.2.3.2 Physical and Chemical Factors

The chemical and physical characteristics of groundwater and recharge water have a great effect on the results of artificial recharge. **(Spandre R., 1999).**

### 2.3 Infiltration Basins (IB)

One artificial recharge method commonly used is infiltration to unconfined aquifers via pond infiltration or surface spreading **(Toze, et al., 2004).** Recharging basins are still the most common method of recharge and provide excellent versatility for water

resources planning **(El Arabi, 2012).** Infiltration basins require a substantial amount of land area with a suitable geology, allowing the water to infiltrate into the aquifer and percolate to the groundwater table. Infiltration basins (Figure 2-2) allows for natural, quality improving processes to take place in the surface of the infiltration ponds and subsoil **(SWECO, 2003).** The spreading basins should excavated in areas of high permeable soils, where the infiltration is most effective (**Guttman, 2012)**
Construction is normally comparatively simple and low cost.

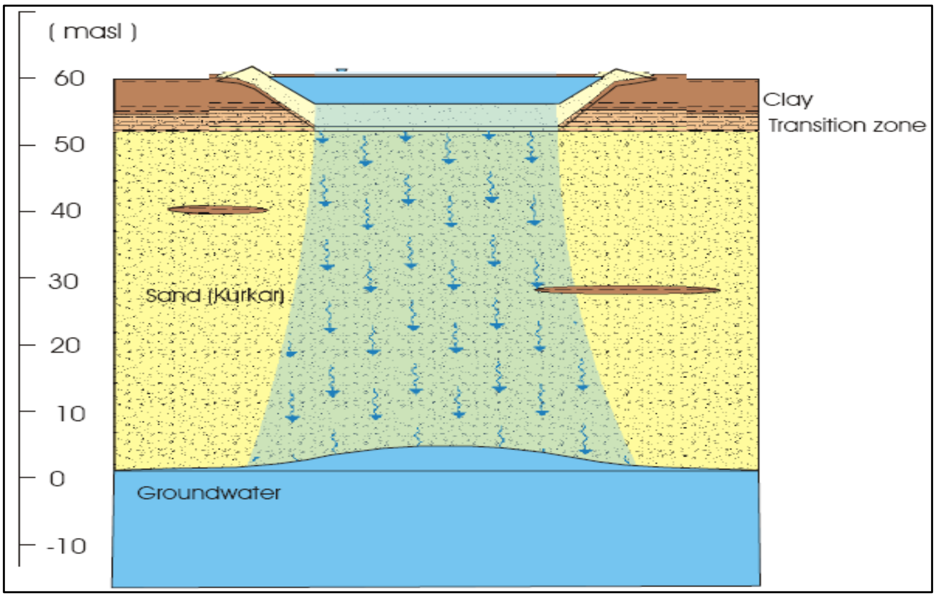


**Figure (2-2):** Principle for basin infiltration, (SWECO, 2003).

### 2.3.1 Infiltration Rate (IR)

Infiltration rates are expressed as volume of water moving into the soil or aquifer per unit infiltration area and per unit time. The dimension of infiltration rate thus is length/time, for example, cm/h or in/h, or m/day or ft/day. For IB, this rate can be visualized as the rate of fall of the water surface in the basin if there is no inflow to or outflow from the basin. IR for surface infiltration recharge systems typically range from 0.3 to 3 m/day (1–10 ft/day) **(Bouwer, 2002)**.

For surface infiltration systems in uniform soils without surface clogging, infiltration rates will be about equal to the vertical hydraulic conductivity of the soil which has the following approximate orders of magnitude:

| | |
|---|---|
| Clay soils | <0.1 m/day |
| Loams | 0.2 m/day |
| Sandy loams | 0.3 m/day |
| Loamy sands | 0.5 m/day |
| Fine sands | 1 m /day |
| Medium sands | 5 m /day |
| Coarse sands | >10 m/day |

These values can be used for preliminary site evaluation and system selection **(Bouwer, 2002 ).**

### 2.3.2 Factors Affecting Infiltration Rate

The infiltration rate of a natural porous body depends on its porosity and saturated hydraulic conductivity, which in turn is a function of the intrinsic permeability of the medium and the fluidity of the penetrating liquid **(Lin, et al., 2003)**. Initially, soil sorptivity is the primary factor affecting infiltration rate; but as infiltration time increases, the hydraulic conductivity becomes the controlling factor **(Lin et al., 2003).** The following factors is also affecting the IR:

### 2.3.3 Temperature

The infiltration rate into a soil will decrease as temperature of the system decreases, most likely due to the increased viscosity of the percolating water. Water viscosity changes by approximately 2% per degree Celsius in the relevant environmental temperature range of 15-35°C. This leads to an estimated 40% change of infiltration rate between the summer and winter months in arid regions The increase in hydraulic conductivity with increase in temperature is commonly attributed to the decrease in viscosity of the water **(M. Braga, 2005).**

Because infiltration rates vary inversely with water viscosity, temperature also affects infiltration rates. In areas with large differences between winter and summer temperatures, viscosity effects alone cause winter infiltration rates to be as low as about half of those in summer **(Bouwer, 2002)**.

### 2.3.4 Basin Water Depth

Achieving a maximum infiltration rate for recharge basins is essential, especially in urban settings where land is limited. The depth of water in recharge basins must be selected to achieve maximum infiltration rates **(M. Braga, 2005).**

### 2.3.5 Clogged Basin Layer

Clogging is one of the most critical factors affecting infiltration performance. Clogging may be defined as the reduction of the available pore volume of a porous media due to a range of physical, biological and chemical processes **(Nadee et al., 2010)**.

Physical processes are accumulation of inorganic and organic suspended solids in the recharge water, such as clay and silt particles, algae cells, microorganism cells and fragments, and sludge flocks in sewage effluent. Another physical process is downward movement of fine particles in the soil that were in the applied water or in the soil itself, and accumulation of these fine particles at some depth where the soil is denser or finer, and where they form a thin subsurface clogging layer. The depth of this layer ranges from a few mm to a few cm or more **(Bouwer, 2002)**.

Biological clogging processes include: accumulation of algae and bacterial flocks in the water on the infiltrating surface; and growth of micro-organisms on and in the soil to form biofilms and biomass (including polysaccharides and other metabolic end products) that block pores and/or reduce pore sizes **(Bouwer, 2002)**.

Chemical processes include: precipitation of calcium carbonate, gypsum, phosphate, and other chemicals on and in the soil. Sometimes, these precipitations are induced by pH increases caused by algae as they remove dissolved $CO_2$ from the water for photosynthesis. Bacteria also produce gases (nitrogen, methane) that block pores and accumulate below clogging layers to create vapor barriers to infiltration **(Bouwer, 2002)**.

Consequently, the immediate effect of clogging is to reduce the intrinsic permeability of a system, leading to a drop in infiltration rates in the case of surface ponding. The poorer the source water quality, the faster and more extensive the reduction in infiltration rate, as illustrated in Figure (2-3) **(Nadee et al., 2010)**.

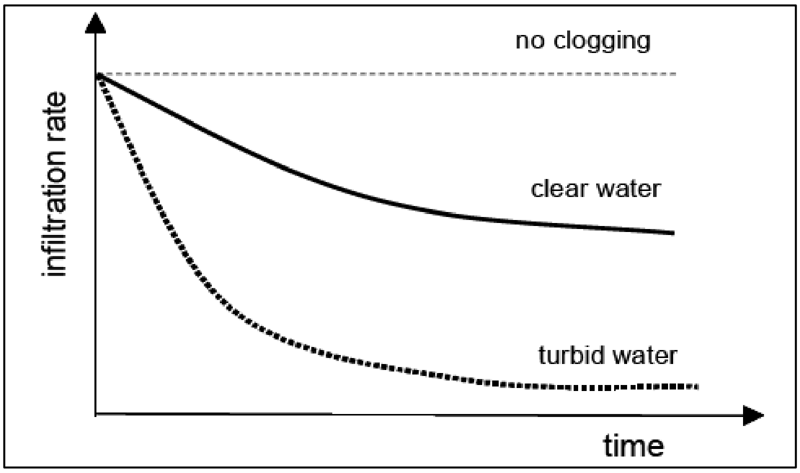


**Figure (2-3):** Illustration of Infiltration and clogging, (Nadee et al., 2010)

Over time, the bottom of the infiltration basin can become clogged by a layer of inorganic and/or organic deposits creating a barrier between the basin and the wetted perimeter as cleared on figure (2-4). As fine particles settle out and biological activity on the bottom continues, the thickness of the clogging layer can increase until infiltration rates eventually become so small that the function of the infiltration basin ends. **(M. Braga, 2005).**

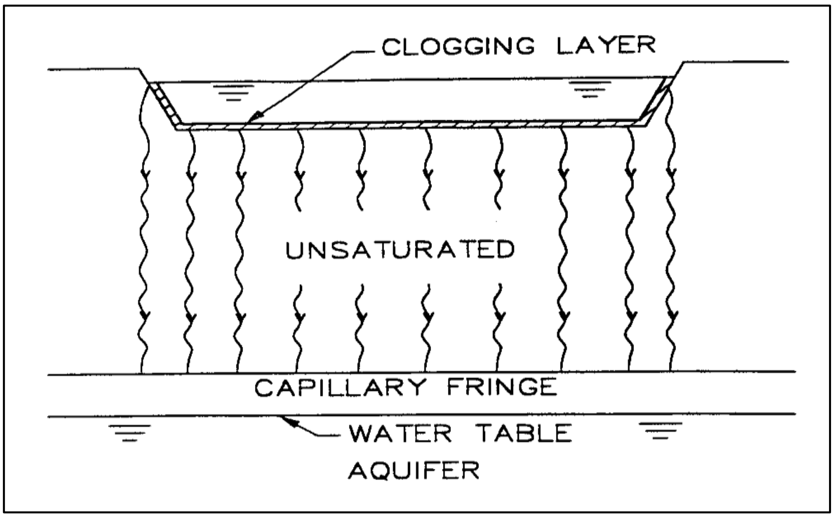


**Figure (2-4):** Illustration of clogging layer, (Bouwer, 1999)

### 2.3.6 Sodium Adsorption Rate (SAR)

Sodic soil, or soil with excessive levels of sodium ions ($Na^+$) relative to divalent ions calcium ($Ca^{2+}$) and magnesium ($Mg^{2+}$), can alter soil structure and reduce soil permeability. The sodium absorption rate (SAR) is an indicator of sodicity. To calculate the SAR of a waste or soil, determine the ($Na^+$), ($Ca^{2+}$), and ($Mg^{2+}$) concentrations in milliequivalents per liters for use in the Gapon equation which is commonly used to determine the ratio of sodium to calcium and magnesium:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}} \qquad 2.1$$

The term milliequivalents per liter (meq/l) expresses the concentration of a dissolved substance in terms of its combining weight. Milliequivalents are calculated for elemental ions such as $Na^{+}$, $Ca^{2+}$, and $Mg^{2+}$ by multiplying the concentration in mg/l by the valence number (1 for $Na^{+}$, 2 for $Ca^{2+}$ and $Mg^{2+}$) and dividing by the atomic weight (22.99 for $Na^{+}$, 40.08 for $Ca^{2+}$, and 24.31 for $Mg^{2+}$).**(EPA, 2013)**

Too much sodium causes problems related to soil structure. As sodium percentage increases, so does the risk of dispersion of soil aggregates, Figure (2-5).

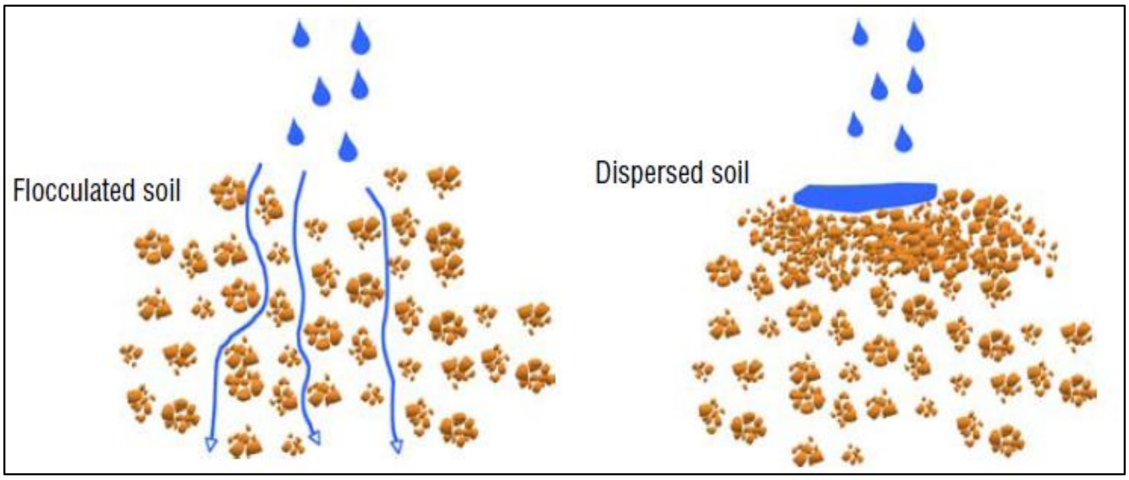


**Figure (2-5):** The difference between flocculated (aggregated) and dispersed soil structure (Horneck, et al., 2007).

Flocculation soil is important because water moves through large pores. Dispersed soil plug soil pores and impede water movement and soil drainage in all but the sandiest soil **(Horneck, et al., 2007).**

Figure (2-6) shows sodium adsorption ratio (SAR). SAR is a ratio of bad ($Na^+$) to good ($Ca^{2+}$ and $Mg^{2+}$) flocculators. When ($Na^+$) dominates (high SAR), soil pores clog (soil disperses), limiting water infiltration **(Horneck, et al., 2007)**

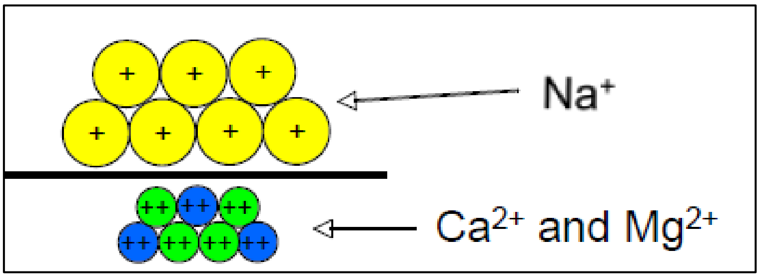


**Figure (2-6):** Representation of Sodium adsorption ratio (SAR) (Horneck, et al., 2007)

According to **(Waskom, et al., 2012)** the following terms mean:

- Saline related to high salt content,
- Sodic related to high sodium content, and
- Saline/sodic related to high salt and high sodium content.

The following Table 2-2 shows the general classification of salt-affected soils.

**Table 2-2: General classification of salt-affected soils (Waskom, et al., 2012)**

| Classification | Electrical Conductivity (EC) (ds/m) | Soil pH | Sodium adsorption ratio (SAR) | Soil physical condition |
|---|---|---|---|---|
| Slightly Sline | 2-4 | <8.5 | <13 | Normal |
| Saline | >4.0 | <8.5 | <13 | Normal |
| Sodic | <4.0 | >8.5 | >13 | Poor |
| Saline-Sodic | >4.0 | <8.5 | >13 | Varies |
| High pH | <4.0 | >7.5 | <13 | Varies |

## 2.4 Maintenance and Monitoring Artificial Recharge System

Managed for optimum performance for artificial recharge system depend entirely on local conditions of soil, hydrogeology, topography, water availability (quality, continuous, or interrupted supply), and climate. Key factors in the design and management of successful artificial recharge systems are site and system selection, maintenance of adequate infiltration rates, hydraulic continuity between the recharge system and the aquifer (no clay layers in the vadose zone), and groundwater control for effective water recovery and prevention of undue groundwater rises in the recharge area **(Bouwer, 2002)**. As stated by **(Guttman, 2012)** recharge is most effective when there are no clay layers between the land surface and the aquifer. Another important factor in the selection of the type of recharge system is the pretreatment of the water required before recharge to minimize physical, chemical, or biological clogging of the infiltrating surface (bottom in basins and walls in trenches, shafts, and wells) **(Bouwer, 2002)**.

Periodic maintenance of artificial recharge structures is essential because infiltration capacity is rapidly reduced because of silting, chemical precipitation, and accumulation of organic matter **(Bhattacharya, 2010).**

Infiltration rates of water through the soil can decrease as a result organic matter (OM) accumulation and the consequential water repellency. OM accumulation in the topsoil layer was found to be the main factor adversely affecting soil permeability, the OM originating from the TWW has water-repellent characteristics that alter soil hydraulic properties. The chemical nature and composition of the OM may have stronger effects on soil water repellency than its quantity **(Nadav et al., 2011).**

Organic matter (OM) in the top soil layer is the main factor determining treated waste water (TWW) infiltration into the soil. Soil plowing reduced OM content in the top soil layer and consequently, reduced the effect of OM on the soil hydraulic properties and restricted the reduction in TWW infiltration that occurs mainly during the winter. Soil plowing was found to be an efficient procedure that can be employed to reduce OM content in the top layer and maintain high infiltration rates of TWW into the soil **(Nadav et al., 2012).**

**(Guttman, 2012)** emphasized that the proper monitoring and maintenance is the key factor in long term operating of the artificial recharge plant.

In order to maintain sufficient infiltration rate to satisfactory values, the clogging layer should control periodically by drying the basins or other infiltration facility, and letting the layer decompose, shrink, crack, and curl up **(Bouwer, 2004)**. Rates of infiltration are maintained mainly by ploughing (plowing) or disking of the ground between or at the end the recharge events **(Guttman, 2012)**.

If clogging materials continue to accumulate, they must be periodically removed at the end of a drying period. This can be done mechanically with scrapers, front-end loaders, graders, or manually with rakes **(Bouwer, 2004)**.

## 2.5 Modeling of the Unsaturated Zone

### 2.5.1 The Green - Ampt Model (GA), 1911

Water infiltration is an important component of hydrological cycles. It serves an important role on many phenomena such as irrigation, runoff generation, soil erosion, and nutrient and contaminant transport **(Ma, et al., 2011).** There always has been a great interest in the modeling of the infiltration process (**Brevnova, 2001)**. A large number of infiltration models, including the Green-Ampt model the Richards equation, the Kostiakov model, the Horton model, and the Philip model have been developed in the last century. The formulation of the Green-Ampt model is very simple and the model parameters can be directly obtained from the physical and hydraulic properties of soil **(Ma, et al., 2011).**

Green-Ampt GA (1911) developed the first physically based model. (**Brevnova, 2001)**. The Green-Ampt equation is one of the most widely used equations for modeling one-dimensional vertical flow of water into soil. It was developed from an integration of Darcy's Law by assuming infiltration from a ponded surface into a deep homogeneous soil of uniform antecedent water content. What makes this model ideal is its reliance on physical parameters, most of which can be evaluated from properties of the soils identified through field-testing **(Braga, 2005).**

### 2.5.2 Assumptions of the GA model:

The following assumptions are made according to the Green-Ampt Model **(Brikowski, 2007)**.

- The wetting front advances at the same rate with depth, which produces a well-defined wetting front.
- The volumetric water contents remain constant above and below the wetting front as it advances.
- The soil-water suction immediately below the wetting front remains constant with both time and location as the wetting front advances.

This model employs a simple equation for describing and calculating infiltration. Green - Ampt arrived at their simplified theory of infiltration by considering the wetting front as a precipitous border between wetted and non-wetted soils. Figure (2-7) shows graphical representation of the Green-Ampt infiltration model: the wetting front penetrates to a depth *L* at time *t*, separating the saturated soil with hydraulic conductivity *K*, and porosity η for the soil which has moisture content $\theta_i$ below the wetting front. There is ponded water with a depth of $h_0$ above the surface (**Brevnova, 2001)**.

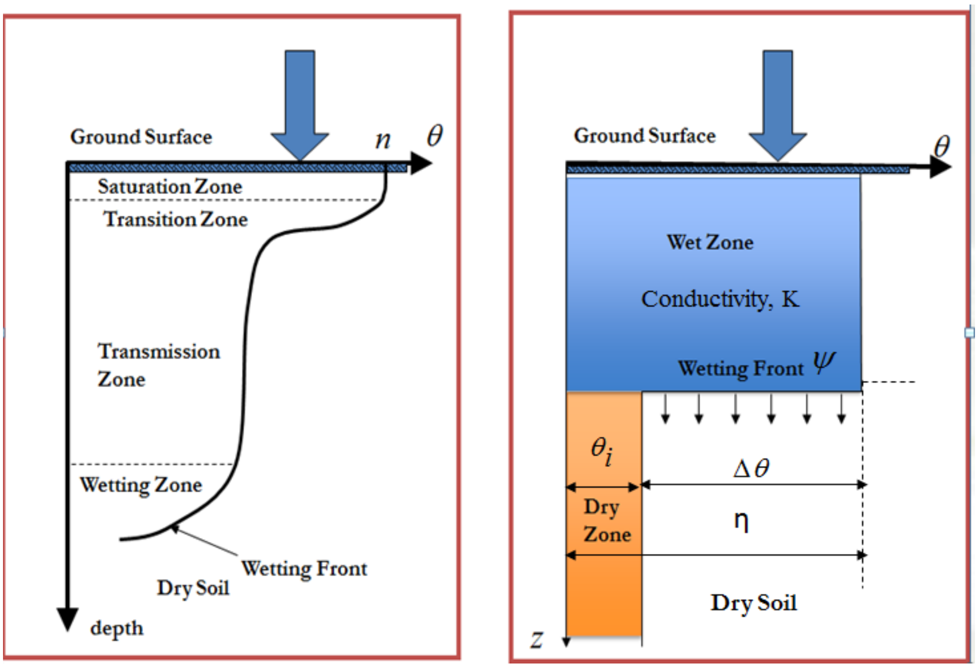


**Figure (2-7):** Graphical Representation of the GA Infiltration Model (Brevnova, 2001)

By applying Darcy's law to an imaginary vertical column of homogeneous soil with a unit cross-sectional area at the top, and a control volume between soil surface and wetting front boundary, infiltration can be expressed as the total gradient which includes a capillary suction ($\psi$) effect due to dryness at lower levels (**Brevnova, 2001)**.

$$f = K_s \frac{ho \quad + \psi \quad + L}{L} \qquad 2.2$$

For the ponded depth, $h_0$, considerably smaller than capillary suction and wetting front depth, equation 2.1 can be simplified as:

$$f = K_s \frac{\psi \quad + L}{L} \qquad 2.3$$

The assumption $h_0$ = 0 is usually appropriate for surface water hydrology problems because it is assumed that ponded water becomes surface runoff**.**

The Green-Ampt equations for cumulative infiltration F(t) and infiltration rate $f$ with time are **(Todd and Mays, 2005):**

$$F(t) = Kt + \psi\Delta\theta \ln\left(1 + \frac{F(t)}{\psi\Delta\theta}\right) \qquad 2.4$$

$$f = K\left(1 + \psi\frac{\Delta\theta}{F}\right) \qquad 2.5$$

The Green-Ampt infiltration equation involves parameters (see table 2-3):

1. The infiltration rate, $f$ (cm/hr),
2. Hydraulic conductivity, $K$ (cm/hr),
3. Wetting front capillary pressure head, $\psi$(cm), and
4. Change in moisture content $\Delta\theta$, which is a difference between porosity $\eta$, and initial soil water content, $\theta_i$.
5. Time, $t$ (hr).
6. The cumulative infiltration, F(t) (cm)

Application of the Green-Ampt model requires estimates of the hydraulic conductivity $K$, the wetting front soil suction head $\psi$ (see table 2-3), and $\Delta\theta$.

The residual moisture content of the soil, denoted by $\theta_r$, is the moisture content after it has been thoroughly drained. The effective saturation ($S_e$) is the ratio of the available moisture ($\theta$ - $\theta_r$) to the maximum possible available moisture content ($\eta$- $\theta_r$), given as:

$$S_e = \frac{\theta-\theta_r}{\eta-\theta_r}, \qquad 2.6$$

where $\eta$ - $\theta_r$ is called the effective porosity $\theta_e$.

The effective saturation has the range $0 \leq S_e \leq 1.0$, provided $\theta_r \leq \theta \leq \eta$. **((Todd and Mays, 2005).**

### 2.5.3 Estimating of Hydraulic conductivity (*K*)

A variety of methods are available for estimating saturated hydraulic conductivity values from grain size information. One of the most simple and most commonly used approaches is the Hazen equation **(Massman, 2003):**

$$Ks = Cd^2_{10} \qquad 2.7$$

Where;

*Ks* : is the saturated hydraulic conductivity,

*C* : is a conversion coefficient, and

$d_{10}$ : is the grain size for which 10% of the sample is more fine (10% of the soil particles have grain diameters smaller than $d_{10}$).

For Ks in units of cm/s and for $d_{10}$ in units of mm, the coefficient, C, is approximately (1).

Table 2-4 contains some representative hydraulic conductivity for different soil types.

**Table 2-3:** Green-Ampt infiltration parameters for various soil classes**, (**Todd and Mays, 2005)

| Soil class | Porosity<br>$\eta$ | Effective Porosity<br>$\theta_i$ | Wetting front soil suction head<br>$\psi$<br>(cm) | Hydraulic Conductivity<br>$K$<br>(cm/hr) |
|---|---|---|---|---|
| Sand | 0.437<br>(0.374-0.500) | 0.417<br>(0.354-0.480) | 4.95<br>(0.97-25.36) | 11.78 |
| Loamy sand | 0.437<br>(0.363-0.506) | 0.401<br>(0.329-0.473) | 6.13<br>(1.35-27.94) | 2.99 |

| | | | | |
|---|---|---|---|---|
| Sandy loam | 0.453 (0.351-0.555) | 0.412 (0.283-0.541) | 11.01 (2.67-45.47) | 1.09 |
| Loam | 0.463 (0.375-0.551) | 0.434 (0.334-0.534) | 8.89 (1.33-59.38) | 0.34 |
| Silt loam | 0.501 (0.420-0.582) | 0.486 (0.394-0.578) | 16.68 (2.292-95.39) | 0.65 |
| Sandy clay Loam | 0.398 (0.332-0.464) | 0.33 (0.235-0.425) | 21.85 (4.42-108.0) | 0.15 |
| Clay loam | 0.464 (0.409-0.519) | 0.309 (0.279-0.501) | 20.88 (4.79-91.10) | 0.10 |
| Silty clay Loam | 0.471 (0.418-0.524) | 0.432 (0.347-0.517) | 27.3 (5.67-131.50) | 0.10 |
| Sandy clay | 0.430 (0.370-0.490) | 0.321 (0.207-0.435) | 23.9 (4.08-140.2) | 0.06 |
| Silty clay | 0.479 (0.425-0.533) | 0.423 (0.334-0.512) | 29.22 (6.13-139.4) | 0.05 |
| Clay | 0.475 (0.427-0.523) | 0.385 (0.269-0.501) | 31.63 (6.39-156.5) | 0.03 |

**Table 2-4:** Some Representative Hydraulic Conductivity for Different Soil Types (Todd and Mays, 2005)

| **Material** | **Hydraulic conductivity (m/day)** |
|---|---|
| Gravel, coarse | 150 |
| Gravel, medium | 270 |
| Gravel, fine | 450 |
| Sand, coarse | 45 |
| Sand, medium | 12 |
| Sand, fine | 2.5 |
| Silt | 0.08 |
| Clay | 0.0002 |

## 2.6 Enhancement of the Lower Layers Infiltration Rate

Injection piles are used in order to enhance the infiltration rate for the deep low permeability layers. From the radial flow concept, it is apparent that as ground water converges a well, its velocity increases. If the velocity exceeds a critical limit, finer particles will be transported from the aquifer into the gravel filter, and the filter subsequently plugs, this velocity is the approach velocity **(Williams, 1981)**.

The relationship between the velocity and hydraulic conductivity of the aquifer is expressed by Sichardt equation **(Williams, 1981)**.:

$$\boldsymbol{V_a < \frac{\sqrt{K}}{15}} \qquad 2.8$$

where $V_a$ is the approach velocity, m/s ,and K is the hydraulic conductivity of the aquifer, m/s with safety factor for design computations of $\boldsymbol{V_a < \frac{\sqrt{K}}{30}}$ (Safety factor of 2 for design considerations).

## 2.7 Enhancement of the Wetting Drying Cycles for Infiltration basins:

Soil Aquifer Treatment (SAT ) basin hydraulics are often controlled by the development of a low-conductivity clogging layer at and near the ground surface. This clogging layer has been found to be subject to compression under seepage forces exerted by infiltrating water with a corresponding reduction in the hydraulic conductivity of the layer, particularly when algae and/or a high concentration of particulate matter is present in the effluent. Limiting the depth of water in the pond can help to prevent excessive compression and a further reduction of hydraulic conductivity of the clogging layer. Additionally, the use of fairly short wetting cycles, designed to cut down on the growth of algae, can be helpful in minimizing the reduction of hydraulic conductivity of the clogging-surface layer **(Sandra et, al., 1999).**

As suspended solids, algae growing in the infiltration basin, and microbes growing in the soil or the basin surface components accumulate on the bottom of the basin floor to form the clogging layer, they begin to restrict infiltration. Therefore, management of surface and near surface basin soils through control of wetting and drying cycle times is generally required to ensure adequate infiltration rates. Longer drying time tends to be more effective in reestablishing infiltration rate compared to shorter drying time. Short drying times did not provide complete nitrification, thus allowing $NH_4$ to build up in soil. Long enough drying times will promote complete nitrification ($NH_4$ to $NO_3$) and will prevent accumulation of $NH_4$ in the soil **(Abushbak, 2004).**

**(AWWA, 1998)** emphasized that longer drying time tends to be more effective in reestablishing infiltration rates compared with shorter drying time. It is reasonable to expect that a more thorough surface drying with corresponding cracking and breaking up of the surface clogging layer would increase infiltration rtae.

## 2.8 Research Contribution

The main enemy of the infiltration basins is the clogging on the infiltration surface which cause severe reduction in the infiltration rate for the system. The findings of the research will help to identify the constraints affecting the efficiency of the infiltration process, and it will help the responsible local authorities to operate the infiltration basins in a proper way by introducing methods of controlling and enhancement of infiltration rate.

# CAHPTER 3 : Study Area Description

## 3.1 Location of the Gaza Strip

The Gaza Strip is located on the eastern coast of the Mediterranean Sea that borders Egypt on the southwest (11 km) and Israel on the east and north (51 km). It is 41 kilometers long, and from 6 to 12 kilometers wide, with a total area of 365 $km^2$ as shown in Figure 3-1 **(PCBS, 2013).**


**Figure (3-1):** Map of the Gaza Strip (Wikipedia, 2013)

The Gaza Strip is located between longitudes 34° 20" east, and latitudes 31° 25" north **(Wikipedia, 2013).**

### 3.2 Demographical Data

Demographic pressures in the Gaza Strip in terms of population density, growth rate, poverty and unemployment are extraordinarily high compared to neighboring countries

and regions. Based on estimates prepared by Palestinian Central Bureau of Statistics (PCBS) according to the results of the Population, Housing and Establishment Census of 2007, the estimated population of Gaza Strip totaled 1.64 million inhabitants **(PCBS, 2012).**

### 3.3 Climate

The Gaza Strip is located at the south-eastern edge of the Mediterranean and has arid to semiarid climate**.** The Gaza Strip is characterized by short winter season, the first real rain starts from October till March, rains in September and April are occasionally and happened two times in the last decade. Therefore, the average yearly rainfall is only distributed to five months a year. Around 30% of the rains occurs in January (**Al Najar, 2011**). The annual rainfall fluctuating from 236 mm in the south to 433 mm in the north **(Hamdan, 2012).**

The maximum temperature ranges between 18.1 and 29.4°C, while the minimum temperature ranges between 10.7 and 24.6 in winter and summer, respectively. The average humidity is 68.3% indicating high humidity in summer than in winter, as the Gaza Strip located on a coastal zone.( **Al Najar, 2011).**

### 3.4 Geology

The ground surface in the Gaza Strip is formed of elongated ridges and depressions parallel to the Mediterranean coast, and it is composed of sedimentary rocks belong to Quaternary Era and divided into two main formations, Holocene at the top is composed of continental alluvial and aeolian deposits called continental kurkar composed of calcareous sandstone covered by recent calcareous sand dunes accumulation lying in 1-4 km belt along the coast which is suitable for natural water recharge. The lower formation, Pleistocene is composed of near shore deposits and called marine kurkar. The kurkar deposits are porous, and this makes it important as a groundwater aquifer showing high hydraulic conductivity. The thickness of both formations constituting the Quaternary formation is estimated at 160 meters, where the kurkar formation is subdivided into sub-aquifers by local aquicludes at the first four kilometers parallel to the coast which are composed of clay and marl beds making confined aquifers, Figure 3-2. Black shale of 100m of Pliocene age deposits are found beneath the Quaternary sediments and known locally as Saqiya formation which forms the base of the water bearing layer i.e. the coastal aquifer of the Gaza Strip **(Hamdan, 2012).**

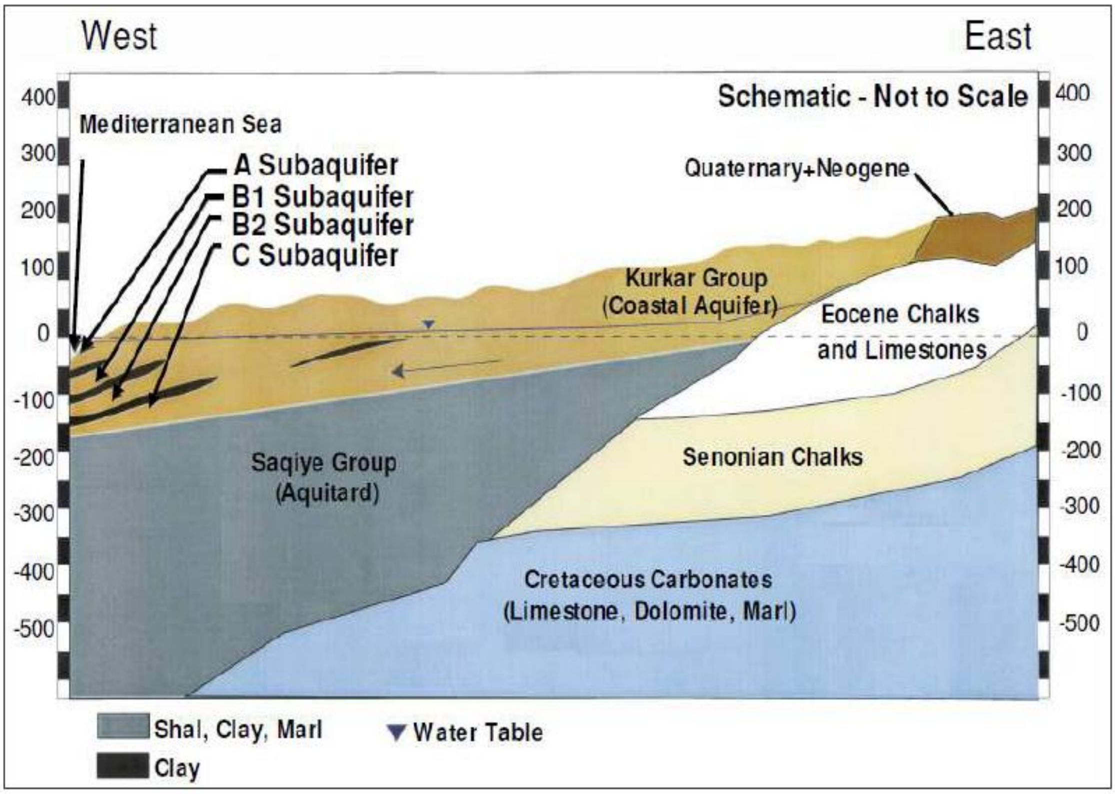


**Figure (3-2):** Generalized Geological Cross-section of the Coastal Plain (Greitzer, and Dan, 1967)

### 3.5 Infiltration Basins Location and Topography

The site is located east of Gaza City, next to the border with Israel. The site is located on a slope with the eastern part elevated at 70 meters above sea level (masl) and the western part at 50 masl, Figure 3-3. The land has previously been used for agriculture. The areas north and south of the site are used for orchards and along the western side a cemetery is located **(SWECO, 2003).**


**Figure (3-3):** The location of the Infiltration Basins

## 3.6 Situation, and Operation of the Infiltration Basins

### 3.6.1 Background

The Swedish Government has supported the Palestinian National Authority (PNA) with assistance in funding of the Northern Gaza Storm Water and Sewerage Project (NGSWSP) through the Palestinian Water Authority (PWA).The purpose of the project was to provide a long-term and sustainable solution of the wastewater situation for Northern Gaza **(SEWCO, 2003)**.

The NGSWSP main components as stated by SWECO International:

- Pressure Mains and Gravity Sewers, which already done.
- Pumping Stations consisting of a New Terminal Pumping Station at the existing WWTP and upgrading of the existing Beit Lahia Pumping Station, and the project was implemented.

- New Wastewater Treatment Plant, including inlet works with screening, grit and grease removal, primary and biological treatment, final clarification and sludge treatment facilities. This component is still under construction.
- Effluent Infiltration Basins for aquifer recharge, which is the subject of the study.

The infiltration area divided into nine ponds with a total area of approximately 80.000 $m^2$. The area of each pond as per design and after construction is presented in Table 3-1 below.

**Table 3-1:** Infiltration Basins Area

| Infiltration Pond | Area ($m^2$) according to the design (SWECO, 2003) | Area ($m^2$) after construction (PWA, 2009) |
|---|---|---|
| 1 | 10700 | 12328 |
| 2 | 12700 | 11142 |
| 3 | 6900 | 6892 |
| 4 | 8900 | 7845 |
| 5 | 9300 | 9174 |
| 6 | 7700 | 6120 |
| 7 | 8400 | 8386 |
| 8 | 7600 | 6302 |
| 9 | 7200 | 7091 |

The infiltration basins are distributed in three groups. Basin 1,2,3, basin 4,5,7 and basin 6,8,9, Figure 3-4. The water is distributed to one to three basins in each group at a time. After flooding for a certain time, 0.5-2 days, the water is redirected to the next group in order. In between flooding cycles, the basins are allowed to dry for period of 1-4 days or longer. The relatively short flooding period and the drying periods will minimize algae growth and this will prevent a quick clogging of the ponds. Normally one basin is out of operation for extended drying and cleaning **(SWECO, 2003).**

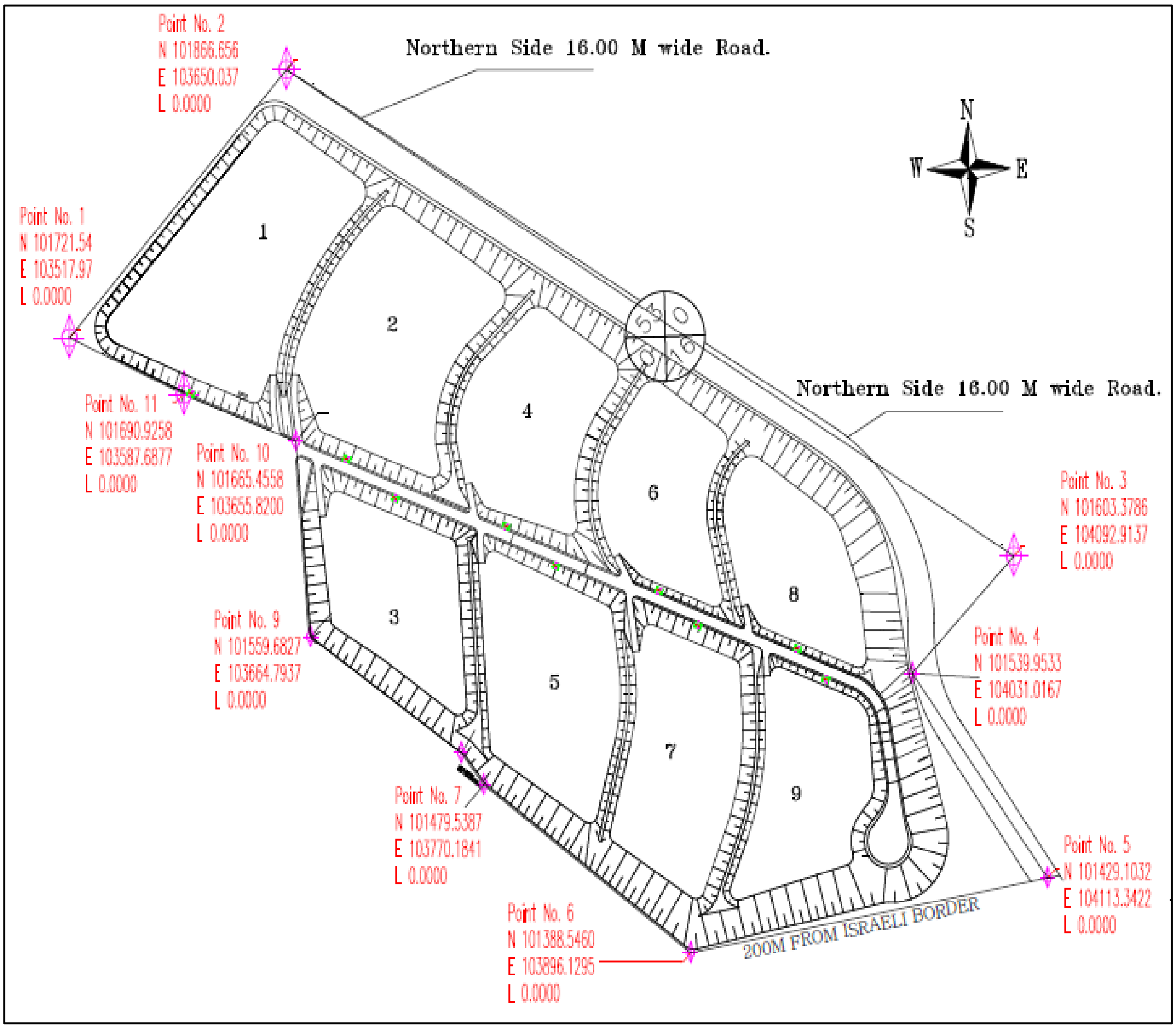


**Figure (3-4):** Infiltration Site Layout (PWA, 2009)

### 3.6.2 Effluent Water Flow, and Effluent water Quality

The infiltration basins are designed to accommodate an average design flow of 35,600 $m^3$/d which will be coming out from the wastewater treatment plant (new northern wastewater treatment plant), Table 3-2.

**Table 3-2: The Design Flow for the Infiltration Basins (SWECO, 2003)**

| Design Flow Values | Unit | Values |
|---|---|---|
| Flow, population | $m^3/d$ | 33,960 |
| Flow, industrial | $m^3/d$ | 1,640 |
| Total flow, average | $m^3/d$ | 35,600 |
| Design flow | $m^3/h$ | 1,975 |
| Peak flow | $m^3/h$ | 3,600 |

The Effluent water quality according to the design criteria to be infiltrated and used for unrestricted irrigation is **(SWECO, 2003)**:

- $BOD_5$ 10-20 mg/l
- SS 15-20 mg/l
- N-tot 10 mg/l
- Helminthes <1 No/l
- Fecal coliform <200 No/100 ml

The effluent water quality according to the periodic (Year 2011, 2012, and 2013) water quality monitoring by the PWA is:

- $BOD_5$ 60-95 mg/l
- SS 60-130 mg/l
- N-tot 55-75 mg/l
- Fecal coliform >1100 No/100 ml

According to the progress report (Quarter # 33 for the Period from January to March, 2013) prepared by the Projects Management Unit (PMU) at PWA, the total accumulated quantity of the effluent transferred to the new infiltration basins from April, 2009 until March, 2013 is about 19 MCM, with average daily flow discharged to the IB of 8,400 $m^3$.

Due to the partially treated effluent, and to reduce the pollution of the aquifer, both PWA and the Coastal Municipalities Water Utility (CMWU) agreed a maximum pumping rate of 15,000 $m^3$/d from the Terminal pump station to the new IB.

The quantity of effluent is still below the agreed quantity between PWA and CMWU which is 15,000 $m^3$/d. The excess quantities of effluent pumped to two emergency ponds northern to Bait Lahia Waste Water Treatment Plant (BLWWTP).

To improve the performance of the infiltration basins, PWA starting the cleaning activities for ponds one and two at BLWWTP during March, 2013. According to PWA progress report the cleaning will help in decreasing the Suspended Solids (SS) concentration, and thus may improve the quality of effluent reaching the basins and improve the infiltration rate.

### 3.6.3 Infiltration Basins Efficiency

According to historical records by the PWA, the efficiency of the basins have deteriorated with compared the average infiltration rates for all basins for the years 2010, 2011, 2012 and 2013, Figure 3-5, and the worst one is infiltration basin IB1, Figure 3-6, and Figure 3-7.

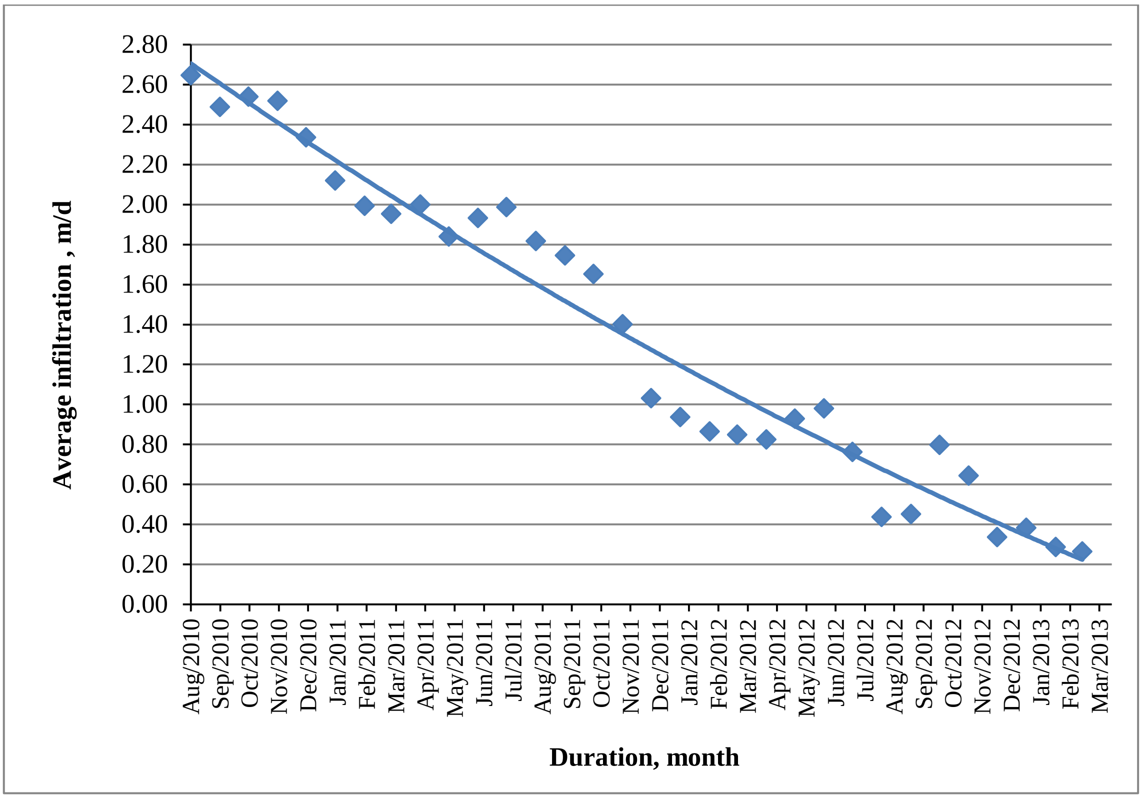


**Figure (3-5):** Average infiltration record for all basins (1-9) from August 2010 to March 2013 (PWA, 2013)

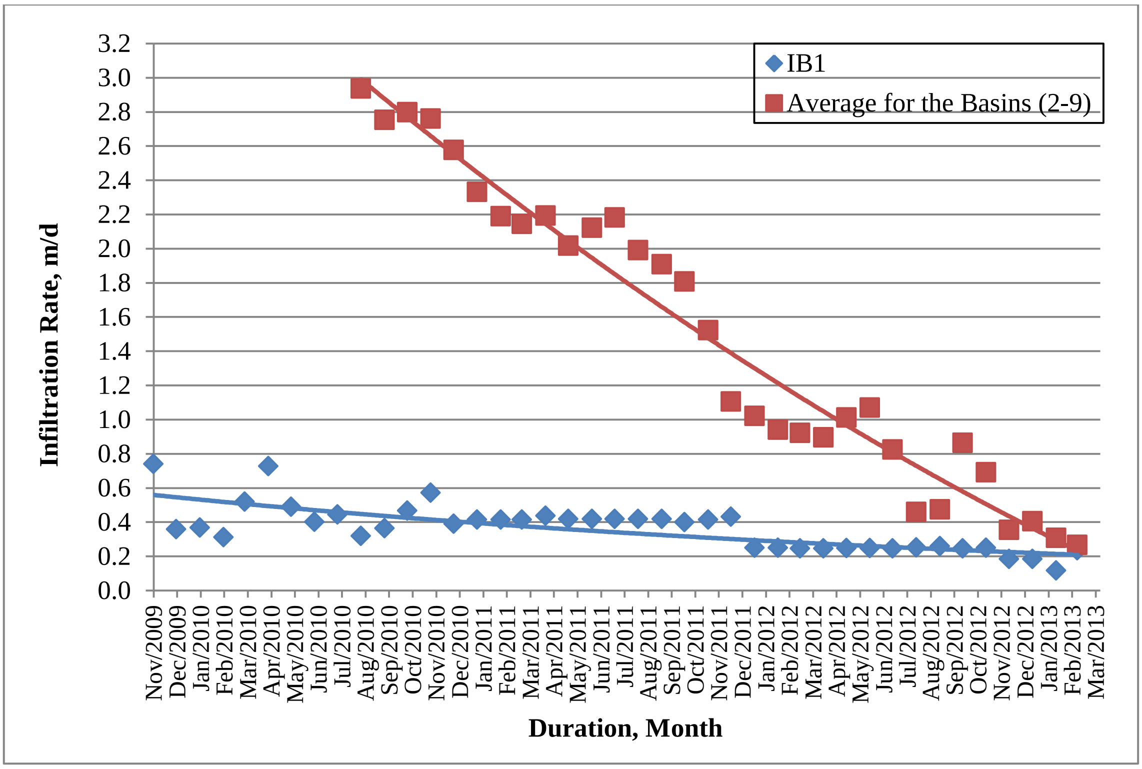


**Figure (3-6):** Average infiltration Record from November 2009 to March 2013 for IB1 Comparing with Basins (2-9), (PWA, 2013)

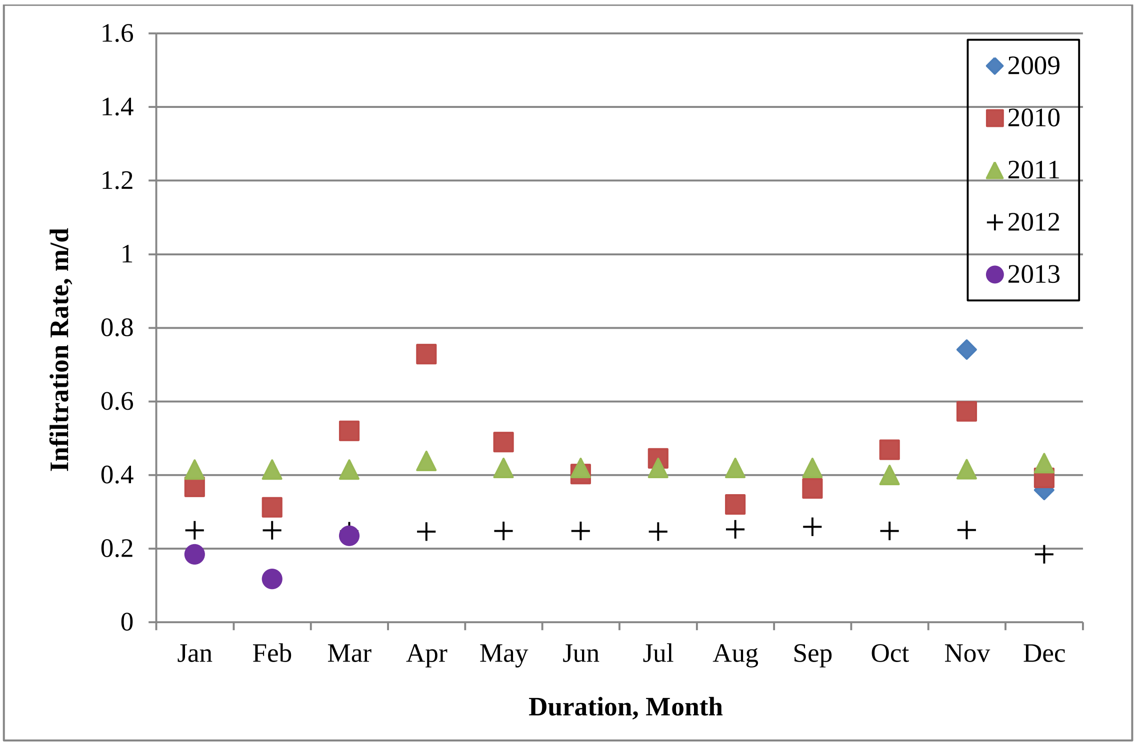


**Figure (3-7):** Average monthly infiltration rate for IB1 for the Years 2009, 2010, 2011, 2012,and 2013 (PWA, 2013)

The efficiency of infiltration basin IB1 is in deteriorating since the operation of the infiltration system as shown in Figure 3-6, and 3-7 with comparing the rate of infiltration for the basin for the years 2009, 2010, 2011, 2012, and up to March, 2013. The basin takes long time to dry (Figure 3-8) and this is clear from the plowing periods recorded by CMWU, the authority who perform the plowing works. It is concluded that the problem of IB1 is not related to operation, but it may related to geological factors.

Appendix (2) shows the schedule of plowing for the IB1, since 14.09.2011 until 13.05.2013 (the last plowing) before stopping pumping to the basin.

**Figure (3-8):** General view for infiltration basin IB1(July, 2013)

# CAHPTER 4 : Methodology

## 4.1 Introduction

The methodology followed in this study was based on the objectives of the study as stated in chapter 1, section 1.4. To achieve the objectives; the study was divided into two parts: field investigations and experiment tasks (experimental methods were employed to determine soil classification tests and soil quality) and modeling tasks for the unsaturated zone.

## 4.2 Soil Classification Tests

The location of Bore holes (5 bore holes) was selected as shown in Figure 4-1, after continuous monitoring for the basin (IB1), at the places which has low infiltration rate. The drilling of bore holes was performed by the method of Rotary Auger, Figure 4-2.

During the drillings, disturbed samples were collected each 30cm until the depth 2.10m and each 1.0 m until the depth of 12.0m (end of bore hole), with a total of 17 samples for each bore hole. Samples were selected in a way representative to the soil strata within the borehole along the depth of 12m for the infiltration basin (IB1). The samples were checked ocular at the site with regards of the soil texture and color, and the soil samples were placed in a clean plastic bags before transported to the laboratory. An identity number, sample location, and depth within the borehole was identified for each sample.

The soil classification tests executed laboratory tests which included: Sieve Analysis; Atterberge Limits; Moisture Content, and Hydraulic Conductivity. Samples were selected in a way representative to the soil strata within the borehole along the depth of 12m for the infiltration basin (IB1).

The tests results are shown in appendix (1). The laboratory analysis of soil samples were carried out in the Consulting Center For Quality and Calibration.

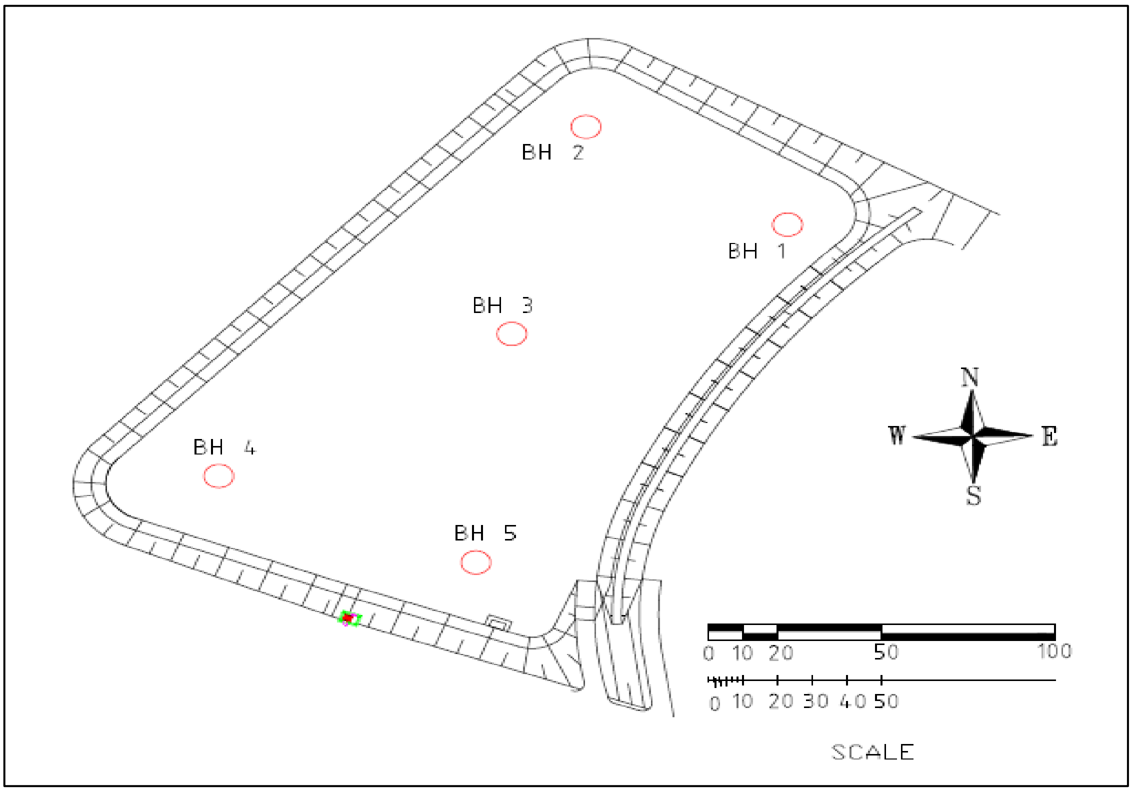


**Figure (4-1):** Location of Bore Holes at Infiltration Basin (IB1)

**Figure (4-2):** Drilling method using Rotary Auger

Tests were performed according to the international standards (American Society for Testing and Materials (ASTM) and British Standards (BS)). The soil layers were classified according to the Unified Soil Classification System (USCS). The following tests with their relevant standards were performed at the laboratory, Table 4-1.

**Table 4-1**: Testing methods and relevant standards

| Testing Method | Relevant Standard |
|---|---|
| Description and Identification of Soils (Visual-Manual Procedure). | ASTM D 2488-93 |
| Particle Size Analysis of Soils. | ASTM D 422-63-Reapproved 1998 |
| Classification of Soils for Engineering Purposes (Unified Soil Classification System). | ASTM D 2487-98 |
| Laboratory Determination of Water (Moisture) Content of Soil. | ASTM D 2216-98 |
| Liquid Limit, Plastic Limit, and Plasticity Index of Soils. | ASTM D 4318-98, BS 1377-1990 |

**4.3 Soil Quality Tests**

Soil quality tests was conducted in order to check if soil contains high load of organic matter (OM) and high rate of sodium adsorption ratio (SAR).

The samples from the same bore holes was taken in parallel with the soil classification samples each 30cm until the depth of 2.10m (7 samples from each bore hole). The soil quality samples was placed in a clean plastic bags before delivered to the laboratory. An identity number, sample location, and depth within the borehole was identified for each sample.

Samples were selected in a way representative to the soil depth within the borehole .

The organic matter test was conducted according to the ASTM standards, ASTM D 2974-00 at Consulting Center For Quality and Calibration.

SAR was carried out in Bir Zeit University Testing Laboratory according to Methods of Soli Analysis, Chemical and Microbiological Properties, Ammonium Acetate Method. Figure 4-3, Figure 4-4, and Figure 4-5 showing some procedures during testing of SAR. SAR was calculated according to Gapon equation as stated in Chapter 2, section 2.3.6.

**Note:** the soil sample for borehole (1) which related to the depth 1.80m was lost during transportation of the samples to the laboratory.


**Figure (4-3):** Preparation of soil samples


**Figure (4-4):** Soil samples after digestion


**Figure (4-5):** Final test of SAR

## 4.4 Water Quality Tests

Quality of the effluent (partially treated wastewater) was tested in order to determine the parameters: Biochemical Oxygen Demand BOD, Chemical Oxygen Demand COD, Temperature T, Total Suspended Solids TSS, Hydrogen Ion Concentration pH, Total Coliform TC, Fecal Coliform FC, and Hardness H. Tests were carried out at Environmental and Rural Research Center (ERRC) at the Islamic University of Gaza by the Project Management Unit at PWA. Table 4-2 shows adopted methods and used instruments performed by ERRC.

**Table 4-2:** Adopted Methods and Instruments

| No. | Parameter | Procedure | Name of Instrument |
|---|---|---|---|
| 1 | BOD | OxiTop method | OxiTop |
| 2 | COD | Close reflux method | Spectrophotometer & COD reactor |
| 3 | TSS | Dry 105 $C^o$ | Oven |
| 4 | TC | Filtration technique | Incubator |
| 5 | FC | Filtration technique | Incubator |

## 4.5 Modeling for the Unsaturated Zone

Chapter six will explain and discuss the modeling for the unsaturated zone by using the Green-Ampt model (1911) for infiltration. Modeling for the exiting infiltration regime, and modeling for the enhancement will be performed by using different soil parameters. Also this chapter will introduce method of enhancement the wetting and drying cycles in order to maintain reasonable infiltration rate.

# CAHPTER 5 : Results and Discussion

This chapter demonstrates and discusses the results of the collected data and their analysis for IB1, also the modeling for the unsaturated zone.

### 5.1 Field Experiments Results

**USCS classification system introducing the following symbols for the soil:**

SP: poorly graded sand, gravely sand, little or no fines.

SM: Silty sands, sand-silt mixture.

SC: clayey sand, sand- clay mixture.

CL: Inorganic clays of low to medium plasticity, gravel clays, sand clays, silt clays, lean clays.

#### 5.1.1 Results of Soil Classification Tests

##### 5.1.1.1 Grain Size Analysis for Bore Hole BH1

According to the bore hole log for BH1, the top soil form depth 0.0-0.30m is sand: yellowish fine sand with little gravel (Kurkar) and a little fines (14.0%), and it is non-plastic. The percentage of water content WC is 11.0%. The depth from 0.30-0.90m is classified as clayey sand: slightly brown clayey sand with little gravel (Kurkar) and some fines (21.6%-29.6%). The layer is of low to medium plasticity, with WC decreasing from 12.7% to 12.0%. The depth from 0.90m until depth of 12.0m the end of the bore hole is sand: yellowish fine sand with little gravel (Kurkar) and a little fines (2.0%-11.9%). The layer is non-plastic, with WC from 3.80% to 8.70%. Figures 5-1, 5-2, and 5-3 showing the geological cross section for the soil according to bore holes (1-3-4), and (2-3-5). Also summary of the soil classification for BH1 is shown in Table 5-1.

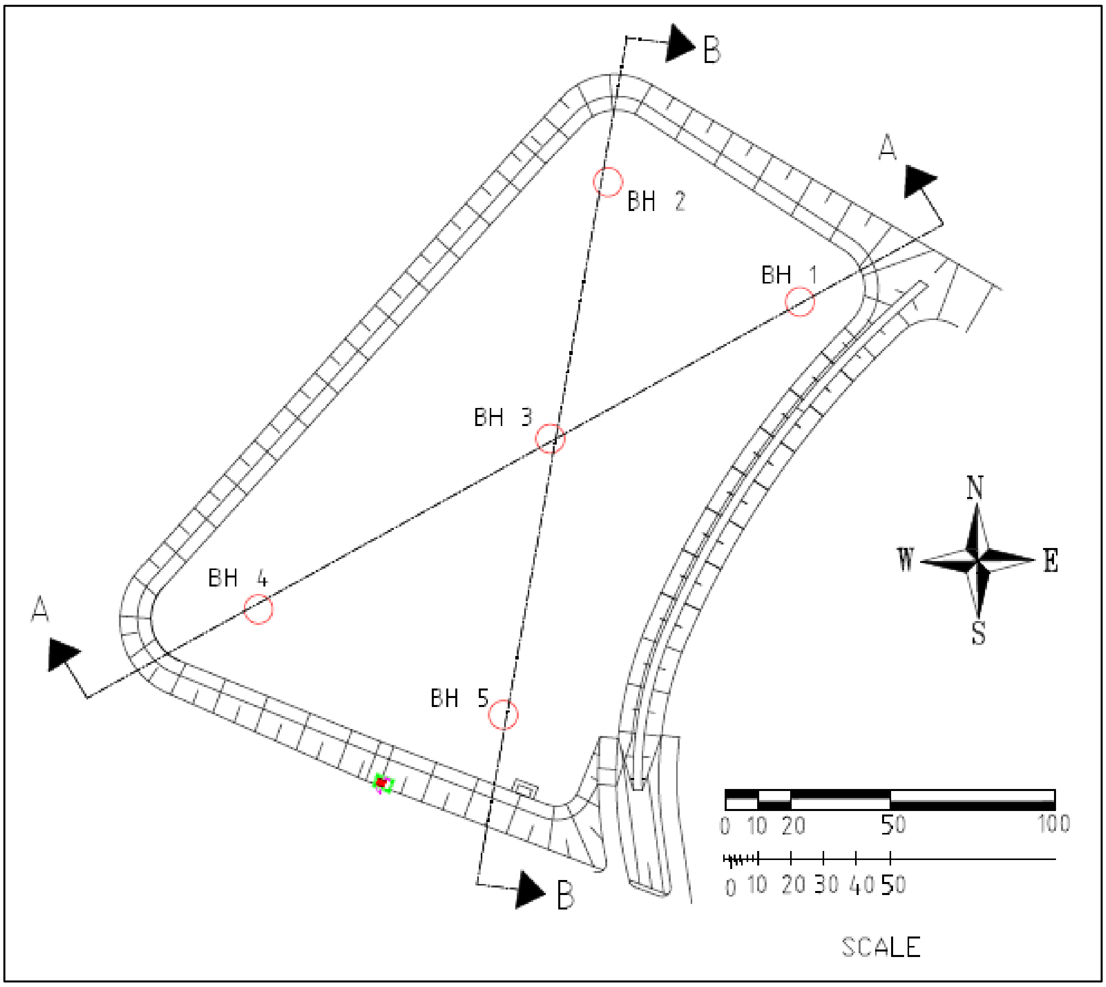


**Figure (5-1):** Section Plan at the Bore Holes for IB1

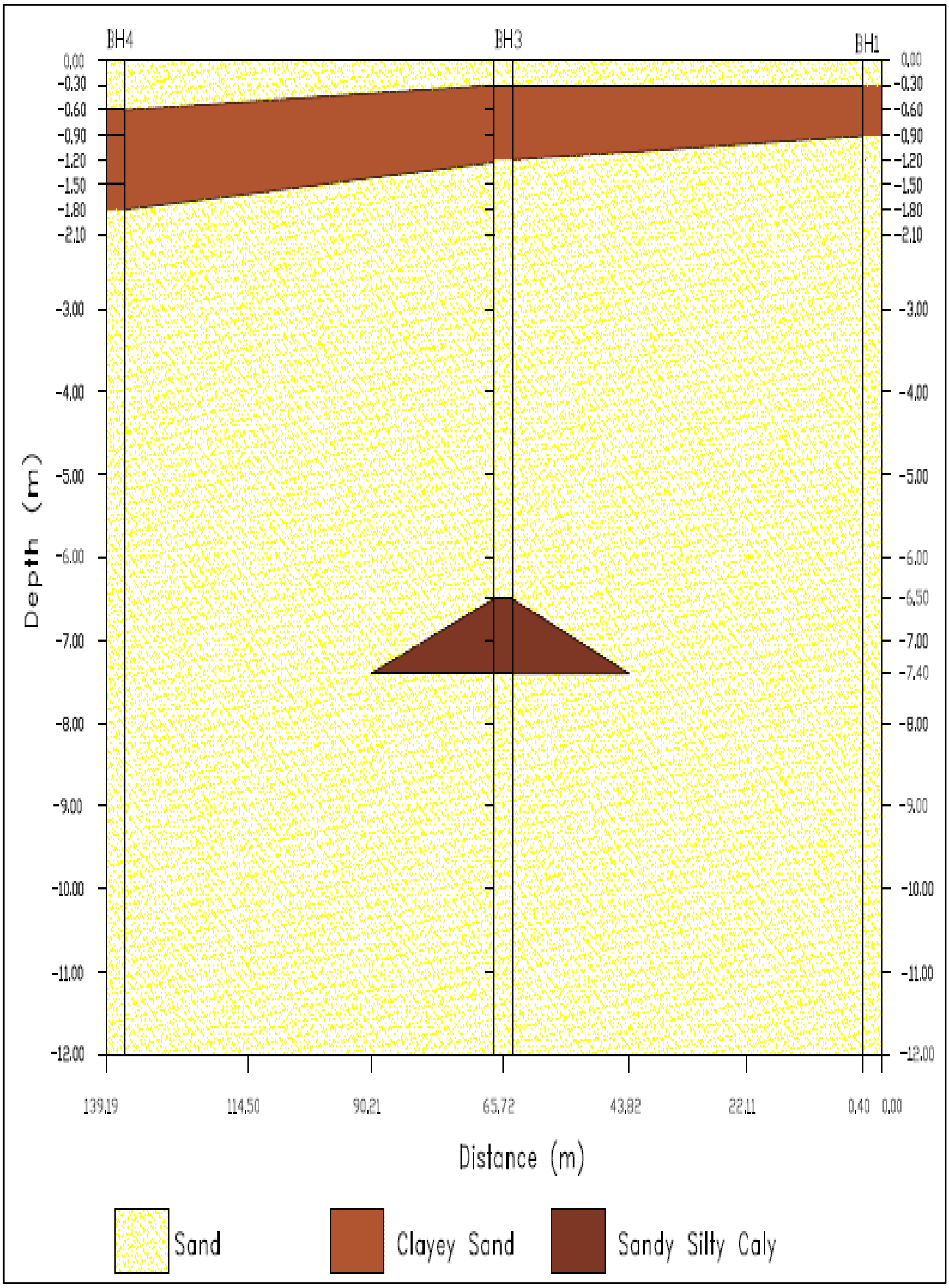


**Figure (5-2):** Geological Cross Section A-A (BH1-BH3-BH4)

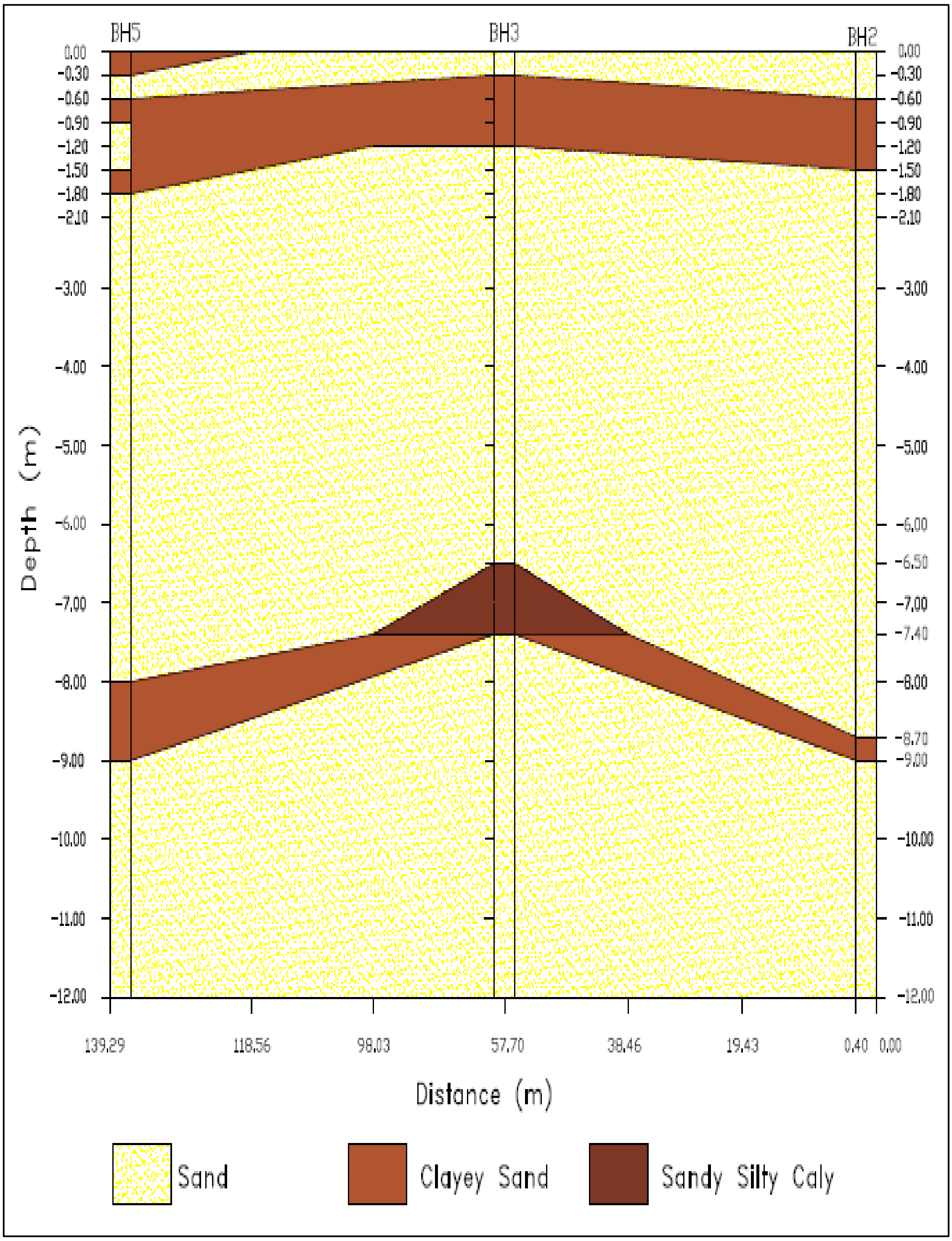


**Figure (5-3):** Geological Cross Section B-B (BH2-BH3-BH5)

**Table 5-1:** Soil Classification for BH1

| Depth (m) | Soil Description | Soil Classification | Fines Content (%) | WC (%) |
|---|---|---|---|---|
| 0-0.3 | Sand: yellowish fine sand with little gravel (Kurkar) and a little fines. | SM | 14.0 | 11.0 |
| 0.3-0.9 | Clayey Sand: slightly brown clayey sand with little gravel (Kurkar) and some fines. | SC | 21.6-29.6 | 12.0-12.7 |
| 0.9-12.0 | Sand: yellowish fine sand with little gravel (Kurkar) and a little fines. | SP-SM | 2.0-11.9 | 3.8-8.7 |

#### 5.1.1.2 Grain Size Analysis for Bore Hole BH2

The bore hole log for BH2 shows that the top soil layer form depth 0.0-0.60m is sand: yellowish fine sand with little gravel (Kurkar) and a little fines (6.3%), the soil layer is non-plastic. The percentage of water content WC is 11.4%. The depth from 0.6-1.5m is classified as clayey sand: slightly brown clayey sand with little gravel (Kurkar) and some fines (18.2%-27.7%). The layer is of low to medium plasticity, with WC decreasing from 15.6% to 14.2%. The depth from 1.5m until the depth of 8.7m is sand: yellowish fine sand with little gravel (Kurkar) and a little fines (4.6%-9.6%). The layer is non-plastic, with WC ranged from 5.60% to 10.5%. The depth from 8.70m up to 9.0m is classified clayey sand: slightly light brown clayey sand with little gravel (Kurkar), with some fines (26.5%). The WC is 10.5%. The layer is of medium plasticity. Depth from 8.70m up to end of BH is sand: yellowish fine sand with little gravel (Kurkar) and a little fines (3.3%), the soil layer is non-plastic, WC ranged from 4.2%-6%. Summary of the soil classification for BH2 is shown in Table 5-2.

**Table 5-2:** Soil Classification for BH2

| Depth (m) | Soil Description | Soil Classification | Fines Content (%) | WC (%) |
|---|---|---|---|---|
| 0-0.6 | Sand: yellowish fine sand with little gravel (Kurkar) and a little fines. | SP-SM | 6.3 | 11.4 |
| 0.6-1.5 | Clayey Sand: slightly brown clayey sand with little gravel (Kurkar) and some fines. | SC | 18.2-27.7 | 14.2-15.6 |
| 1.5-8.7 | Sand: yellowish fine sand with little gravel (Kurkar) and a little fines. | SP-SM | 4.6-9.6 | 5.6-10.5 |
| 8.7-9.0 | Clayey Sand: slightly brown clayey sand with little gravel (Kurkar) and some fines. | SC | 26.5 | 10.5 |
| 9.0-12.0 | Sand: yellowish fine sand with little gravel (Kurkar) and a little fines. | SP | 3.3 | 4.2-6 |

#### 5.1.1.3 Grain Size Analysis for Bore Hole BH3

The bore hole log for BH3 shows that the top soil layer form depth 0.0-0.30m is sand: yellowish fine sand with little gravel (Kurkar) and a little fines (13.8%), the soil layer is non-plastic. The percentage of water content WC is 12.8%. The depth from 0.30-1.20m is classified as clayey sand: light brown clayey sand with little gravel (Kurkar) and some fines (22.9%-39.9%). The layer is of low to medium plasticity, with WC ranged from 12.1%-15.6%. The depth from 1.2m until the depth of 6.5m is sand: yellowish fine sand with little gravel (Kurkar) and a little fines (9.1%-11.6%). The layer is non-plastic, with WC ranged from 6.8% to 9.0%. The depth from 6.50m up to 7.4m is classified sandy silty clay: dark brown sandy clay with little gravel (Kurkar). The layer is of medium plasticity. Fines content 55.6%, WC is 17.9%. The depth from 7.4m to the end of BH is sand: yellowish fine sand with little gravel (Kurkar) and a little fines (2.3%-6.8%), the soil layer is non-plastic, WC ranged from 3.5%-4.2%. Summary of the soil classification for BH3 is shown in Table 5-3.

**Table 5-3:** Soil Classification for BH3

| Depth (m) | Soil Description | Soil Classification | Fines Content (%) | WC (%) |
|---|---|---|---|---|
| 0-0.3 | Sand: yellowish fine sand with little gravel (Kurkar) and a little fines. | SM | 13.8 | 12.8 |
| 0.3-1.2 | Clayey Sand: light brown clayey sand with little gravel (Kurkar) and some fines. | SM-SC | 22.9-39.9 | 12.1-15.6 |
| 1.2-6.5 | Sand: yellowish fine sand with little gravel (Kurkar) and a little fines. | SP-SM | 9.1-11.6 | 6.8-9.0 |
| 6.5-7.4 | Sandy Silty Clay: dark brown sandy clay sand with little gravel (Kurkar) and some fines. | CL | 55.6 | 17.9 |
| 7.4-12.0 | Sand: yellowish fine sand with little gravel (Kurkar) and a little fines. | SP-SM | 2.3-6.8 | 3.5-4.2 |

#### 5.1.1.4 Grain Size Analysis for Bore Hole BH4

The bore hole log for BH4 shows that the top soil layer form depth 0.0-0.60m is sand: yellowish fine sand with little gravel (Kurkar) and a little fines (5.4%-8.7%), the soil layer is non-plastic. The percentage of water content WC is ranged from (7.2-9.2%). The depth from 0.60-0.9m is classified as clayey sand: light brown clayey sand with little gravel (Kurkar) and some fines (21.3%). The layer is of low to medium plasticity, with WC of 7.7%. The depth from 0.9-1.5m is sand: yellowish fine sand with little gravel (Kurkar) and a little fines (6.8%-10.8%). The layer is non-plastic, with WC ranged from (6.2% to 7.8%). The depth from 1.50m up to 1.8m is classified clayey sand: slightly light brown clayey sand with little gravel (Kurkar), fines content 20.70%. The layer is of low plasticity, and WC is 5.1%. The depth from 1.8m to the end of BH is sand: yellowish fine sand with little gravel (Kurkar) and a little fines (2.1%-11.4%), the soil layer is non-plastic, WC ranged from (4.7%-7.6%). Summary of the soil classification for BH4 is shown in Table 5-4.

**Table 5-4:** Soil Classification for BH4

| Depth (m) | Soil Description | Soil Classification | Fines Content (%) | WC (%) |
|---|---|---|---|---|
| 0-0.6 | Sand: yellowish fine sand with little gravel (Kurkar) and a little fines. | SP-SM | 5.4-8.7 | 7.2-9.2 |
| 0.6-0.9 | Clayey Sand: light brown clayey sand with little gravel (Kurkar) and some fines. | SC | 21.3 | 7.7 |
| 0.9-1.5 | Sand: yellowish fine sand with little gravel (Kurkar) and a little fines. | SP-SM | 6.8-10.8 | 6.2-7.8 |
| 1.5-1.8 | Clayey Sand: slightly light brown clayey sand with little gravel (Kurkar) | SC | 20.7 | 5.1 |
| 1.8-12.0 | Sand: yellowish fine sand with little gravel (Kurkar) and a little fines. | SP-SM | 2.1-11.4 | 4.7-7.6 |

#### 5.1.1.5 Grain Size Analysis for Bore Hole BH5

The bore hole log for BH5 shows that the top soil layer form depth 0.0-0.30m is clayey sand: slightly dark brown clayey sand with little gravel (Kurkar), fines content 31.5%. The layer is of medium plasticity, and WC is 12.3%. Depth from 0.3-0.6m is classified as sand: yellowish fine sand with little gravel (Kurkar) and a little fines (6.1%), the soil layer is non-plastic. The percentage of water content WC is 5.8%. The depth from 0.60-0.9m is classified as clayey sand: light brown clayey sand with little gravel (Kurkar) and some fines (26.5%). The layer is of medium plasticity, with WC of 11.0%. The depth from 0.9-1.5m is sand: yellowish fine sand with little gravel (Kurkar) and a little fines (5.3%-6.1%). The layer is non-plastic, with WC ranged from (5.5% to 5.9%). The depth from 1.50m up to 1.8m is classified clayey sand: slightly light brown clayey sand with little gravel (Kurkar), fines content 23.40%. The layer is of medium plasticity, and WC is 9.6%. The depth from 1.8m up to 8.0m is sand: yellowish fine sand with little gravel (Kurkar) and a little fines (2.3%-5.0%), the soil layer is non-plastic, WC ranged from (3.3%-7.5%). The depth from 8.0- 9.0m is clayey sand: slightly light brown clayey sand with little gravel (Kurkar), fines content 20.3%. The layer is of low plasticity, and WC is 3.4%. Finally, depth from 9.0m up to the end of BH is sand: yellowish fine sand with little gravel (Kurkar) and a little fines (2.1%-3.2%), the soil layer is non-plastic, WC ranged from (3.5%-4.0%).

BH Summary of the soil classification for BH5 is shown in Table 5-5.

**Table 5-5:** Soil Classification for BH5

| Depth (m) | Soil Description | Soil Classification | Fines Content (%) | WC (%) |
|---|---|---|---|---|
| 0-0.3 | Clayey Sand: slightly dark brown clayey sand with little gravel (Kurkar). | SC | 31.5 | 12.3 |
| 0.3-0.6 | Sand: yellowish fine sand with little gravel (Kurkar) and a little fines. | SP-SM | 6.1 | 5.8 |
| 0.6-0.9 | clayey sand: light brown clayey sand with little gravel (Kurkar) and some fines. | SC | 26.5 | 11.0 |
| 0.9-1.50 | Sand: yellowish fine sand with little gravel (Kurkar) and a little fines. | SP-SM | 5.3-6.1 | 5.5-5.9 |
| 1.5-1.8 | clayey sand: slightly light brown clayey sand with little gravel (Kurkar), fines content. | SC | 23.4 | 9.6 |
| 1.80-8.0 | Sand: yellowish fine sand with little gravel (Kurkar) and a little fines. | SP | 2.3-5.0 | 3.3-7.5 |
| 8.0-9.0 | clayey sand: slightly light brown clayey sand with little gravel (Kurkar), fines content | SC | 20.3 | 3.4 |
| 9.0-12.0 | Sand: yellowish fine sand with little gravel (Kurkar) and a little fines. | SP | 2.1-3.2 | 3.5-4.0 |

### 5.1.2 Discussion of Grain Size Analysis Test Results for Bore Holes (1-5)

According to the USCS classification system, the bore holes indicated that the soil strata in the infiltration basin IB1 consists the following layers (soil types):

- **Sand:** is a poorly graded Sand, dim yellowish with little gravel (Kurkar) exist at depths as indicated in the soil logs in the appendix (2). It contains (85%-100%) Sand, (1%-19%) % gravel, and a little fines contents (0%-15%). The layer is non-plastic and has good permeability characteristics.
- **Clayey Sand:** is a poorly graded Clayey Sand, Slightly light brown with little gravel (Kurkar) exist at depths as indicated in the soil logs in the appendix (2). The layer is of low to medium plasticity, contains (3%-10%) gravel, (60%-85%) sand, and (15%-40%) fines. This layer is of low permeability.
- **Sandy Silty Clay:** is well graded sandy silty clay, dark brown sandy clay with little gravel (kurkar). The layer is of medium plasticity, and contains (3%) gravel, (1-33%) sand, (12%-28%) silt, and (16%) clay. This layer is of low permeability as shown in Figure 4, and Figure 5.

According to Taylor & Ashcroft, 1972, sandy soils have the highest infiltration rates and clayey soils have the lowest infiltration rates, Figure 5-4 and Figure 5-5 illustrate soil type effects on infiltration rate.

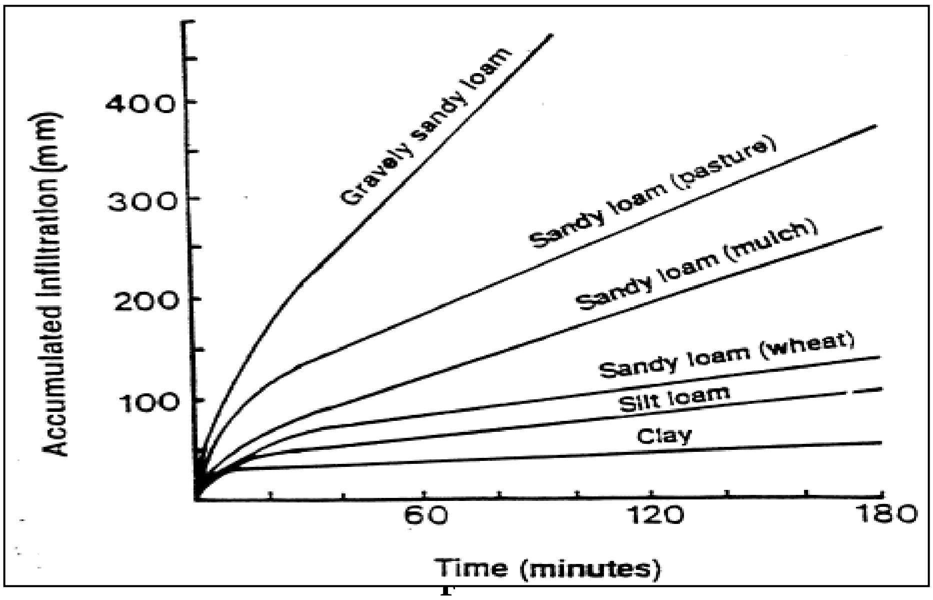


**Figure (5-4):** Soil type effects on accumulated infiltration (Taylor & Ashcroft, 1972)

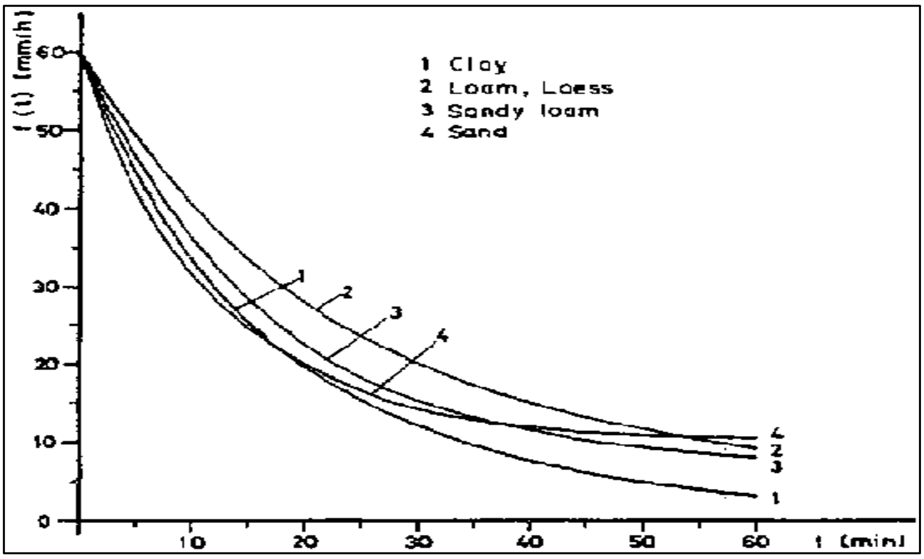


**Figure (5-5):** Soil type effects on infiltration rate (Taylor & Ashcroft, 1972)

### 5.1.3 Permeability Test Results for the Bore Holes from (1-5)

The hydraulic conductivity K was estimated according to Hazen equation, as stated previously in Chapter 2, section 2.5.3. Table 5-6 illustrates the estimated hydraulic conductivity K for the different soil types for soil samples which taken from bore holes (1-5).

**Table 5-6:** Estimated hydraulic conductivity K for the testing soil samples

| **Estimated hydraulic conductivity (K)** | | | | | |
|---|---|---|---|---|---|
| **Depth (m)** | **BH1 (m/d)** | **BH2 (m/d)** | **BH3 (m/d)** | **BH4 (m/d)** | **BH5 (m/d)** |
| 0.3 | 2.68 | 6.14 | 2.73 | 5.18 | 0.04 |
| 0.6 | 0.26 | 4.85 | 0.20 | 6.86 | 6.18 |
| 0.9 | 0.09 | 1.93 | 0.19 | 0.29 | 0.09 |
| 1.2 | 3.46 | 0.08 | 0.02 | 4.03 | 6.13 |
| 1.5 | 5.59 | 0.09 | 4.12 | 5.81 | 5.94 |
| 1.8 | 6.92 | 4.83 | 4.78 | 0.34 | 0.17 |
| 2.1 | 5.44 | 5.49 | 4.76 | 6.57 | 2.18 |
| 3 | 5.05 | 5.38 | 4.96 | 4.10 | 7.27 |

| Estimated hydraulic conductivity (K) | | | | | |
|---|---|---|---|---|---|
| Depth | BH1 | BH2 | BH3 | BH4 | BH5 |
| (m) | (m/d) | (m/d) | (m/d) | (m/d) | (m/d) |
| 4 | 5.24 | 6.26 | 2.98 | 5.35 | 7.47 |
| 5 | 5.26 | 5.58 | 2.35 | 5.55 | 7.14 |
| 6 | 6.16 | 5.76 | 3.61 | 6.20 | 8.15 |
| 7 | 6.59 | 5.94 | 0.01 | 3.71 | 6.07 |
| 8 | 6.43 | 6.26 | 7.10 | 5.57 | 6.34 |
| 9 | 6.88 | 0.92 | 6.09 | 6.42 | 0.38 |
| 10 | 5.61 | 7.13 | 6.32 | 6.09 | 7.33 |
| 11 | 5.76 | 6.81 | 7.19 | 7.57 | 7.03 |
| 12 | 7.02 | 8.99 | 7.17 | 7.15 | 7.12 |

According to Table 5-6, the values of hydraulic conductivity ranged between 0.01m/d, and 8.99m/d. According to Table 2-4 in Chapter 2, the range of estimated hydraulic conductivity is laid between the classification sand medium and clay.

**(Todd and Mays, 2005)**, stated that the hydraulic conductivity of a soil depends on a variety physical factors, including porosity, particle size and distribution, shape of particles, arrangement of particles, and other factors. In general, for unconsolidated pours media, hydraulic conductivity varies with particle size; clayey material exhibit low values, where sands and gravel display high values. Figure 5-6 showing the variation of hydraulic conductivity with depth.

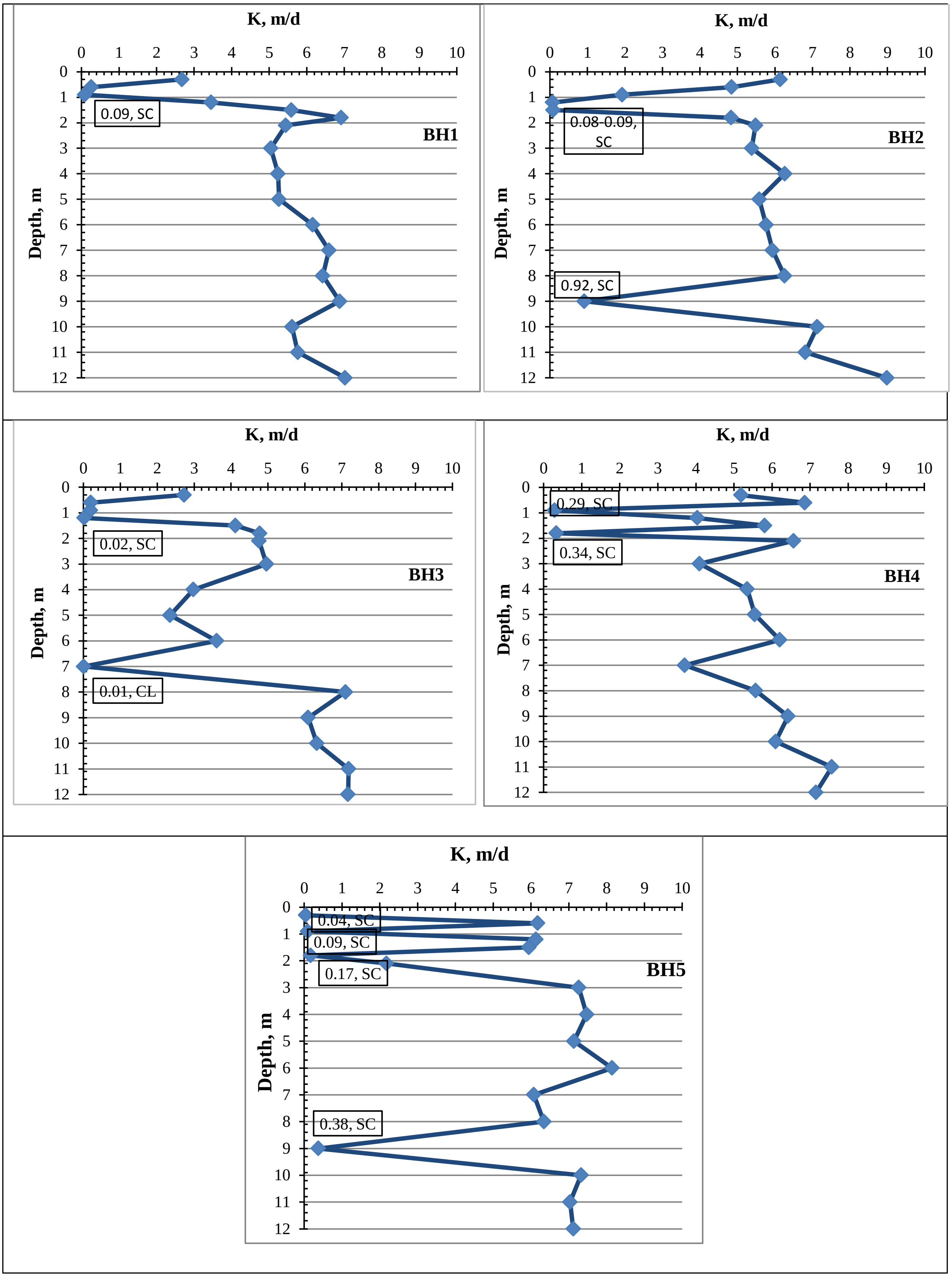


**Figure (5-6):** Variation of HC (K) according to Soil Depth for Bore Holes (1-5)

### 5.1.4 Results of Soil Quality Tests

#### 5.1.4.1 Organic Matter Test Results

Organic Matter is the carbonaceous material contained in plants or animals and wastes. Organic matter is oxygen-demanding substances, and BOD is a measure of oxygen consumed in biological processes that break down organic matter **(EPA, 2004).**

According to the test results, OM was found at variable depths with variable rates, Table 5-7 shows OM test results for bore holes from (1-5). The explanation of the existence of OM in the soil is that the BOD load resulting from the partially treated wastewater still high. The organic loads which are expressed by BOD and COD in the waste water are considered the main problems and pollutants in the recharged water. The organic load causes the following **(El Arabi, 2012)**:

- Increasing the organic matter content in the soil.
- Decreasing the infiltration rate of the soil by time.

**Table 5-7**: Organic Matter Test Results

| Organic Matter (%) | | | | | |
|---|---|---|---|---|---|
| **Depth (m)** | **BH1** | **BH2** | **BH3** | **BH4** | **BH5** |
| 0.3 | 0.5 | 0.5 | 0.7 | 0.9 | 0.9 |
| 0.6 | 0.4 | 0.3 | 0.8 | 0.7 | 0.7 |
| 0.9 | 0.2 | 0.7 | 0.7 | 0.8 | 0.8 |
| 1.2 | 0.1 | 0.6 | 0.8 | 0.2 | 0.5 |
| 1.5 | 0.0 | 0.4 | 0.3 | 0.2 | 0.4 |
| 1.8 | 0.0 | 0.4 | 0.1 | 0.2 | 0.5 |
| 2.1 | 0.0 | 0.4 | 0.2 | 0.2 | 0.6 |

In general the OM still with low values and will affect soil hydraulic conductivity or the infiltration rate. Figure 5-7 showing the variation of OM with depth.

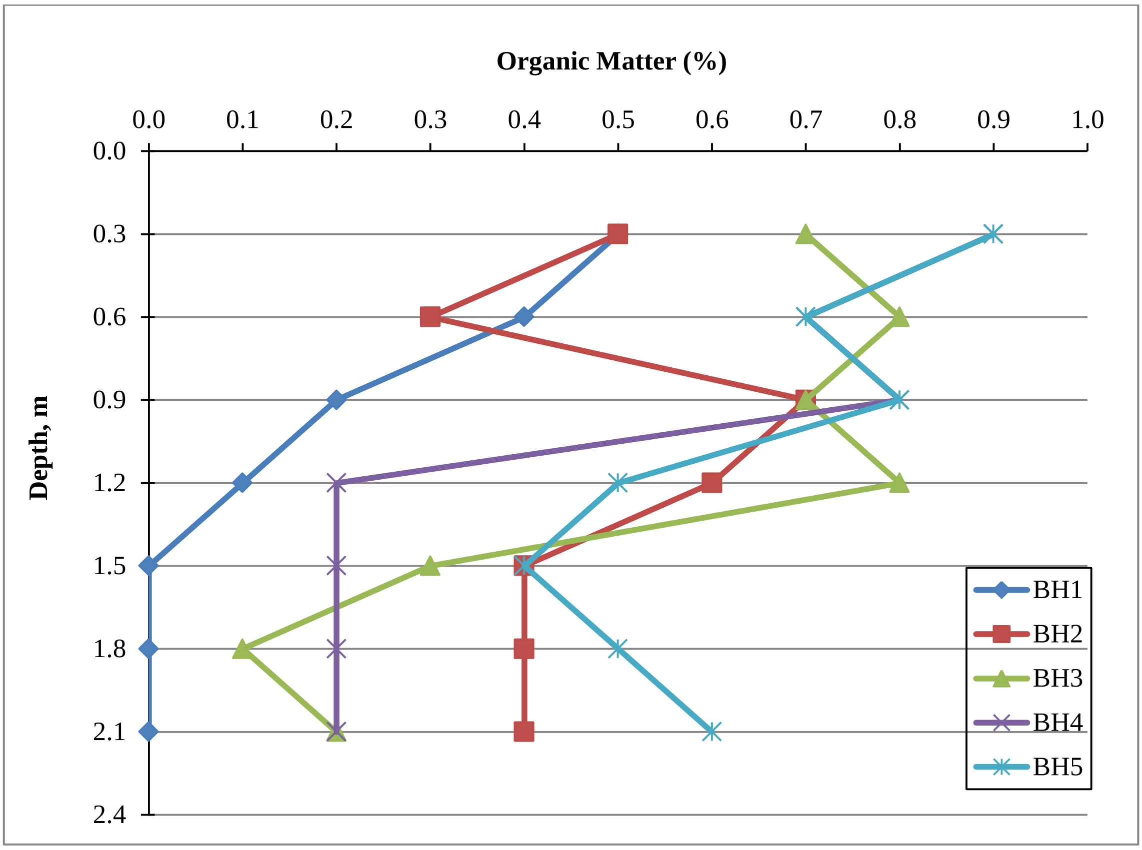


**Figure (5-7):** Organic Matter Test Results for Bore Holes (1-5)

### 5.1.4.2 SAR Test Results

SAR Tests results for each bore hole are shown in Tables (5-8 to 5-12).

**Table 5-8:** SAR, test results for bore hole (1)

| Depth M | Ca mg/kg | Mg mg/kg | Na mg/kg | Ca meq/kg | Mg meq/kg | Na meq/kg | SAR |
|---|---|---|---|---|---|---|---|
| 0.30 | 3607 | 2067 | 500 | 180.35 | 172.25 | 21.74 | 1.64 |
| 0.60 | 3848 | 2159 | 300 | 192.4 | 179.92 | 13.04 | 0.96 |
| 0.90 | 3928 | 2038 | 300 | 196.4 | 169.83 | 13.04 | 0.97 |
| 1.20 | 4329 | 1732 | 300 | 216.45 | 144.33 | 13.04 | 0.97 |
| 1.50 | 3928 | 1819 | 150 | 196.4 | 151.58 | 6.52 | 0.50 |
| 2.10 | 3687 | 1844 | 100 | 184.35 | 153.67 | 4.36 | 0.34 |

**Table 5-9:** SAR, test results for bore hole (2)

| Depth M | Ca mg/kg | Mg mg/kg | Na mg/kg | Ca meq/kg | Mg meq/kg | Na meq/kg | SAR |
|---|---|---|---|---|---|---|---|
| 0.30 | 3607 | 1941 | 200 | 180.35 | 161.75 | 8.70 | 0.67 |
| 0.60 | 3848 | 1722 | 160 | 192.4 | 143.50 | 6.96 | 0.54 |
| 0.90 | 3968 | 1965 | 300 | 198.4 | 163.75 | 13.04 | 0.97 |
| 1.20 | 3607 | 2402 | 300 | 180.35 | 200.17 | 13.04 | 0.95 |
| 1.50 | 4008 | 2329 | 300 | 200.4 | 194.08 | 13.04 | 0.93 |
| 1.80 | 3848 | 1989 | 180 | 192.4 | 165.75 | 7.83 | 0.59 |
| 2.10 | 3848 | 2023 | 150 | 192.4 | 168.58 | 6.52 | 0.49 |

**Table 5-10:** SAR, test results for bore hole (3)

| Depth M | Ca mg/kg | Mg mg/kg | Na mg/kg | Ca meq/kg | Mg meq/kg | Na meq/kg | SAR |
|---|---|---|---|---|---|---|---|
| 0.30 | 4409 | 2086 | 320 | 220.45 | 173.83 | 13.91 | 0.99 |
| 0.60 | 4569 | 2183 | 250 | 228.45 | 181.92 | 10.87 | 0.76 |
| 0.90 | 4569 | 2135 | 280 | 228.45 | 177.92 | 12.17 | 0.86 |
| 1.20 | 4890 | 2135 | 400 | 244.5 | 177.92 | 17.39 | 1.20 |
| 1.50 | 4168 | 2086 | 220 | 208.4 | 173.83 | 9.57 | 0.69 |
| 1.80 | 4008 | 2086 | 160 | 200.4 | 173.83 | 6.96 | 0.51 |
| 2.10 | 4008 | 2038 | 190 | 200.4 | 169.83 | 8.26 | 0.61 |

**Table 5-11:** SAR, tests results for bore hole (4)

| Depth M | Ca mg/kg | Mg mg/kg | Na mg/kg | Ca meq/kg | Mg meq/kg | Na meq/kg | SAR |
|---|---|---|---|---|---|---|---|
| 0.30 | 4008 | 1989 | 170 | 200.4 | 165.75 | 7.39 | 0.55 |
| 0.60 | 4008 | 1795 | 160 | 200.4 | 149.58 | 6.96 | 0.53 |
| 0.90 | 3848 | 2038 | 160 | 192.4 | 169.83 | 6.96 | 0.52 |
| 1.20 | 3367 | 1941 | 140 | 168.35 | 161.75 | 6.09 | 0.48 |
| 1.50 | 3607 | 1990 | 100 | 180.35 | 165.83 | 4.35 | 0.33 |
| 1.80 | 4008 | 1941 | 110 | 200.4 | 161.75 | 4.78 | 0.36 |
| 2.10 | 3928 | 1989 | 100 | 196.4 | 165.75 | 4.35 | 0.32 |

**Table 5-12:** SAR, tests results for bore hole (5)

| Depth M | Ca mg/kg | Mg mg/kg | Na mg/kg | Ca meq/kg | Mg meq/kg | Na meq/kg | SAR |
|---|---|---|---|---|---|---|---|
| 0.30 | 4088 | 2184 | 400 | 204.4 | 182.00 | 17.39 | 1.26 |
| 0.60 | 3848 | 1941 | 140 | 192.4 | 161.75 | 6.09 | 0.46 |
| 0.90 | 4409 | 1892 | 260 | 220.45 | 157.67 | 11.30 | 0.82 |
| 1.20 | 4008 | 1989 | 300 | 200.4 | 165.75 | 13.04 | 0.97 |
| 1.50 | 4409 | 1892 | 120 | 220.45 | 157.67 | 5.22 | 0.38 |
| 1.80 | 4409 | 2329 | 250 | 220.45 | 194.08 | 10.87 | 0.76 |
| 2.10 | 4248 | 2111 | 250 | 212.4 | 175.92 | 10.87 | 0.78 |

SAR test results shows that the rate of SAR is less than 2. According to section 2.3.6, Sodium Absorption Rate (SAR), Chapter 2, Table 2-2, SAR < 13, which means that the soil physical condition is normal. Accordingly SAR will not affect the infiltration rate. Figure 5-8 showing the variation of SAR with depth.

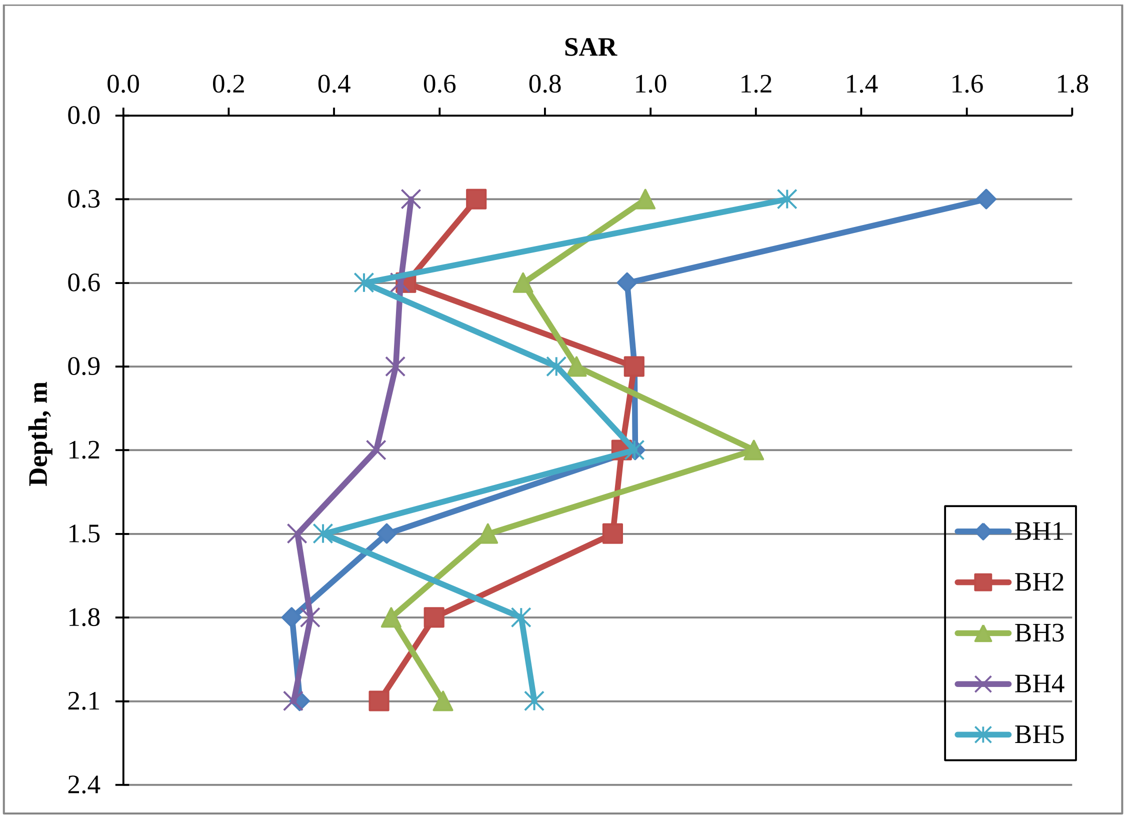


**Figure (5-8):** Organic Matter Test Results for Bore Holes (1-5)

### 5.1.5 Results of Water Quality Tests

The historical records of water quality results for the influent to the infiltration basin (Grab samples) for the first round are shown in Table 5-13. Infiltration basin IB4 was empty during the period of collecting samples which began on 30.06.2013 and finished on 24.07.2013. The PH, Temperature, and Hardness were not tested during the first round period.

With comparing contaminant strength among different infiltration basins, the extreme difference of BOD and COD (there are no limits for the COD in the design criteria) concentration values refer to the accumulation of pollutants at the basins which mean that the samples are not representative (wrong sampling), also it may refer to the poor performance of BLWWTP. According to the design criteria done by SWECO international, 2003, the BOD concentration is still out of range (10-20mg/l), and accordingly; the BOD and COD (150mg/l according to the Palestinian Standards for Treated Wastewater) concentration are not suitable for the infiltration purposes.

Figure 5-9 illustrate the variation of BOD, and COD concentration in the influent to the basins.

**Table 5-13:** Water Quality Tests Results (PWA, 1st Round Report, 2013)

| Location | BOD(mg/l) | COD(mg/l) | TSS(mg/l) | TC(n/100ml) |
|---|---|---|---|---|
| IB1 | 100 | 320 | 78 | 120 |
| IB2 | 480 | 2000 | 295 | 1500 |
| IB3 | 480 | 2200 | 145 | 5 |
| IB4 | - | - | - | - |
| IB5 | 120 | 270 | 255 | 1900 |
| IB6 | 310 | 720 | 180 | $5x10^4$ |
| IB7 | 270 | 540 | 22 | $10x10^4$ |
| IB8 | 370 | 770 | 170 | $10x10^4$ |
| IB9 | 200 | 400 | 250 | 45 |

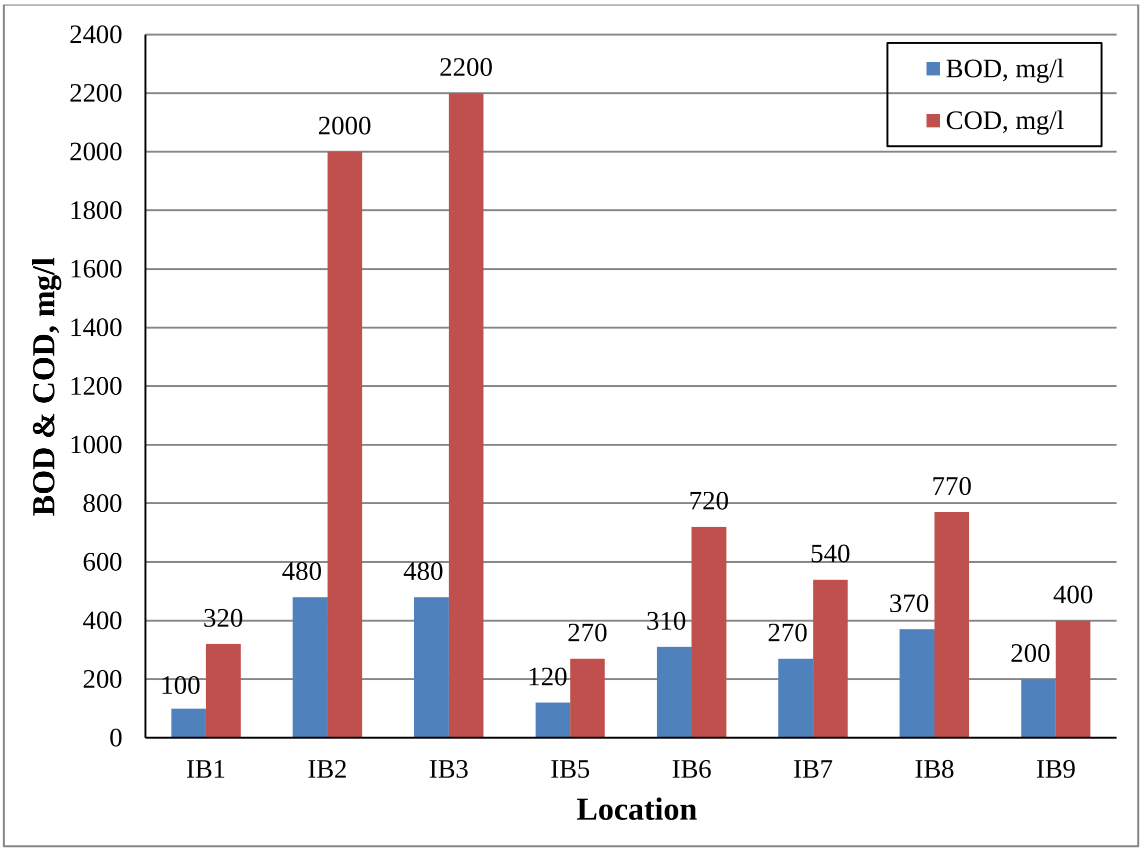


**Figure (5-9):** Concentration of BOD and COD in the influent to the Basins

As per design criteria the suspended solids ranged 15-20 mg/l (SWECO,2003). The TSS concentration for the basins ranged from 22 at IB7 to 295 mg/l at IB2. The high concentration of TSS may refer to wrong sampling, and to the poor performance of BLWWTP. The TSS concentration still out of the design criteria. Accordingly, the TSS concentration is not suitable for the infiltration process. Figure 5-10 shows the concentration of TSS in the influent to the infiltration basins. Historical utilization of infiltration basins for partially treated effluent with high TSS might have been the reason for diminishing the infiltration capacity of the top soil layer of the basin.

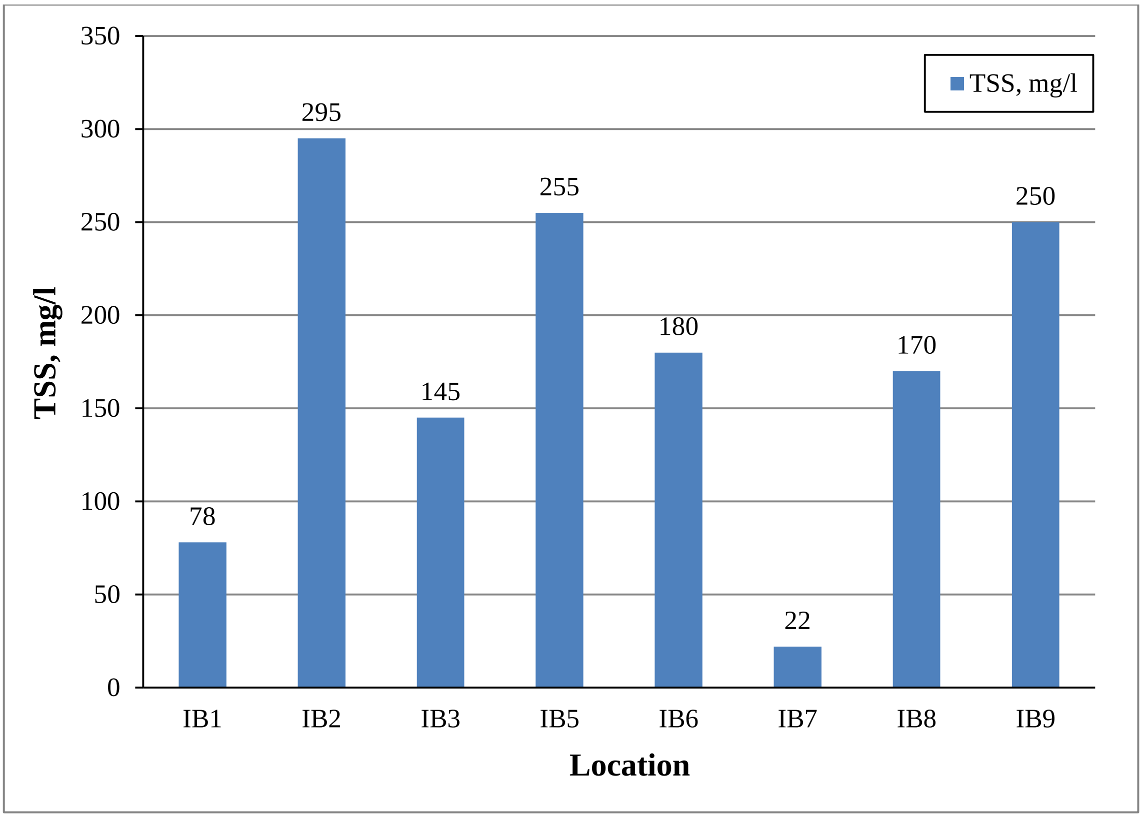


**Figure (5-10):** Concentration of TSS in the influent to the Basins

The concentration of FC ranged from 0 (No/100 ml) to 1700 (No/100 ml) According to the design criteria the Fecal coliform (FC) should be < 200 No/100 ml **(SWECO, 2003).** As the treated wastewater will infiltrate to the aquifer; the concentration of FC should be less than the design criteria in all the basins. TC ranged concentration ranged from 5 (No/100 ml) to 100,000 (No/100 ml) and the values still high even though there are some values still less than the FC value as per design criteria. The variation of FC and TC concentration at the basins is refere to differnet influent batches from BLWWTP, and to the poor treatemnt effeicncy also it may refer to wrong sampleing. In genral the vlaues of FC and TC are not good for the infiltration purposes according to the design criteria and to the Palestinian standard (100-1000 No/100 ml). Figure 5-11 and 5-12 showing the values of FC, and TC at the basins.

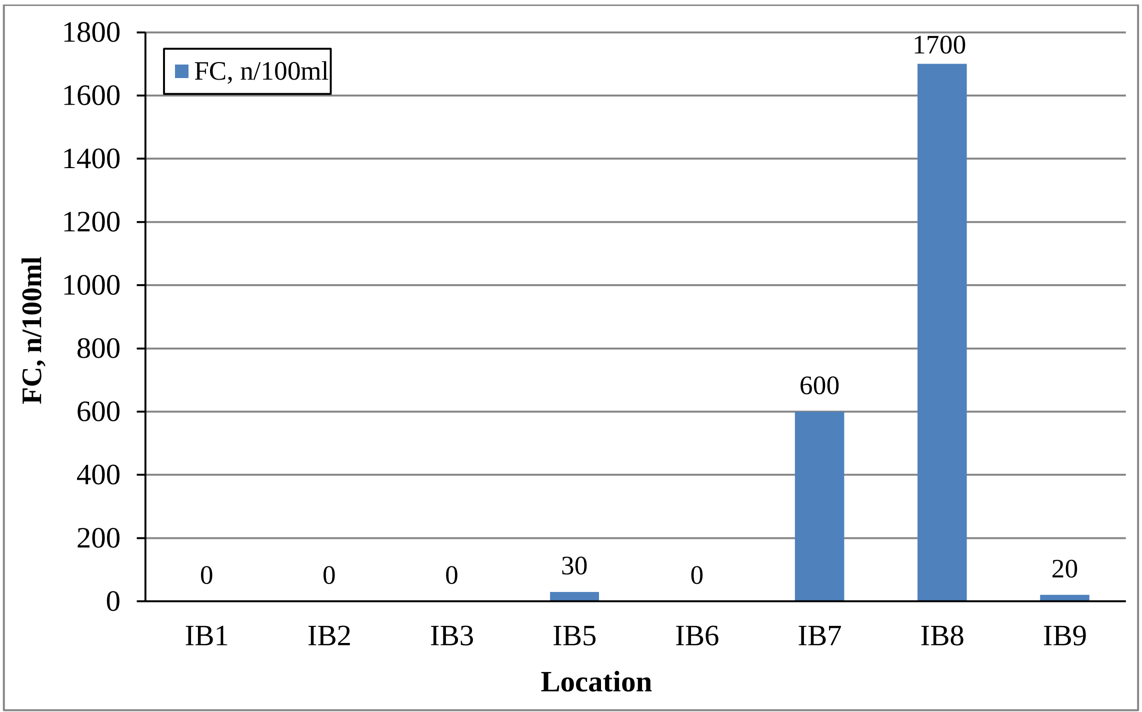


**Figure (5-11):** Concentration of FC in the Influent to the Basins

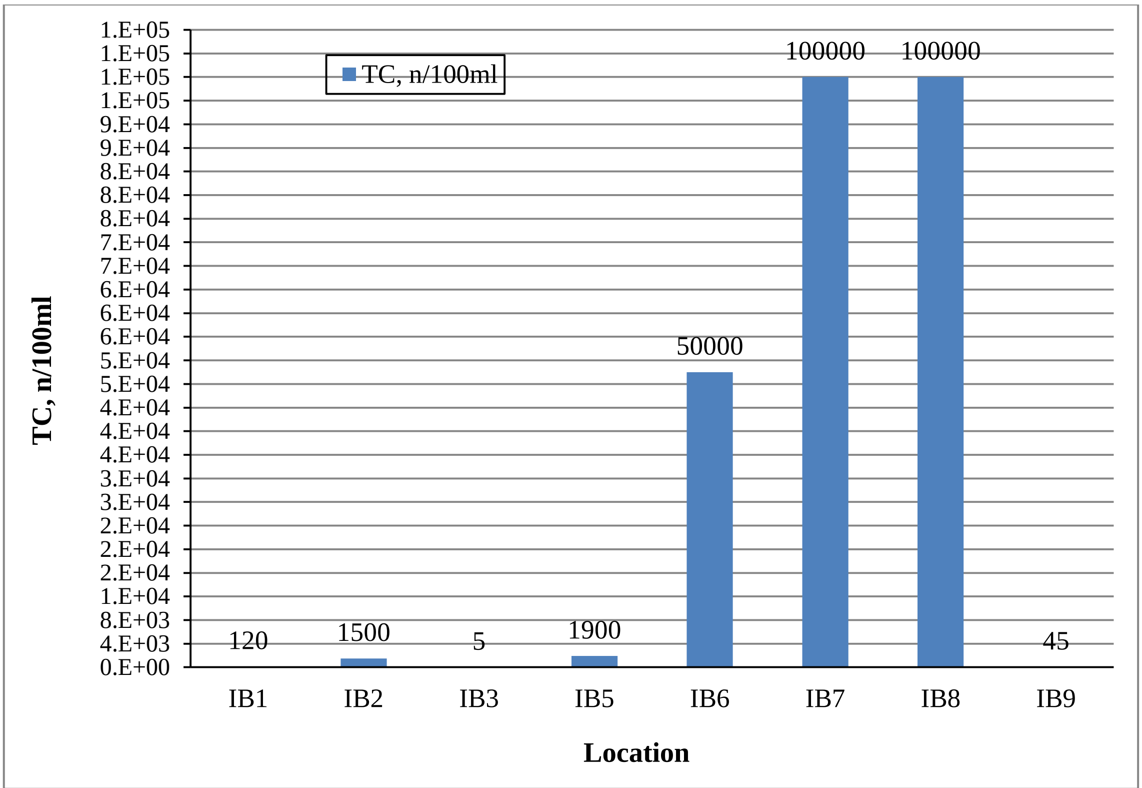


**Figure (5-12):** Concentration of TC in the Influent to the Basins

Table 5-14 shows comparsion between the influent quality to the IB1, the design criteria, and the Palestinina Sandrd (PS) for treated wastewater. Figure 5-13 to Figure 5-15 illustrating the influent qualtiy with refernece to the design criteria and PS.

**Table 5-14:** Influent Quality with referenc to Desing criteria and PS

| Description | BOD(mg/l) | COD(mg/l) | TSS(mg/l) | FC (No/100ml) |
|---|---|---|---|---|
| IB1 | 100 | 320 | 78 | 0 |
| Design Criteria | 10-20 | - | 15-20 | < 200 |
| PS | 40 | 150 | 50 | 1000 |

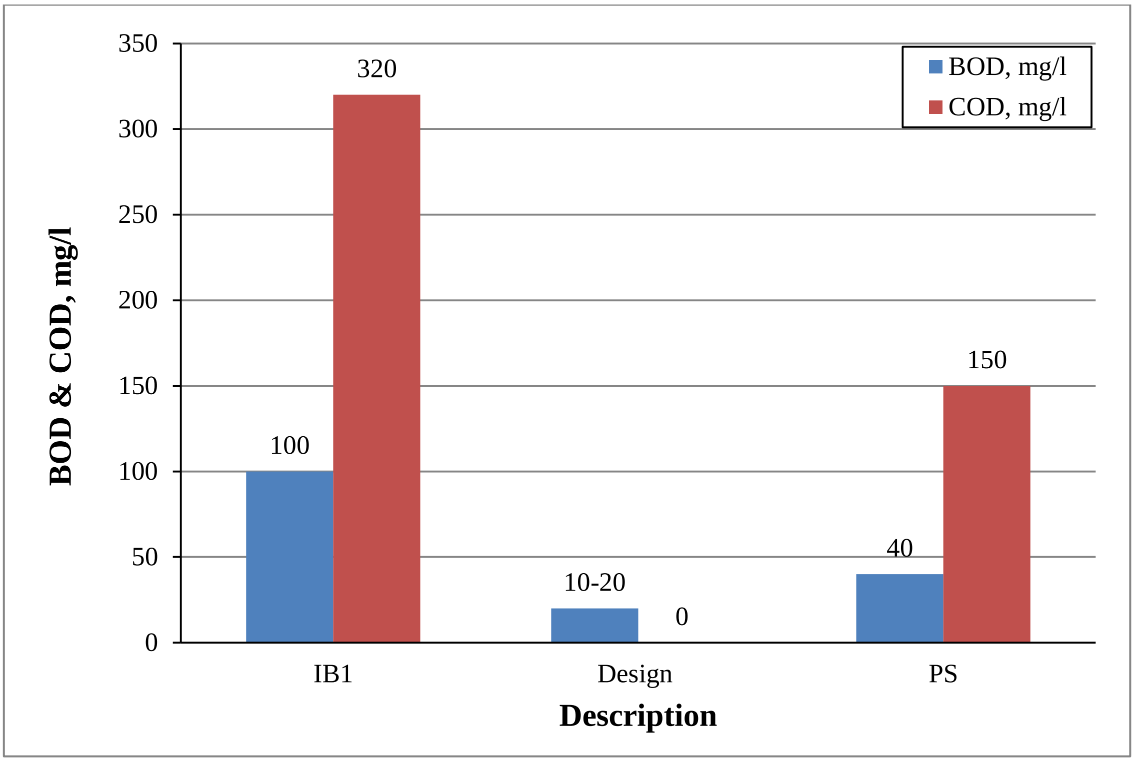


**Figure (5-13):** BOD & COD concentration with reference to Design Criteria & PS

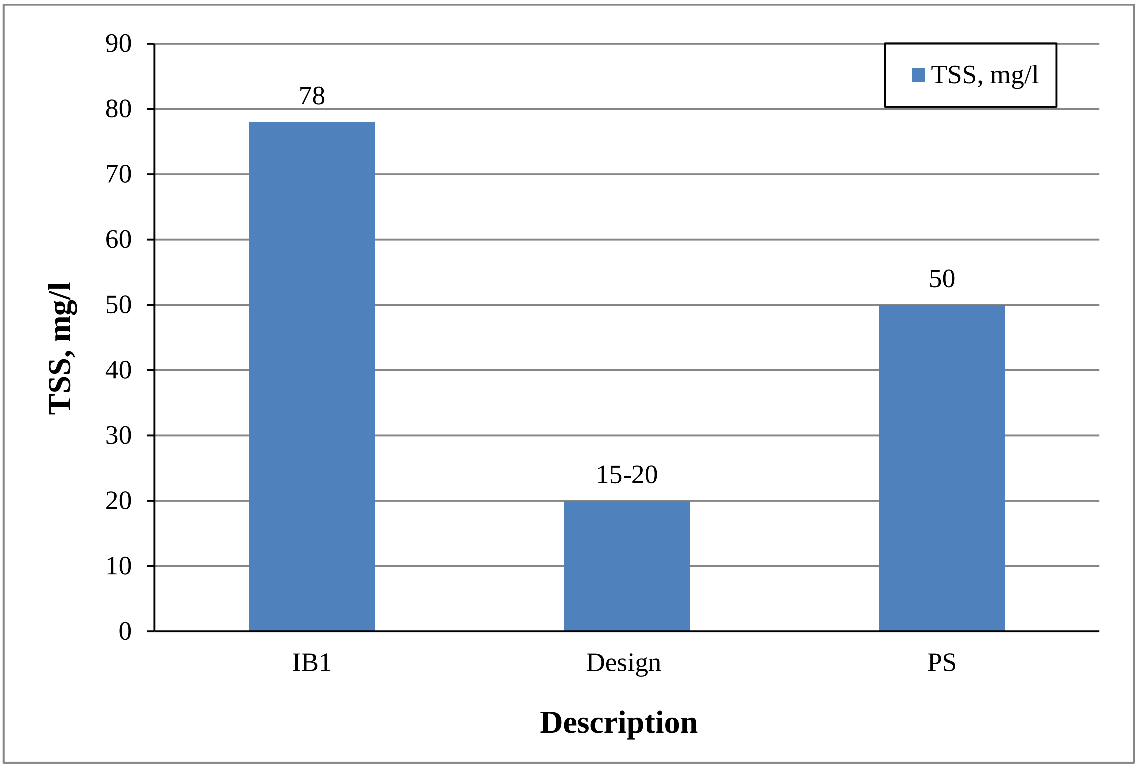


**Figure (5-14):** TSS concentration with reference to Design Criteria & PS

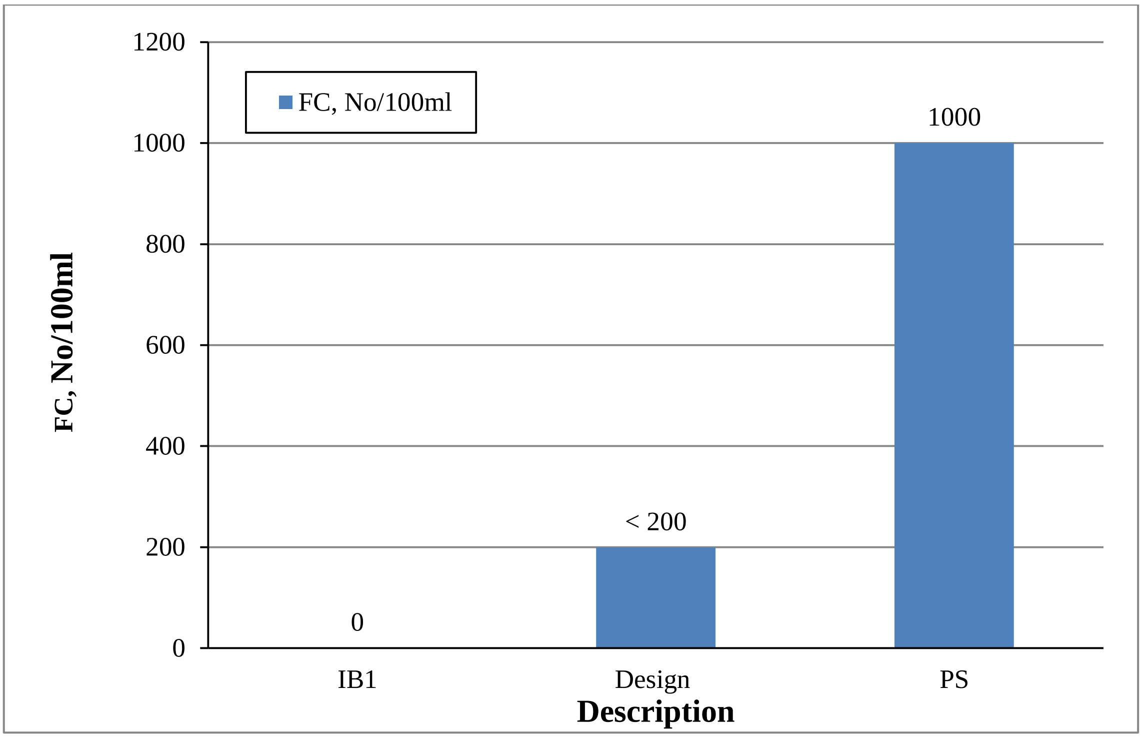


**Figure (5-15):** FC concentration with reference to Design Criteria & PS

## 5.2 Modeling of the Unsaturated Zone

### 5.2.1 Introduction

This chapter represents the modeling of the unsaturated zone for the exiting infiltration regime, and modeling for enhancement of the infiltration rate for IB1 by using the Green-Ampt infiltration model (1911). The Green-Ampt model is a more physical approach to computing infiltration losses. It is derived from physical parameters such as hydraulic conductivity, soil moisture, and capillary suction. Because of its simplicity and versatility, the Green-Ampt model is becoming more frequently used in models for determining infiltration **(Smemoe, et al., 2003).** The Green-Ampt infiltration model developed from an approximate theory to an exact solution **(Maidment, 2010).**

As explained previously in Chapter 2, section 2.5 the Green- Ampt infiltration equations for cumulative infiltration (equation 2.4), and for infiltration rate (equation 2.5) are:

$$F(t) = Kt + \psi\Delta\theta \ln\left(1 + \frac{F(t)}{\psi\Delta\theta}\right), \text{ cm.}$$

$$f = K\left(1 + \psi\frac{\Delta\theta}{F}\right), \text{ cm/hr.}$$

The modeling domain for the unsaturated zone for the existing infiltration regime, and the modeling domain for enhancement of the infiltration rate for IB1 will be performed for the upper two meters for the soil layer. The soil parameters used in computing the cumulative infiltration and the infiltration rate were taken from the laboratory soil tests results as discussed previously in this Chapter, and from Table (2-3): Green-Ampt infiltration parameters for various soil classes**.**

Since cumulative infiltration is non-linear equation, which requiring iterative solution to solve it; Excel Solver was used to solve the equation. More details are clear in appendix (3).

### 5.2.2 Modeling the existing Infiltration Regime for IB1

Many trials was performed using different hydraulic conductivities and different soil parameters to calculate the cumulative infiltration and the infiltration rate for the existing infiltration regime in order to predict the model which describes the real infiltration rate recorded by PWA. Table 5-15 and Table 5-16 showing the behavior of cumulative infiltration and infiltration rate with time for the first and second trials. Figure 5-16, Figure 5-17 and Figure 5-18 are the representation for the infiltration with time for the same trials.

#### 5.2.2.1 First Model with Minimum K (0.042cm/hr) in IB1

**Table 5-15:** F (t) & *f* at K= 0.042*cm/hr*

| *t (hr)* | F *(cm)* | *f (cm/hr)* | *f (m/d)* |
|---|---|---|---|
| 0.0 | 0 | ∞ | ∞ |
| 0.1 | 0.203 | 1.073 | 0.258 |
| 0.2 | 0.289 | 0.767 | 0.184 |
| 0.3 | 0.371 | 0.608 | 0.146 |
| 0.4 | 0.425 | 0.535 | 0.128 |
| 0.5 | 0.474 | 0.484 | 0.116 |
| 1 | 0.679 | 0.351 | 0.084 |
| 1.1 | 0.712 | 0.337 | 0.081 |
| 1.2 | 0.743 | 0.324 | 0.078 |
| 1.3 | 0.774 | 0.313 | 0.075 |
| 1.4 | 0.803 | 0.303 | 0.073 |
| 1.5 | 0.839 | 0.292 | 0.070 |
| 2 | 0.970 | 0.258 | 0.062 |
| 2.5 | 1.094 | 0.233 | 0.056 |
| 3 | 1.207 | 0.216 | 0.052 |
| 3.5 | 1.312 | 0.202 | 0.048 |
| 4 | 1.411 | 0.190 | 0.046 |
| 4.5 | 1.504 | 0.181 | 0.043 |
| 5 | 1.589 | 0.174 | 0.042 |
| 6 | 1.758 | 0.161 | 0.039 |

| *t (hr)* | **F** *(cm)* | *f (cm/hr)* | *f (m/d)* |
|---|---|---|---|
| 8 | 2.060 | 0.144 | 0.034 |
| 10 | 2.336 | 0.131 | 0.032 |
| 12 | 2.589 | 0.123 | 0.029 |
| 16 | 3.054 | 0.110 | 0.026 |
| 20 | 3.476 | 0.102 | 0.024 |
| 24 | 3.872 | 0.096 | 0.023 |

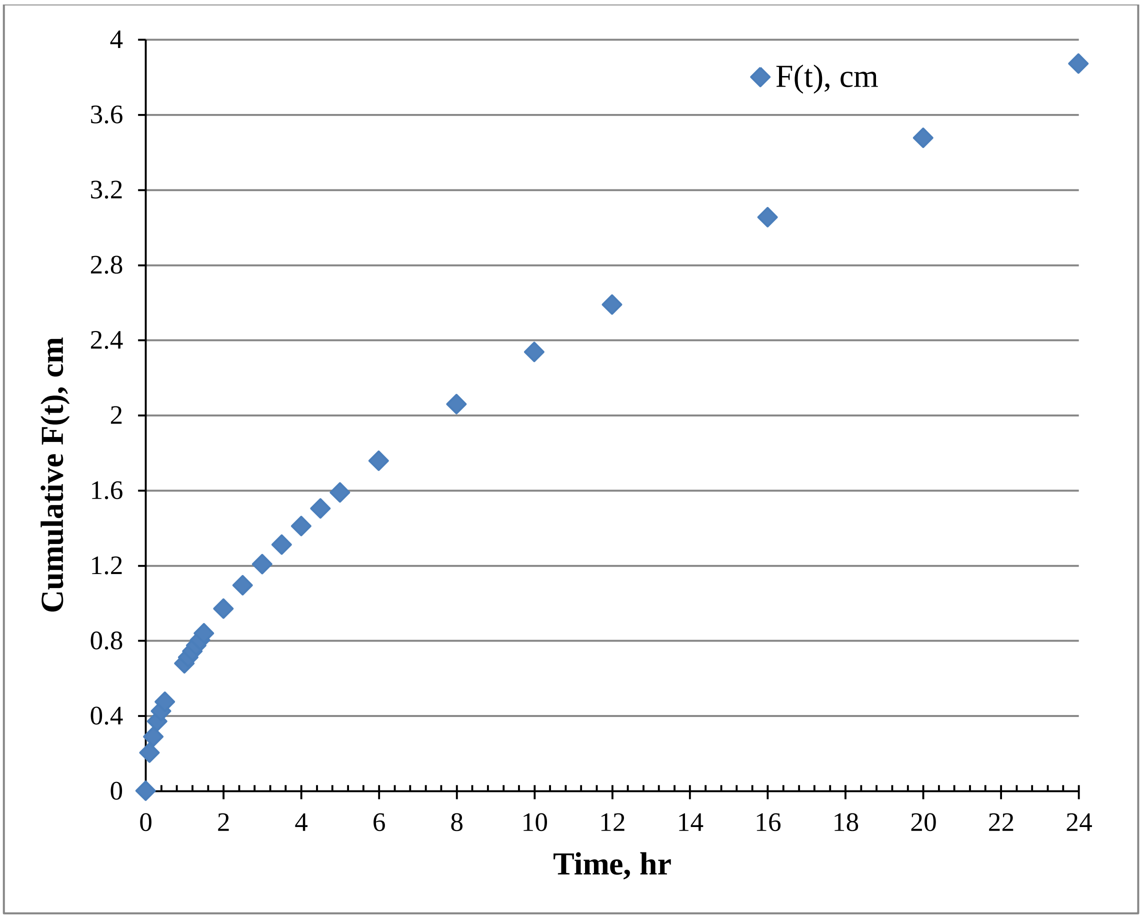


**Figure (5-16):** Cumulative infiltration with time, 1st Model

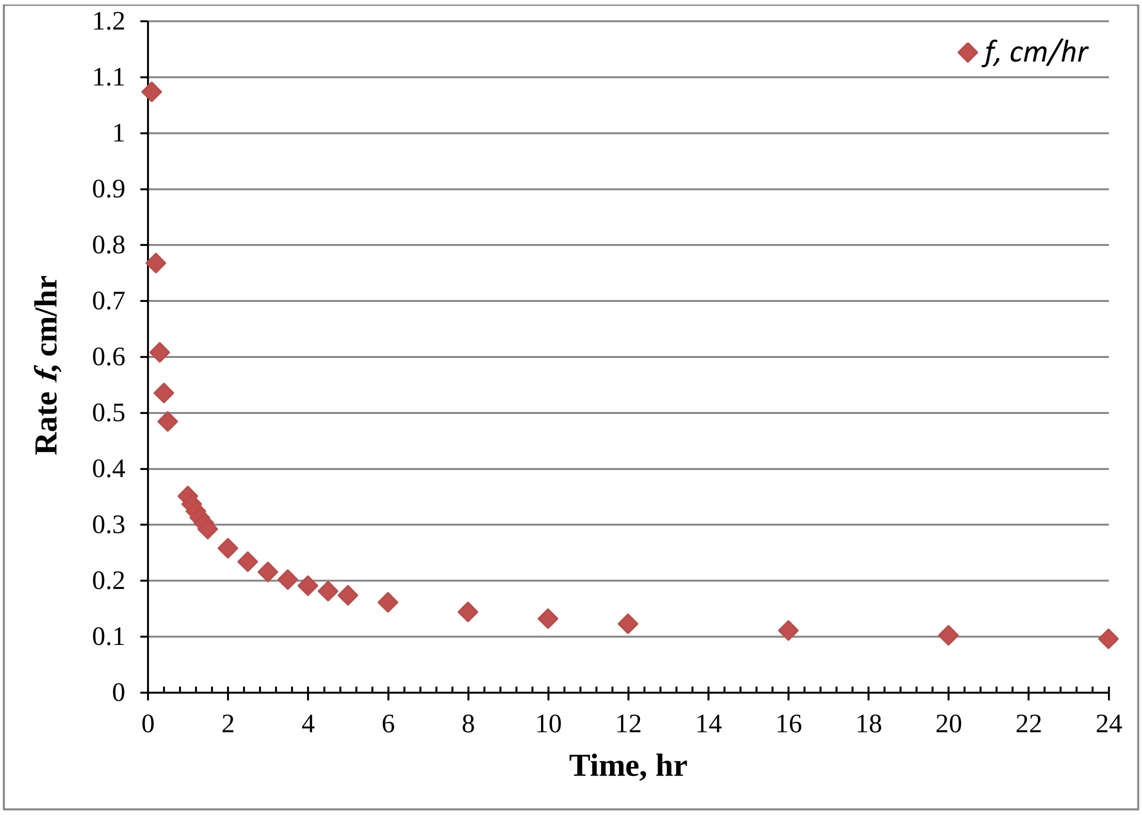


**Figure (5-17):** Infiltration Rate with Time, 1st Model

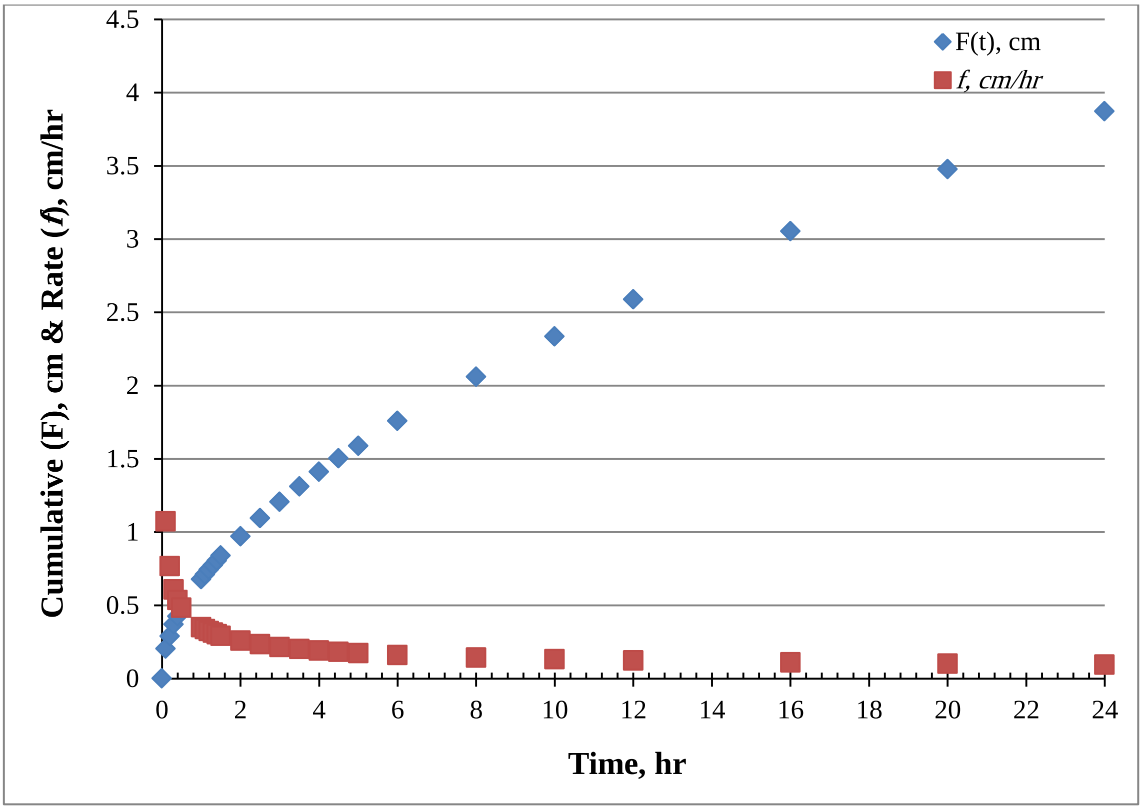


**Figure (5-18):** Cumulative Infiltration, and Rate with Time,1st Model

### 5.2.2.2 Second Model with Maximum K (37.458cm/hr) in IB1

**Table 5-16:** F (t) & *f* at K= 37.458*cm/hr*

| *t (hr)* | **F (cm)** | ***f (cm/hr)*** | ***f (m/d)*** |
|---|---|---|---|
| 0.0 | 0 | ∞ | ∞ |
| 0.1 | 6.428 | 47.531 | 11.408 |
| 0.2 | 10.934 | 43.380 | 10.411 |
| 0.3 | 15.180 | 41.724 | 10.014 |
| 0.4 | 19.302 | 40.813 | 9.795 |
| 0.5 | 22.869 | 40.290 | 9.670 |
| 1 | 43.085 | 38.961 | 9.351 |
| 1.1 | 46.975 | 38.837 | 9.321 |
| 1.2 | 50.853 | 38.732 | 9.296 |
| 1.3 | 54.722 | 38.642 | 9.274 |
| 1.4 | 58.582 | 38.564 | 9.255 |
| 1.5 | 62.435 | 38.495 | 9.239 |
| 2 | 81.616 | 38.252 | 9.180 |
| 2.5 | 100.702 | 38.101 | 9.144 |
| 3 | 119.725 | 37.999 | 9.120 |
| 3.5 | 138.705 | 37.925 | 9.102 |
| 4 | 157.653 | 37.869 | 9.089 |
| 4.5 | 176.577 | 37.825 | 9.078 |
| 5 | 195.480 | 37.790 | 9.069 |
| 6 | 233.241 | 37.736 | 9.057 |
| 8 | 308.639 | 37.668 | 9.040 |
| 10 | 383.930 | 37.627 | 9.030 |
| 12 | 459.155 | 37.599 | 9.024 |
| 16 | 609.476 | 37.565 | 9.015 |
| 20 | 759.690 | 37.544 | 9.010 |
| 24 | 909.834 | 37.529 | 9.007 |

Figure 5-19, Figure 5-20, and Figure 5-21 are the representation for the infiltration with time for the same trials.

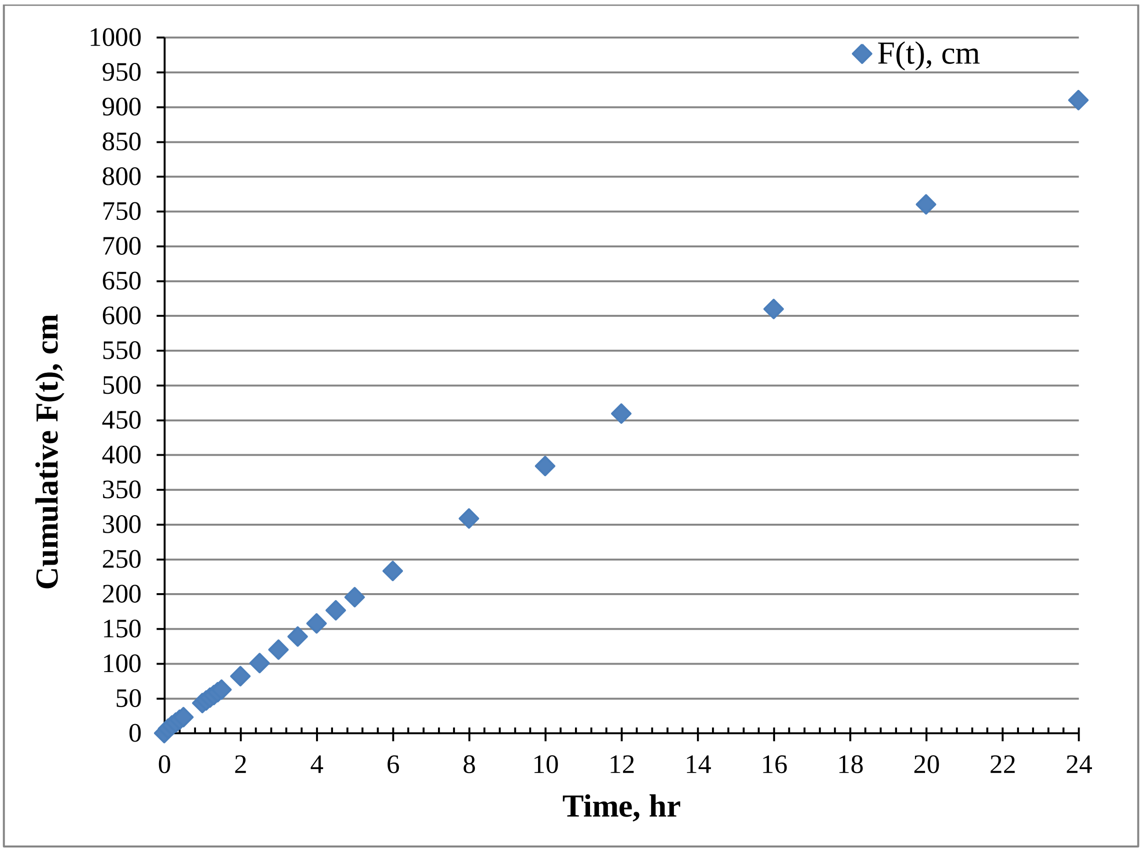


**Figure (5-19):** Cumulative infiltration with Time, 2nd Model

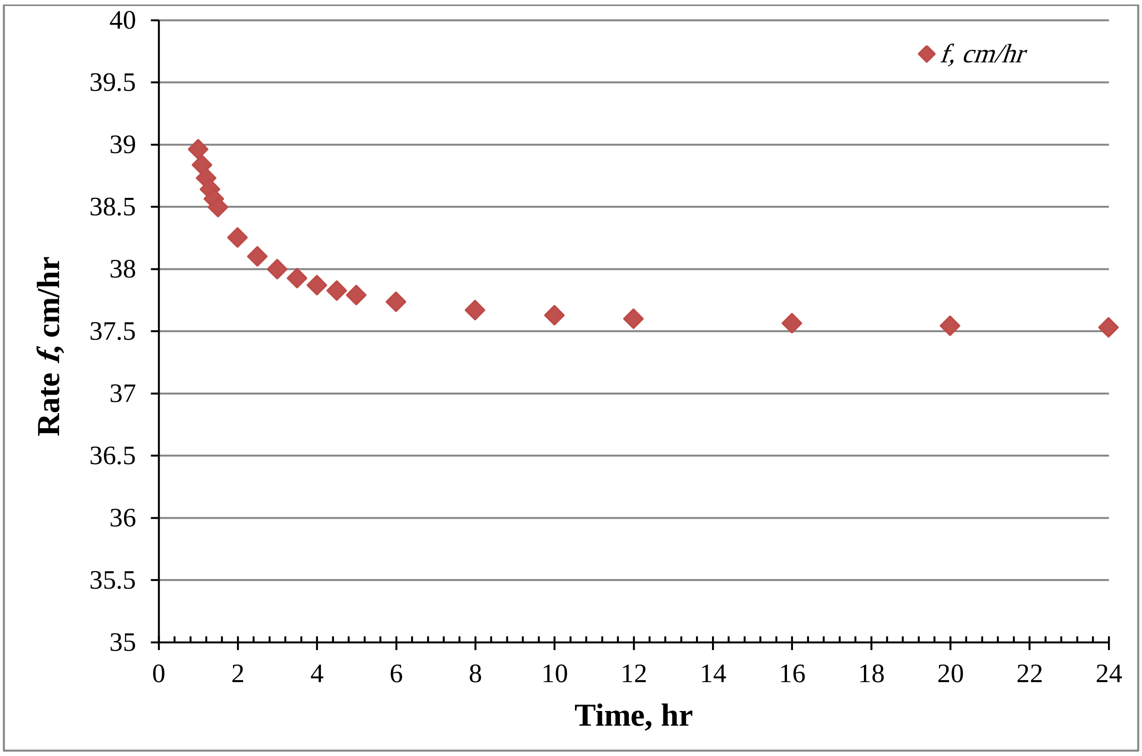


**Figure (5-20):** Infiltration Rate with Time, 2nd Model

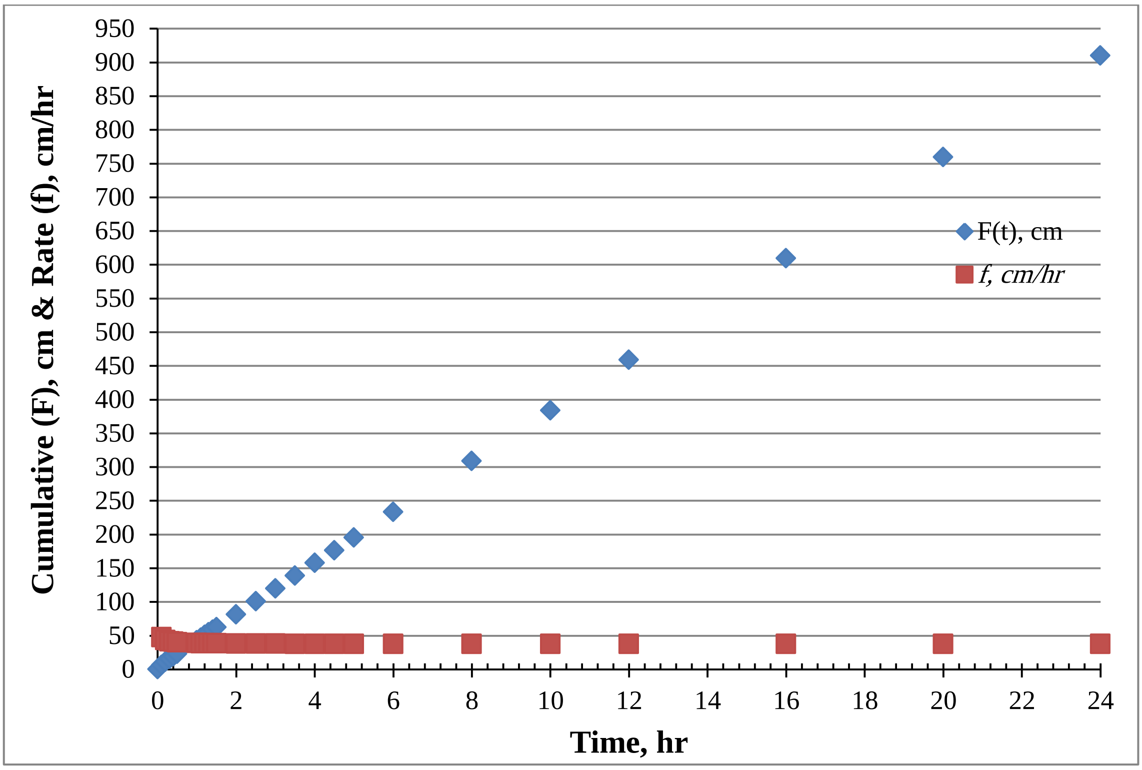


**Figure (5-21):** Cumulative Infiltration, and Rate with Time,2nd Model

None of the first or the second model matched the real behavior of infiltration regime for IB1. So the trials continuing with different K's (11.167 cm/hr, 8.042 cm/hr, 1.083 cm/hr, and finally 0.833 cm/hr), and different soil parameters. It was found that the real model for infiltration can achieved when K (0.833 cm/hr), and rate (0.98 cm/hr), and this model approximately representing the data recorded by PWA especially for the year 2013 (rate, 0.96 cm/hr equal to 0.23 m/d) as obvious in Figure 3-7, Chapter 3.

Tables 5-17 shows the results taken from the model which representing the real infiltration regime for IB1, also Figures 5-22, 5-23, and 5-24 representing the real cumulative infiltration and infiltration rate for the same basin from the same model.

Figure 5-25 illustrating the modeled and measured infiltration values for IB. The measured values is approximately closed to the data obtained by the model and with very high correlation coefficient $R^2$ equal to (0.9951), which is considered as an excellent value. It can be concluded that the model is representing the real infiltration rate for the basin. Figure 5-26 shows the summary for infiltration rate with time for different soil parameters.

**Table 5-17:** F (t) & *f* at K= 0.833*cm/hr*

| *t (hr)* | F (cm) | *f (cm/hr)* | *f (m/d)* |
|---|---|---|---|
| 0.0 | 0 | ∞ | ∞ |
| 0.1 | 0.995 | 5.280 | 1.2672 |
| 0.2 | 1.445 | 3.895 | 0.9347 |
| 0.3 | 1.800 | 3.291 | 0.7899 |
| 0.4 | 2.109 | 2.931 | 0.7035 |
| 0.5 | 2.391 | 2.684 | 0.6441 |
| 1 | 3.553 | 2.078 | 0.4988 |
| 1.1 | 3.759 | 2.010 | 0.4824 |
| 1.2 | 3.957 | 1.951 | 0.4684 |
| 1.3 | 4.148 | 1.900 | 0.4559 |
| 1.4 | 4.337 | 1.853 | 0.4448 |
| 1.5 | 4.520 | 1.812 | 0.4349 |
| 2 | 5.384 | 1.655 | 0.3972 |
| 2.5 | 6.183 | 1.549 | 0.3717 |
| 3 | 6.937 | 1.471 | 0.3530 |
| 3.5 | 7.658 | 1.411 | 0.3386 |
| 4 | 8.350 | 1.363 | 0.3272 |
| 4.5 | 9.022 | 1.324 | 0.3177 |
| 5 | 9.676 | 1.291 | 0.3097 |
| 6 | 10.938 | 1.238 | 0.2971 |
| 8 | 13.336 | 1.165 | 0.2796 |
| 10 | 15.614 | 1.117 | 0.2680 |
| 12 | 17.811 | 1.082 | 0.2596 |
| 16 | 22.035 | 1.034 | 0.2482 |
| 20 | 26.105 | 1.003 | 0.2407 |
| 24 | 30.069 | 0.980 | 0.2353 |

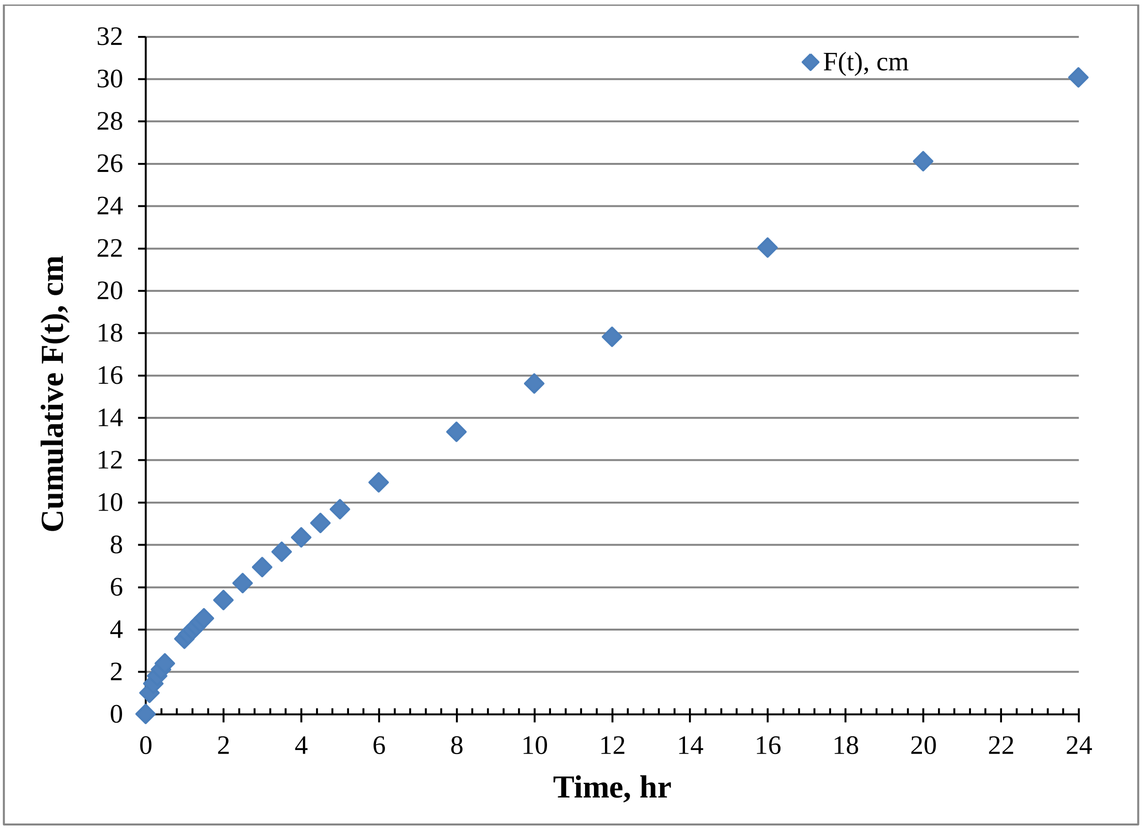


**Figure (5-22):** Cumulative Infiltration, and Rate with Time, the Real Model

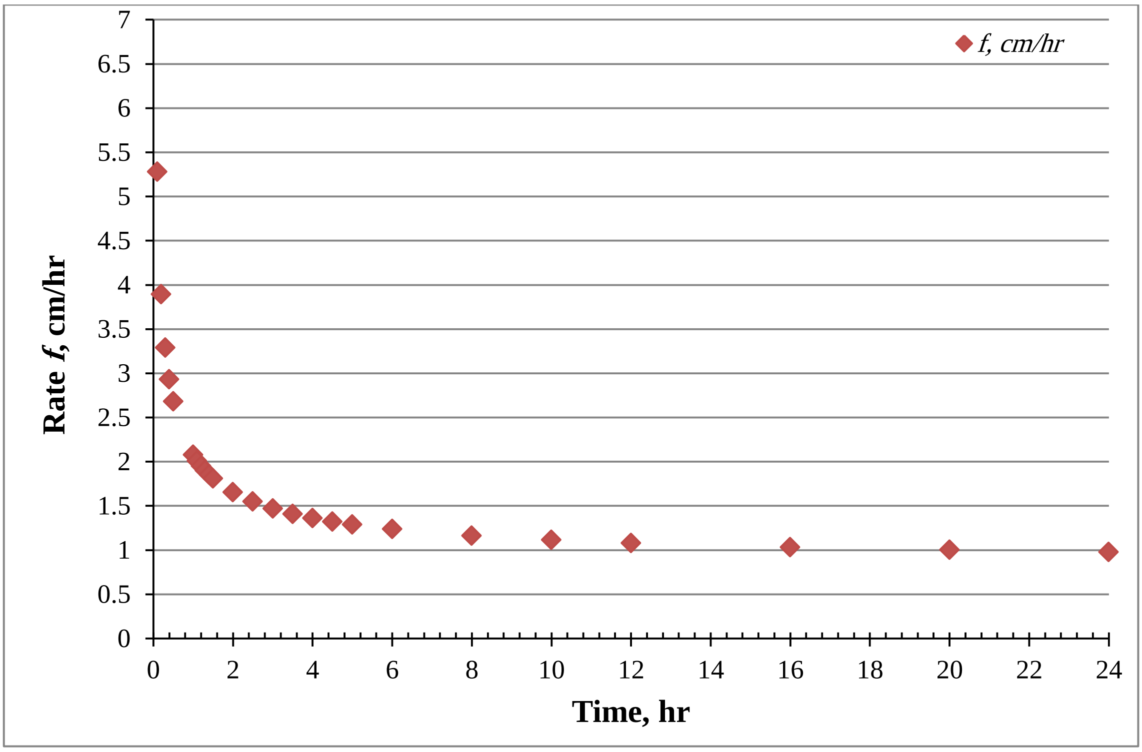


**Figure (5-23):** Infiltration Rate with Time, the Real Model

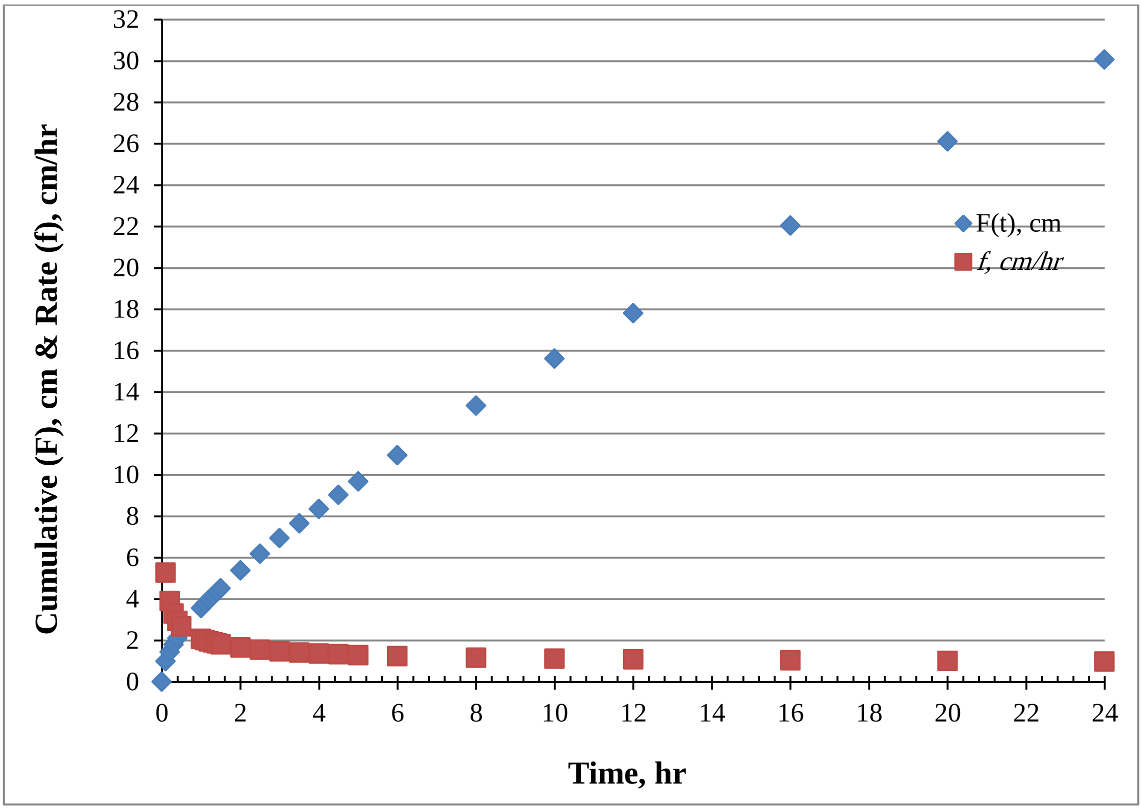


**Figure (5-24):** Cumulative Infiltration, and Rate with Time, the Real Model

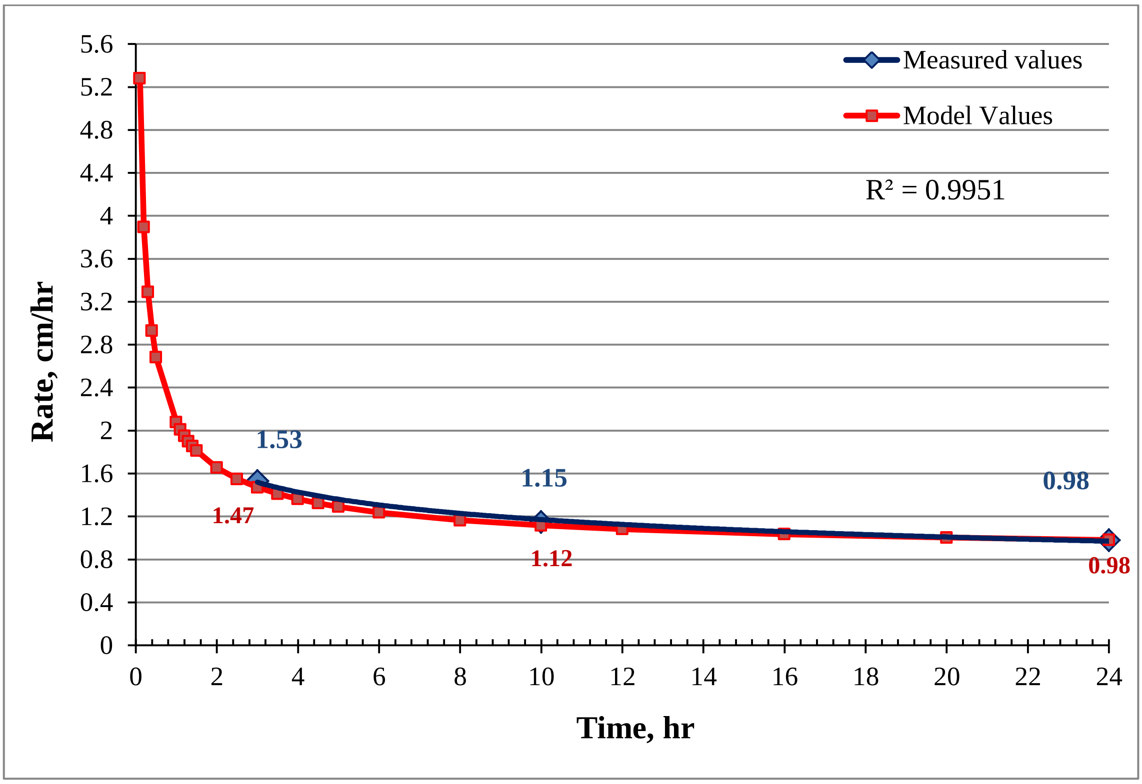


**Figure (5-25):** Measured and Model Values for Infiltration Rate at IB1

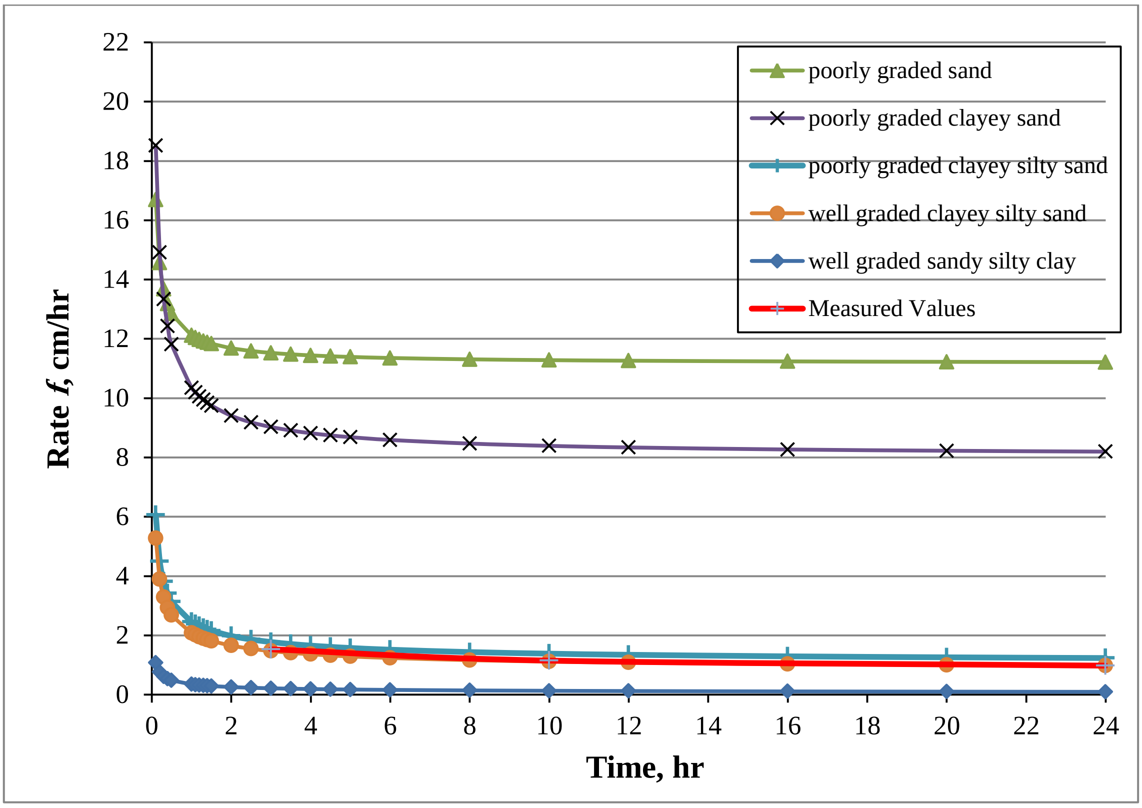


**Figure (5-26):** Infiltration Rate with Time, for different Soil Parameters.

### 5.2.3 Enhancement the Infiltration Rate for IB1

#### 5.2.3.1 Enhancement the Upper Soil Layer

According to the geological cross section for the soil (Figures 5-1, and 5-2, Chapter 5), a clayey sand la layer, which is a poorly graded clayey sand, slightly light brown with little gravel (Kurkar) exist at variable depths. The layer is of low to medium plasticity, and contains (3.0-10.0)% gravel, (60-85)% sand, and (15-40)% fines, and this layer is of low permeability. The clayey sand layer is spreading widely at the first two meters in the basin. The effect of the clayey sand layer on the infiltration rate was obvious during modeling the existing infiltration regime, as discussed previously. In order to enhance the infiltration rate; this layer should be completely removed and should be replaced by a new sand layer with high permeability.

Todd and Mays, 2005 mentioned that the sand can give permeability of 11.78cm/hr (2.827m/d) as stated in Table 2-3, Chapter 2, Green-Ampt infiltration parameters for various soil classes. A model for describing the infiltration for the proposed sand layer was performed. The output of the model is shown in Table 5-18, and Figures 5-27, 5-28, and 5-29.

**Table 5-18:** F (t) & *f* at K= 11.78*cm/hr* for the Proposed Sand Layer

| ***t (hr)*** | **F (cm)** | ***f (cm/hr)*** | ***f (m/d)*** |
|---|---|---|---|
| 0.0 | 0 | ∞ | ∞ |
| 0.1 | 3.085 | 19.909 | 4.778 |
| 0.2 | 4.898 | 16.899 | 4.056 |
| 0.3 | 6.517 | 15.627 | 3.751 |
| 0.4 | 8.041 | 14.898 | 3.576 |
| 0.5 | 9.505 | 14.418 | 3.460 |
| 1 | 16.384 | 13.310 | 3.194 |
| 1.1 | 17.709 | 13.196 | 3.167 |
| 1.2 | 19.024 | 13.098 | 3.144 |
| 1.3 | 20.329 | 13.013 | 3.123 |
| 1.4 | 21.627 | 12.939 | 3.105 |
| 1.5 | 22.917 | 12.874 | 3.090 |
| 2 | 29.290 | 12.636 | 3.033 |
| 2.5 | 35.568 | 12.485 | 2.996 |
| 3 | 41.782 | 12.380 | 2.971 |
| 3.5 | 47.952 | 12.303 | 2.953 |
| 4 | 54.088 | 12.244 | 2.938 |
| 4.5 | 60.198 | 12.197 | 2.927 |
| 5 | 66.286 | 12.158 | 2.918 |
| 6 | 78.414 | 12.100 | 2.904 |
| 8 | 102.531 | 12.025 | 2.886 |
| 10 | 126.531 | 11.978 | 2.875 |
| 12 | 150.454 | 11.947 | 2.867 |
| 16 | 198.153 | 11.907 | 2.858 |
| 20 | 245.726 | 11.882 | 2.852 |
| 24 | 293.219 | 11.866 | 2.848 |

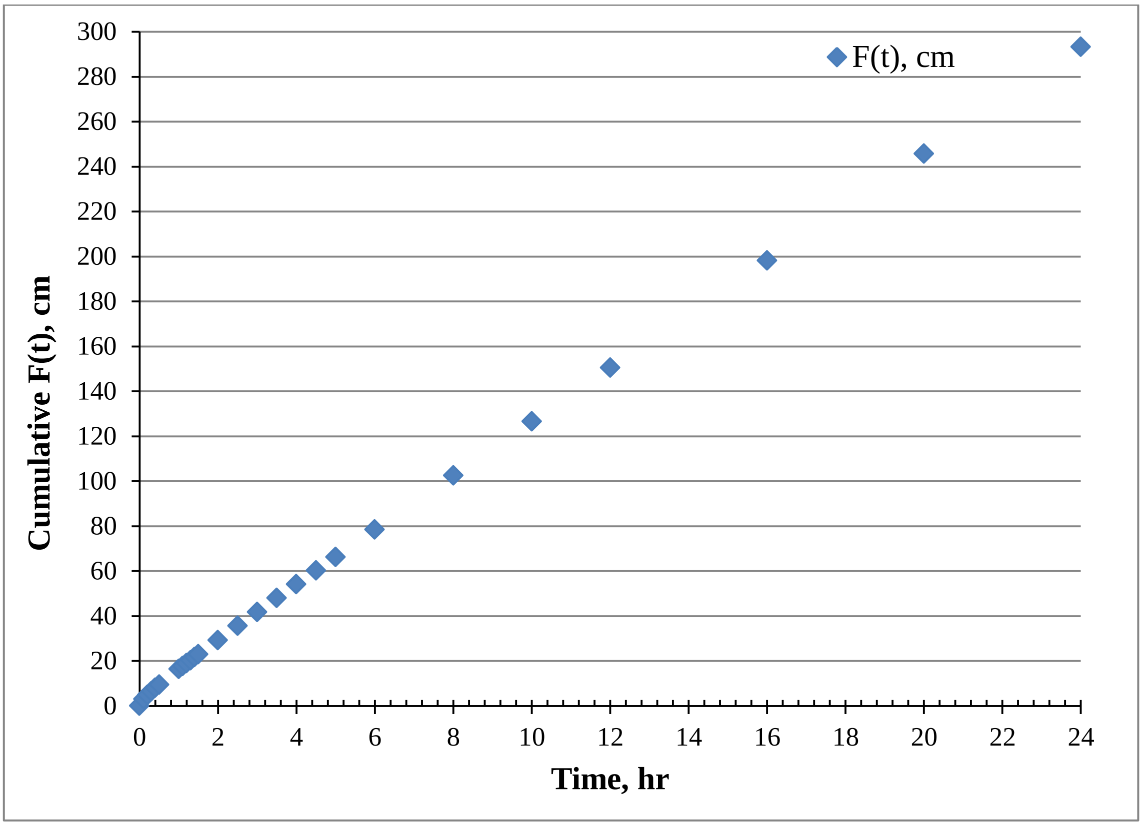


**Figure (5-27):** Cumulative Infiltration with Time for the Proposed Sand Layer

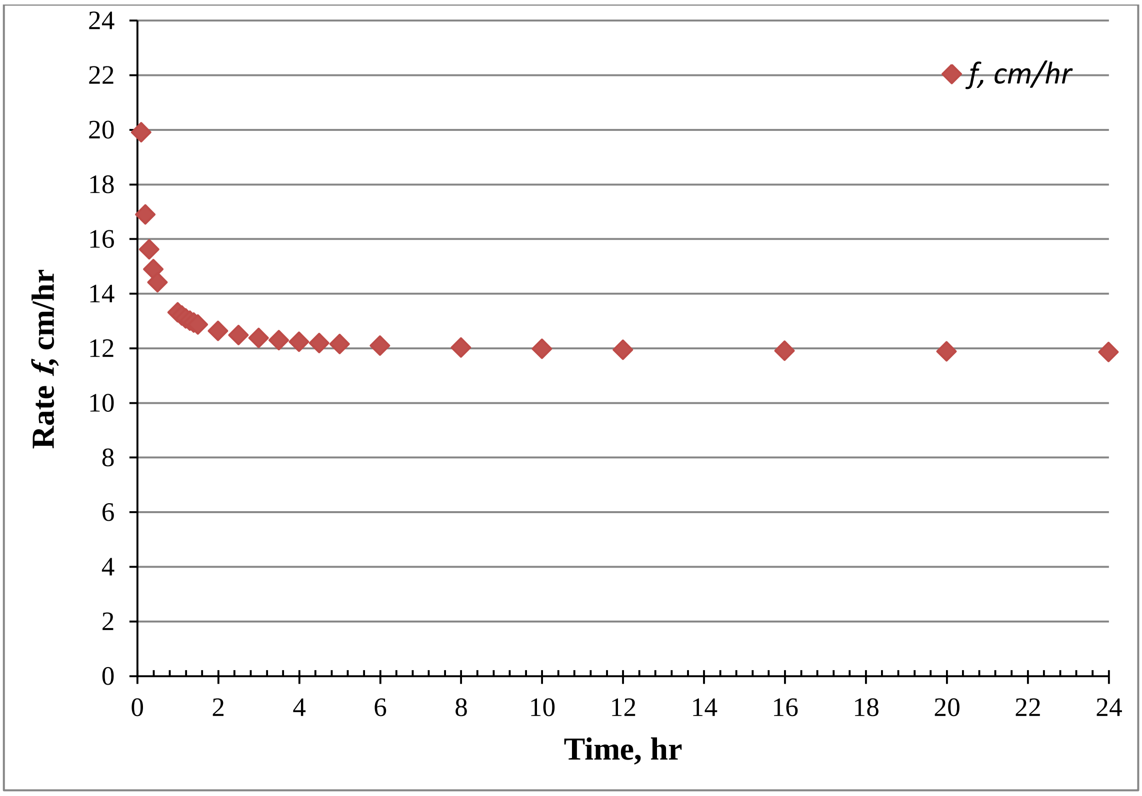


**Figure (5-28):** Infiltration Rate with Time for the Proposed Sand Layer

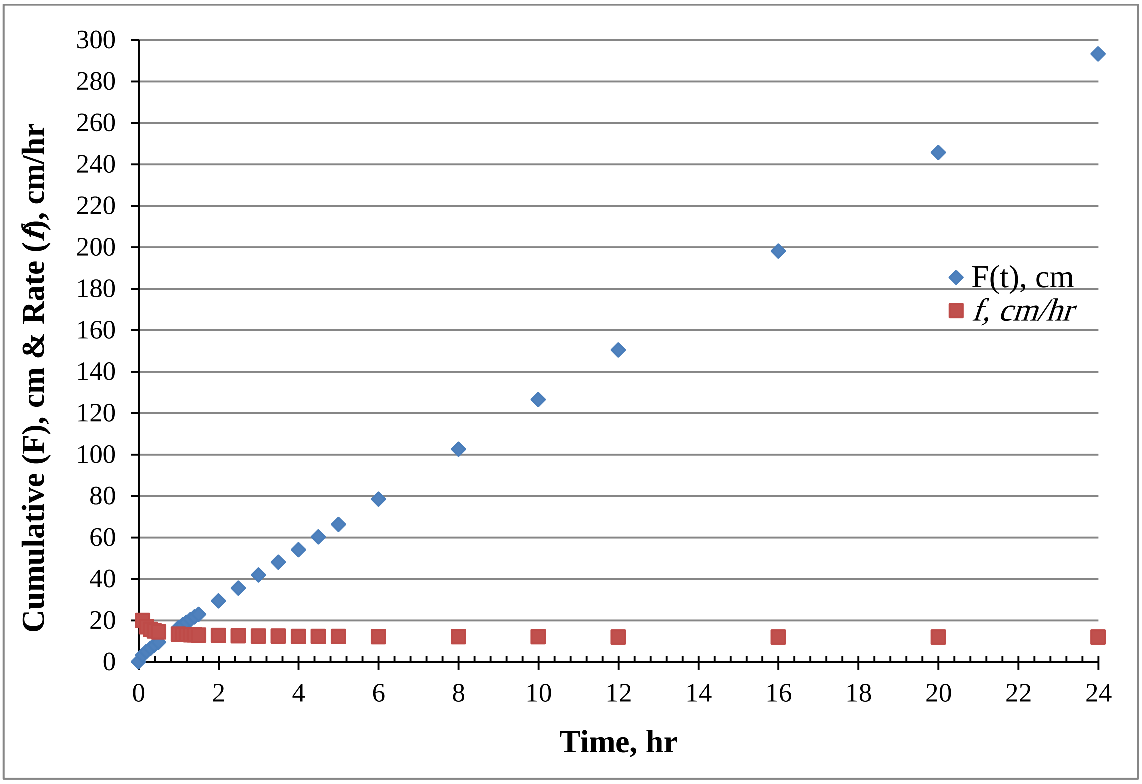


**Figure (5-29):** Cumulative Infiltration, & Rate with Time for the Proposed Sand Layer

The output of the model illustrating that the infiltration rat will reach 11.866 cm/hr (2.848 m/d) after 24 hours with cumulative infiltration of 293.219 cm, which is approximately closed to the permeability (11.78 cm/hr) stated by (Todd and Mays, 2005).

### 5.2.3.2 Enhancement the Lower Soil Layers

According to the geological cross section for the soil; a layer of sandy silt clay is exists at depth ranged from 6.40 m to a depth of 7.50 m (0.90 m thick) at the middle of IB1, and the layer appeared only on BH3. This layer is dark brown sandy clay with little gravel (Kurkar), and the layer is of medium plasticity, and of low permeability. The layer contains Fine gravel (3.0)%, sand (41.50)%, silt (39.45)%, and finally clay (16.10)%. The effect of this layer was clear on the infiltration rate during modeling the infiltration, because this layer has the minimum hydraulic conductivity (0.042 cm/hr). Another soil layer was found at depth ranged from 8.0 m to a depth of 9.0 m (1.0 m thick) at BH2, and BH5 only, this layer is same as in the first two meters.

In order to enhance the infiltration rate, a group of piles should be performed and penetrate the soil layers with a depth at least of 14 m , these piles should contain a media with high permeability. The piles can be implemented after the removal of the first two meters immediately. The numbers of piles and the diameter for each pile, will be designed in the following section.

#### 5.2.3.2.1 Design of the Piles

As illustrated in Chapter 3, Table 3-2, Infiltration area after construction, the area of IB1 is 12,328 $m^2$. According to the design criteria, the infiltration basins designed to receive 35,600$m^3$/day of treated wastewater. The amount of treated wastewater will be distributed to three ponds according to the area of each basin. IB1 will take 14,455 $m^3$/d. the rate for IB1 will equal to (14,455 $m^3$/d)/(12,328 $m^2$) = 1.20 m/d.

According to Table 2-4, Some Representative Hydraulic Conductivity for Different Soil Types, the Gravel fine can give hydraulic conductivity of 450 m/d (Todd and Mays, 2005). The total area of the piles will be: (14,455 $m^3$/d)/(450 m/d) = 32 $m^2$. A pile diameter of 60cm will be used with surface area of 0.28$m^2$, thus lead to number of piles = 32 $m^2$/0.28 $m^2$ = 114 pile.

Sichardt equation will be used as stated previously in Chapter 2, section 2.6 in order to calculate the velocity of the aquifer.

K for the aquifer will be equal to 7.20 m/d (0.0001 m/s), which is the average K for layers at depth 11.0 m, and 12.0 m, (Table 5-6**,** Estimated hydraulic conductivity K for the testing soil samples).

$\mathbf{V_a} < \frac{\sqrt{\mathbf{0.0001}}}{\mathbf{30}}$ , Va< 0.0003 m/s, take Va = 0.00025 m/s.

The flow inside the pile $\mathbf{Q = 2\pi}$RLV $m^3$/s, where:

R: is the radius of the pile, m

L: is the length of pile below the clay sad layer (6.0 m), and

V: is the approach velocity, m/s.

Q = 2* $\boldsymbol{\pi * 0.3m * 6m * 0.00025\ m/s}$ = 0.003 $m^3$/s (244 $m^3$/d).

As the pile will drainage 244 $m^3$/d, the number of piles (114 pile) can be reduced as following:

(14,455 $m^3$/d)/(244 $m^3$/d) = 60 pile, these piles will distributed at the middle area of the basin, because the worst permeably (0.01m/d) was found at BH3 at depth 7.0m.

The piles will distributed at area of 90x50 $m^2$ from the middle of the basin, with 10x10m grid between piles center to center as shown in Figure 5-30. In order to maintain good drainage for the infiltrated water, it is preferred to use closed UPVC 22" in diameter with total length of 9.0 m in order to prevent clogging of the gravel media due to entrance of the fine particles from the surrounding soil (clayey sand at depth 8-9 m, and sandy silty clay at depth 6.5-7.40 m), also perforated UPVC pipe 22" diameter with total length of 5.0 m below the 9.0 m pipe in order to maintain good infiltrated water to the lower strata as shown in Figure 5-31. The gravel media is designed on the basis of seive analysis of aquifer sample.If aquifer samples from different depths show considerable variation in gradation, the gravel should be based stable against the finer grade samples. Uniformity coeffecient (Uc) of the aquifer is the controle in this case **(Boonstra, 1999)**.

Uc = $d_{60}/d_{10}$, where the effective particle size is the 10 percent finer than value ($d_{10}$), and $d_{60}$ is the 60 percent finer than value. A uniform material has a low uniformity coefficient, while a well graded material has a high uniformity coefficient **(Todd and Mays, 2005)**.

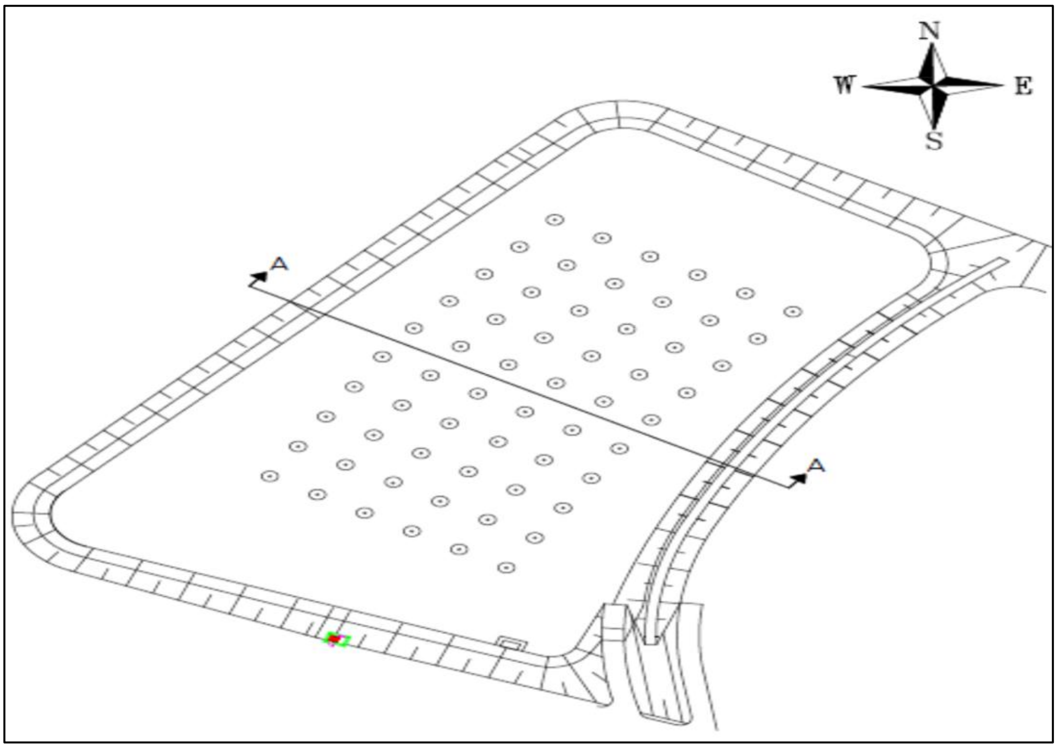


**Figure (5-30):** Distribution of Piles at IB1

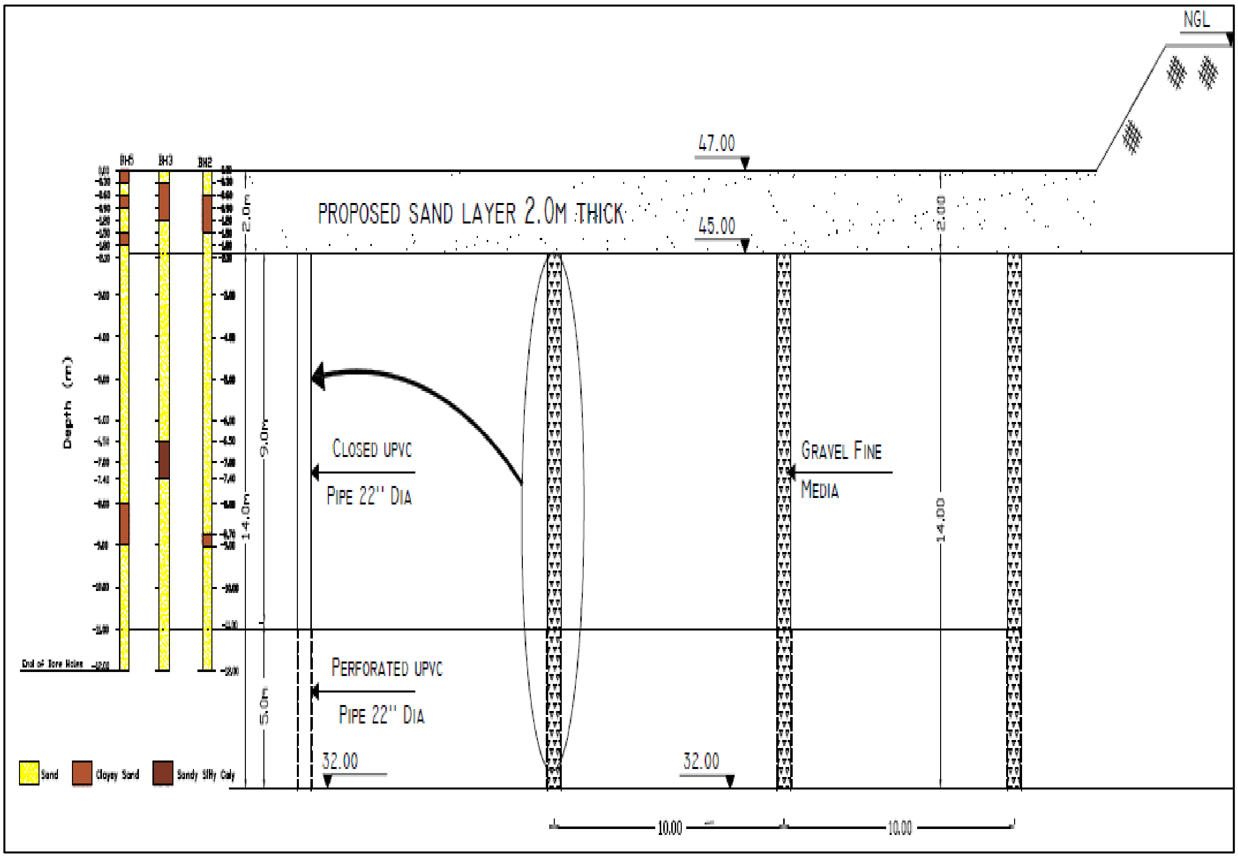


**Figure (5-31):** Section A-A in the Piles

#### 5.2.3.3 Design of Wetting Drying Cycles

A regular drying period is essential for the successful performance of infiltration system. For primary effluent the ratios of loading to drying periods within a single cycle are generally less than 0.2 to allow for adequate drying, Table 5-19 presents suggested hydraulic loading/drying periods. In all cases, to avoid excessive soil clogging, the hydraulic loading period for primary effluent does not exceed 1-2 days regardless of season or treatment goals **(EPA, 1981).**

**Table 5-19:** Suggested Loading Cycles (EPA, 1981)

| Loading cycle objective | Applied Wastewater | Season | Application Period D | Drying Period D |
|---|---|---|---|---|
| Maximize infiltration rates | Primary | Summer | 1-2 | 5-7 |
| | | Winter | 1-2 | 7-12 |
| | Secondary | Summer | 1-3 | 4-5 |
| | | Winter | 1-3 | 5-10 |
| Maximize nitrogen removal | Primary | Summer | 1-2 | 10-14 |
| | | Winter | 1-2 | 12-16 |
| | Secondary | Summer | 7-9 | 10-15 |
| | | Winter | 9-12 | 12-16 |
| Maximize nitrification | Primary | Summer | 1-2 | 5-7 |
| | | Winter | 1-2 | 7-12 |
| | Secondary | Summer | 1-3 | 4-5 |
| | | Winter | 1-3 | 5-10 |

For treatment goals with primary effluent are to maximize infiltration rates:

Summer period (from April to October, 241d): Wet (2d), Dry (7d), and Total (2+7) = 9d

So, summer period each cycle equal to 9d.

Cycles per season (summer) = 214d/9d = 24 cycles.

Winter period (from November to March, 151 d): Wet (2d), Dry (12d), and Total (2+12) =14d.

The winter period each cycle equal to 14d.

Cycle per season (winter) = 151/14 = 11 cycles.

Total cycles per year = 24+11 = 35 cycles.

Accordingly; 35 cycles of wetting and drying should be performed during the year in order to reach the optimal infiltration rate.

# CAHPTER 6 : Conclusions and Recommendations

## 6.1 Conclusions

1. The results showed that the soil strata in the infiltration basin IB1 consists of Sand which is non-plastic and has good permeability characteristics, Clayey Sand: which is the wide spreading layer at the top of the basin, and of low to medium plasticity, and of low permeability, and Sandy Silty Clay which is of medium plasticity, and of low permeability. The results showed that that the infiltration rate is affected by the soil properties; sandy soils have the highest infiltration rates and clayey soils have the lowest infiltration rates.

2. The hydraulic conductivity of the soil layers ranged between 0.01m/d, and 8.99m/d with the range laid between the classification of sand medium and clayey material. Clayey material exhibit low hydraulic conductivity values, where sandy soil display high values. The effect of hydraulic conductivity was obvious on infiltration rate.

3. OM in the soil still with low values, and will not affect the infiltration rate and soil plowing is efficient procedure that can be employed to reduce OM content in the top layer and maintain high infiltration rates of TWW into the soil.

4. SAR test results shows that the rate of SAR is less than <13, which means that the soil physical condition is normal (not sodic soil) and SAR will not affect the infiltration rate.

5. BOD and COD values are still out of range with comparing with design values, and this refer to the accumulation of pollutants and to the poor performance of BLWWTP. The BOD and COD concentration are not suitable for the infiltration purposes.
6. The TSS concentration still out of the design criteria, which is not suitable for the infiltration process, and it has a direct influence in reducing the IR in IB (2-9).

7. The concentration of FC, and TC is facultative; sometimes less and sometimes high. The variation of FC, and TC concentration is refere to differnet influent batches from BLWWTP, and to the poor treatemnt effeicncy. In genral the vlaue of FC and TC is not suitable for infiltration purposes based on the design criteria and the Palestinian standard for ground water recharge.

8. Different models with different soil properties were developed by using the Green-Ampt infiltration model in order to describe the existing infiltration regime for the IB1, the existing infiltration was reached, and it was compatible with the data recorded by PWA.

9. Penetrating the lower soil layers (after removing the upper 2.0 meters soil layer), with 60 piles and filling the piles with gravel fine media with high permeability, will increase the infiltration rate for hole of the basin.

## 6.2 Recommendations

### 6.2.1 Recommendations for Good Operation

1. In order to enhance the infiltration rate; the upper soil layer with thickness of 2.0m should be completely removed and it should be replaced by a new sand layer with high permeability.
2. The quality of the influent water to IB1 depends on the efficiency of BLWWTP, so increasing the performance of BLWWTP (until finishing the Northern Wastewater Treatment Plant) will reducing the concentration of TSS, and the organic load.
3. Field measurements such as temperature, pH, and turbidity for the influent water to the basins should be recoded daily to ensure good water quality for infiltration process.
4. In order to reach the optimal infiltration rate; it is recommended to perform 35 cycles of wetting and drying with 2 days of flooding in winter and summer and 7 days of drying in summer and 12 days of drying in winter.
5. Soil plowing should be performed immediately after each drying cycle for the basins in order to maintain good infiltration rate and to prevent accumulation of the OM in the top soil layer.

### 6.2.2 Recommendations for the Research

1. It is recommended to perform further bore holes at the middle of IB1 in order to ensure that the sandy silty clay layer is spreading at variable depths before the implementation of the injection piles (60 piles).
2. As the clogging layer is subject to compression under seepage forces exerted by infiltrating water, it is recommended to try variable water depths (for example 0.6-1.0m) in the basin in order to determine the optimal depth which may help to prevent excessive compression and further reduction of hydraulic conductivity.
3. OM accumulation in the topsoil layer is the one of the main factors adversely affecting soil permeability. Up on that; it is recomnded to perfrom additional studies in order to detrmine the chemical nature and composition of the OM and it is effect on the soil.
4. The pumping to the infiltration basins should be stopped until reaching BOD load suitable for infiltration purposes.

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# APPENDICES

# APPENDIX (1)

Schedule of Plowing for IB1 (CMWU, 2013)

| Plowing Date | Tool of Plowing |
|---|---|
| 14.09.2011 | PLOW |
| 03.11.2011 | PLOW |
| 05.01.2012 | PLOW |
| 21.03.2012 | PLOW |
| 22.05.2012 | PLOW |
| 28.07.2012 | PLOW |
| 29.08.2012 | PLOW |
| 06.10.2012 | PLOW |
| 01.01.2013 | PLOW |
| 30.03.2013 | PLOW |
| 13.05.2013 | PLOW |

# APPENDIX (2)

## Borehole Log (BH1)

| SUBSURFACE PROFILE | | | |
|---|---|---|---|
| Depth (m) | Graphic Log | Elev. | Soil Description |
| 0.0 | | 0.00 | Ground Surface |
| | | -0.30 | **Sand** Yellowish fine Sand with little gravel (Kurkar) and a little fines. Non plastic. |
| 1.0 | | -0.90 | **Clayey Sand** Light Brown Clayey Sand with little gravel (Kurkar) and some fines. The layer is of low to medium plasticity. |
| 2.0 | | | **Sand** Yellowish fine Sand with little gravel (Kurkar) and a little fines. Non plastic. |
| 3.0 | | | |
| 4.0 | | | |
| 5.0 | | | |
| 6.0 | | | |

| SAMPLE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| No. | USCS Classification | Fines Content % | Liquid Limit % | Plastic Limit % | Plasticity Index | Coefficient of Uniformity CU | Coefficient of Gradation Cc | Average Size D50 | Water Content WC% |
| 1 | SM | 14.0 | | | NP | 5.974 | 0.841 | 0.240 | 11.0 |
| 2 | SM | 21.6 | | | NP | 14.255 | 2.15 | 0.181 | 12.7 |
| 3 | SC | 26.9 | | | | 24.789 | 2.785 | 0.172 | 12.0 |
| 4 | SP-SM | 11.9 | | | NP | 5.548 | 0.797 | 0.254 | 8.7 |
| 5 | SP-SM | 7.1 | | | NP | 4.2 | 0.75 | 0.250 | 6.4 |
| 6 | SP | 4.1 | | | NP | 4.974 | 0.733 | 0.326 | 4.9 |
| 7 | SP-SM | 7.6 | | | NP | 4.364 | 0.745 | 0.258 | 6.8 |
| 8 | SP-SM | 9.0 | | | NP | 4.864 | 0.729 | 0.271 | 6.8 |
| 9 | SP-SM | 8.2 | | | NP | 4.175 | 0.751 | 0.244 | 7.2 |
| 10 | SP-SM | 8.1 | | | NP | 4.069 | 0.755 | 0.240 | 7.5 |
| 11 | SP-SM | 5.4 | | | NP | 4.15 | 0.752 | 0.264 | 4.4 |

| SUBSURFACE PROFILE | | | | SAMPLE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (m) | Graphic Log | Elev. | Soil Description | No. | USCS Classification | Fines Content % | Liquid Limit % | Plastic Limit % | Plasticity Index | Coefficient of Uniformity CU | Coefficient of Gradation Cc | Average Size D50 | Water Content WC% |
| | | | | 12 | SP | 3.6 | | | NP | 3.651 | 0.772 | 0.246 | 4.5 |
| 7.0 | | | | | | | | | | | | | |
| | | | | 13 | SP | 3.7 | | | NP | 3.4 | 0.784 | 0.230 | 4.4 |
| 8.0 | | | | | | | | | | | | | |
| | | | | 14 | SP | 2.0 | | | NP | 3.221 | 0.791 | 0.227 | 4.1 |
| 9.0 | | | | | | | | | | | | | |
| | | | | 15 | SP-SM | 6.7 | | | NP | 3.671 | 0.771 | 0.228 | 5.4 |
| 10.0 | | | | | | | | | | | | | |
| | | | | 16 | SP-SM | 6.5 | | | NP | 4.12 | 0.753 | 0.253 | 5.0 |
| 11.0 | | | | | | | | | | | | | |
| | | | | 17 | SP | 3.1 | | | NP | 4.226 | 0.75 | 0.286 | 3.8 |
| 12.0 | | -12.00 | End of Borehole | | | | | | | | | | |

Borehole Log (BH2)

**SUBSURFACE PROFILE**

| Depth (m) | Elev. | Soil Description |
|---|---|---|
| 0.0 | 0.00 | Ground Surface |
| | -0.60 | **Sand** Yellowish fine Sand with little gravel (Kurkar) and a little fines. Non plastic. |
| 1.0 | -1.50 | **Clayey Sand** Light Brown Clayey Sand with little gravel (Kurkar) and some fines. The layer is of low to medium plasticity. |
| 2.0 – 6.0 | | **Sand** Yellowish fine Sand with little gravel (Kurkar) and a little fines. Non plastic. |

**SAMPLE**

| No. | USCS Classification | Fines Content % | Liquid Limit % | Plastic Limit % | Plasticity Index | Coefficient of Uniformity CU | Coefficient of Gradation Cc | Average Size D50 | Water Content WC% |
|---|---|---|---|---|---|---|---|---|---|
| 1 | SP-SM | 6.3 | | | NP | 5.348 | 0.765 | 0.345 | 11.4 |
| 2 | SP-SM | 9.6 | | | NP | 4.915 | 0.727 | 0.268 | 11.3 |
| 3 | SM | 18.2 | | | | 7.245 | 0.803 | 0.237 | 15.6 |
| 4 | SC | 27.7 | | | | 25.117 | 2.958 | 0.164 | 14.3 |
| 5 | SC | 26.8 | | | | 21.042 | 3.169 | 0.154 | 14.2 |
| 6 | SP-SM | 9.6 | | | NP | 4.01 | 0.757 | 0.227 | 7.6 |
| 7 | SP-SM | 7.4 | | | NP | 4.174 | 0.751 | 0.25 | 7.0 |
| 8 | SP-SM | 7.8 | | | NP | 4.274 | 0.784 | 0.252 | 5.6 |
| 9 | SP | 4.6 | | | NP | 3.703 | 0.77 | 0.243 | 6.2 |
| 10 | SP-SM | 7.0 | | | NP | 3.904 | 0.762 | 0.239 | 7.5 |
| 11 | SP-SM | 6.2 | | | NP | 3.694 | 0.77 | 0.232 | 6.8 |

| SUBSURFACE PROFILE | | | | SAMPLE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (m) | Graphic Log | Elev. | Soil Description | No. | USCS Classification | Fines Content % | Liquid Limit % | Plastic Limit % | Plasticity Index | Coefficient of Uniformity CU | Coefficient of Gradation Cc | Average Size D50 | Water Content WC% |
| | | | | 12 | SP-SM | 6.6 | | | NP | 5.208 | 0.72 | 0.311 | 5.7 |
| 7.0 | | | | | | | | | | | | | |
| | | | | 13 | SP-SM | 5.7 | | | NP | 4.981 | 0.725 | 0.307 | 6.0 |
| 8.0 | | | | | | | | | | | | | |
| | | -8.70 | | 14 | SC | 26.5 | | | | 25.702 | 2.618 | 0.181 | 10.5 |
| 9.0 | | -9.00 | **Clayey Sand** Slightly Light Brown Clayey Sand with little gravel (Kurkar). The layer is of medium plasticity. | | | | | | | | | | |
| | | | **Sand** Yellowish fine Sand with little gravel (Kurkar) and a little fines. Non plastic. | 15 | SP | 3.3 | | | NP | 4.614 | 0.737 | 0.309 | 6.0 |
| 10.0 | | | | | | | | | | | | | |
| | | | | 16 | SP | 3.3 | | | NP | 3.893 | 0.762 | 0.263 | 4.6 |
| 11.0 | | | | | | | | | | | | | |
| | | | | 17 | SP | 0.0 | | | NP | 4.617 | 0.788 | 0.372 | 4.2 |
| 12.0 | | -12.00 | End of Borehole | | | | | | | | | | |

# Borehole Log (BH3)

**SUBSURFACE PROFILE**

| Depth (m) | Elev. | Soil Description |
|---|---|---|
| 0.0 | 0.00 | Ground Surface |
| 0.0 – 0.30 | -0.30 | **Sand** Yellowish fine Sand with little gravel (Kurkar) and a little fines. Non plastic. |
| 0.30 – 1.20 | -1.20 | **Clayey Sand** Light Brown Clayey Sand with little gravel (Kurkar) and some fines. The layer is of low to medium plasticity. |
| 1.20 – 6.2 | | **Sand** Yellowish fine Sand with little gravel (Kurkar) and a little fines. Non plastic. |

**SAMPLE**

| No. | USCS Classification | Fines Content % | Liquid Limit % | Plastic Limit % | Plasticity Index | Coefficient of Uniformity CU | Coefficient of Gradation Cc | Average Size D50 | Water Content WC% |
|---|---|---|---|---|---|---|---|---|---|
| 1 | SM | 13.8 | | | | 5.496 | 0.858 | 0.227 | 12.8 |
| 2 | SM | 22.8 | | | | 16.126 | 2.368 | 0.177 | 12.1 |
| 3 | SM | 22.9 | | | | 16.806 | 2.348 | 0.18 | 12.6 |
| 4 | SC | 39.9 | | | | 38.485 | 3.913 | 0.116 | 15.6 |
| 5 | SP-SM | 10.7 | | | NP | 4.136 | 0.798 | 0.217 | 7.9 |
| 6 | SP-SM | 9.8 | | | NP | 3.882 | 0.762 | 0.22 | 7.0 |
| 7 | SP-SM | 9.9 | | | NP | 4.632 | 0.736 | 0.253 | 7.6 |
| 8 | SP-SM | 9.1 | | | NP | 3.876 | 0.763 | 0.224 | 6.8 |
| 9 | SM | 13.0 | | | NP | 6.11 | 0.813 | 0.256 | 6.9 |
| 10 | SM | 15.4 | | | NP | 4.619 | 0.943 | 0.185 | 9.0 |
| 11 | SP-SM | 11.6 | | | NP | 4.207 | 0.839 | 0.208 | 7.4 |

| SUBSURFACE PROFILE | | | | SAMPLE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (m) | Graphic Log | Elev. | Soil Description | No. | USCS Classification | Fines Content % | Liquid Limit % | Plastic Limit % | Plasticity Index | Coefficient of Uniformity CU | Coefficient of Gradation Cc | Average Size D50 | Water Content WC% |
| | | -6.50 | | | | | | | | | | | |
| | | | *Sandy Silty Clay*<br>Dark Brown Sandy Clay with little gravel (Kurkar). The layer is of medium plasticity. | 12 | CL | 55.6 | | | | 30.881 | 7.67 | 0.067 | 17.9 |
| 7.0 | | -7.40 | | | | | | | | | | | |
| | | | *Sand*<br>Yellowish fine Sand with a little gravel (Kurkar) and a little fines. Non plastic. | 13 | SP-SM | 5.1 | | | NP | 6.309 | 0.828 | 0.454 | 3.7 |
| 8.0 | | | | | | | | | | | | | |
| | | | | 14 | SP-SM | 6.8 | | | NP | 6.222 | 0.793 | 0.414 | 3.5 |
| 9.0 | | | | | | | | | | | | | |
| | | | | 15 | SP | 4.5 | | | NP | 3.745 | 0.768 | 0.246 | 4.2 |
| 10.0 | | | | | | | | | | | | | |
| | | | | 16 | SP | 2.4 | | | NP | 3.958 | 0.759 | 0.274 | 4.0 |
| 11.0 | | | | | | | | | | | | | |
| | | | | 17 | SP | 2.3 | | | NP | 3.881 | 0.762 | 0.27 | 3.7 |
| | | -12.00 | | | | | | | | | | | |
| 12.0 | | | End of Borehole | | | | | | | | | | |

## Borehole Log (BH4)

**SUBSURFACE PROFILE**

| Elev. | Soil Description |
|---|---|
| 0.00 | Ground Surface |
| | **Sand** Yellowish fine Sand with little gravel (Kurkar) and a little fines. Non plastic. |
| -0.60 | **Clayey Sand** Light Brown Clayey Sand with little gravel (Kurkar) and some fines. The layer is of low plasticity. |
| -0.90 | **Sand** Yellowish fine Sand with little gravel (Kurkar) and a little fines. Non plastic. |
| -1.50 | **Clayey Sand** Slightly Light Brown Clayey Sand with little gravel (Kurkar). The layer is of low plasticity. |
| -1.80 | **Sand** Yellowish fine Sand with little gravel (Kurkar) and a little fines. Non plastic. |

Depth (m): 0.0, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0

**SAMPLE**

| No. | USCS Classification | Fines Content % | Liquid Limit % | Plastic Limit % | Plasticity Index | Coefficient of Uniformity CU | Coefficient of Gradation Cc | Average Size D50 | Water Content WC% |
|---|---|---|---|---|---|---|---|---|---|
| 1 | SP-SM | 8.7 | | | NP | 5.777 | 0.72 | 0.322 | 9.2 |
| 2 | SP-SM | 5.4 | | | NP | 6.335 | 0.806 | 0.444 | 7.2 |
| 3 | SM | 21.3 | | | | 22.278 | 1.584 | 0.262 | 7.7 |
| 4 | SP-SM | 10.8 | | | NP | 4.989 | 0.767 | 0.252 | 7.8 |
| 5 | SP-SM | 6.8 | | | NP | 5.028 | 0.724 | 0.299 | 6.2 |
| 6 | SM | 20.7 | | | NP | 15.389 | 1.776 | 0.212 | 5.1 |
| 7 | SP | 4.5 | | | NP | 4.455 | 0.742 | 0.288 | 5.4 |
| 8 | SP-SM | 10.8 | | | NP | 6.379 | 0.74 | 0.311 | 7.5 |
| 9 | SP-SM | 8.3 | | | NP | 5.821 | 0.733 | 0.336 | 6.8 |
| 10 | SP-SM | 7.6 | | | NP | 5.209 | 0.719 | 0.30 | 7.6 |
| 11 | SP-SM | 6.1 | | | NP | 5.443 | 0.746 | 0.344 | 5.7 |

| SUBSURFACE PROFILE | | | | SAMPLE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (m) | Graphic Log | Elev. | Soil Description | No. | USCS Classification | Fines Content % | Liquid Limit % | Plastic Limit % | Plasticity Index | Coefficient of Uniformity CU | Coefficient of Gradation Cc | Average Size D50 | Water Content WC% |
| | | | | 12 | SP-SM | 11.4 | | | NP | 7.273 | 0.773 | 0.345 | 6.6 |
| 7.0 | | | | | | | | | | | | | |
| | | | | 13 | SP-SM | 7.8 | | | NP | 5.959 | 0.764 | 0.365 | 6.0 |
| 8.0 | | | | | | | | | | | | | |
| | | | | 14 | SP-SM | 5.4 | | | NP | 5.115 | 0.738 | 0.326 | 5.9 |
| 9.0 | | | | | | | | | | | | | |
| | | | | 15 | SP-SM | 6.4 | | | NP | 5.443 | 0.752 | 0.344 | 5.8 |
| 10.0 | | | | | | | | | | | | | |
| | | | | 16 | SP | 2.1 | | | NP | 4.399 | 0.744 | 0.306 | 5.1 |
| 11.0 | | | | | | | | | | | | | |
| | | | | 17 | SP | 3.6 | | | NP | 4.916 | 0.743 | 0.332 | 4.7 |
| 12.0 | | 12.00 | | | | | | | | | | | |
| | | | End of Borehole | | | | | | | | | | |

## Borehole Log (BH5)

| SUBSURFACE PROFILE | | | SAMPLE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Elev. | Soil Description | No. | USCS Classification | Fines Content % | Liquid Limit % | Plastic Limit % | Plasticity Index | Coefficient of Uniformity CU | Coefficient of Gradation Cc | Average Size D50 | Water Content WC% |
| 0.00 | Ground Surface | | | | | | | | | | |
| -0.30 | **Clayey Sand** Slightly Dark Brown Clayey Sand with little gravel (Kurkar). The layer is of medium plasticity. | 1 | SC | 31.5 | | | | 31.028 | 3.176 | 0.15 | 12.3 |
| -0.60 | **Sand** Yellowish fine Sand with little gravel (Kurkar) and a little fines. Non plastic. | 2 | SP-SM | 6.1 | | | NP | 5.347 | 0.731 | 0.33 | 5.8 |
| -0.90 | **Clayey Sand** Light Brown Clayey Sand with little gravel (Kurkar) and some fines. The layer is of medium plasticity. | 3 | SC | 26.5 | | | | 23.599 | 2.789 | 0.171 | 11.0 |
| | | 4 | SP-SM | 5.3 | | | NP | 4.003 | 0.758 | 0.256 | 5.9 |
| -1.50 | **Sand** Yellowish fine Sand with little gravel (Kurkar) and a little fines. Non plastic. | 5 | SP-SM | 6.1 | | | NP | 4.304 | 0.747 | 0.267 | 5.5 |
| -1.80 | **Clayey Sand** Slightly Light Brown Clayey Sand with little gravel (Kurkar). The layer is of medium plasticity. | 6 | SC | 23.4 | | | | 31.796 | 1.708 | 0.282 | 9.6 |
| | **Sand** Yellowish fine Sand with little gravel (Kurkar) and a little fines. Non plastic. | 7 | SM | 16.4 | | | NP | 6.93 | 0.824 | 0.244 | 7.5 |
| | | 8 | SP | 4.3 | | | NP | 5.453 | 0.818 | 0.409 | 3.8 |

Depth (m): 0.0, 1.0, 2.0, 3.0

| SUBSURFACE PROFILE | | | | SAMPLE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (m) | Graphic Log | Elev. | Soil Description | No. | USCS Classification | Fines Content % | Liquid Limit % | Plastic Limit % | Plasticity Index | Coefficient of Uniformity CU | Coefficient of Gradation Cc | Average Size D50 | Water Content WC% |
| | | | | 9 | SP | 2.8 | | | NP | 4.811 | 0.742 | 0.332 | 3.8 |
| 4.0 | | | | | | | | | | | | | |
| | | | | 10 | SP | 3.1 | | | NP | 4.468 | 0.741 | 0.301 | 4.1 |
| 5.0 | | | | | | | | | | | | | |
| | | | | 11 | SP | 2.3 | | | NP | 5.202 | 0.788 | 0.398 | 3.3 |
| 6.0 | | | | | | | | | | | | | |

| SUBSURFACE PROFILE | | | | SAMPLE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (m) | Graphic Log | Elev. | Soil Description | No. | USCS Classification | Fines Content % | Liquid Limit % | Plastic Limit % | Plasticity Index | Coefficient of Uniformity CU | Coefficient of Gradation Cc | Average Size D50 | Water Content WC% |
| | | | | 12 | SP | 5.0 | | | NP | 3.447 | 0.781 | 0.226 | 4.1 |
| 7.0 | | | | | | | | | | | | | |
| | | | | 13 | SP | 5.0 | | | NP | 4.288 | 0.747 | 0.275 | 5.0 |
| 8.0 | | -8.00 | *Clayey Sand* Slightly Light Brown Clayey Sand with little gravel (Kurkar). The layer is of low plasticity. | | | | | | | | | | |
| | | | | 14 | SM | 20.3 | | | | 14.263 | 1.732 | 0.21 | 3.4 |
| 9.0 | | -9.00 | | | | | | | | | | | |

| SUBSURFACE PROFILE | | | | SAMPLE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (m) | Graphic Log | Elev. | Soil Description | No. | USCS Classification | Fines Content % | Liquid Limit % | Plastic Limit % | Plasticity Index | Coefficient of Uniformity CU | Coefficient of Gradation Cc | Average Size D50 | Water Content WC% |
| | | | *Sand* Yellowish fine Sand with little gravel (Kurkar) and a little fines. Non plastic. | | | | | | | | | | |
| | | | | 15 | SP | 2.1 | | | NP | 3.989 | 0.758 | 0.279 | 4.0 |
| 10.0 | | | | | | | | | | | | | |
| | | | | 16 | SP | 2.7 | | | NP | 3.892 | 0.762 | 0.268 | 3.9 |
| 11.0 | | | | | | | | | | | | | |
| | | | | 17 | SP | 3.2 | | | NP | 4.483 | 0.741 | 0.301 | 3.5 |
| 12.0 | | 12.00 | End of Borehole | | | | | | | | | | |

# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

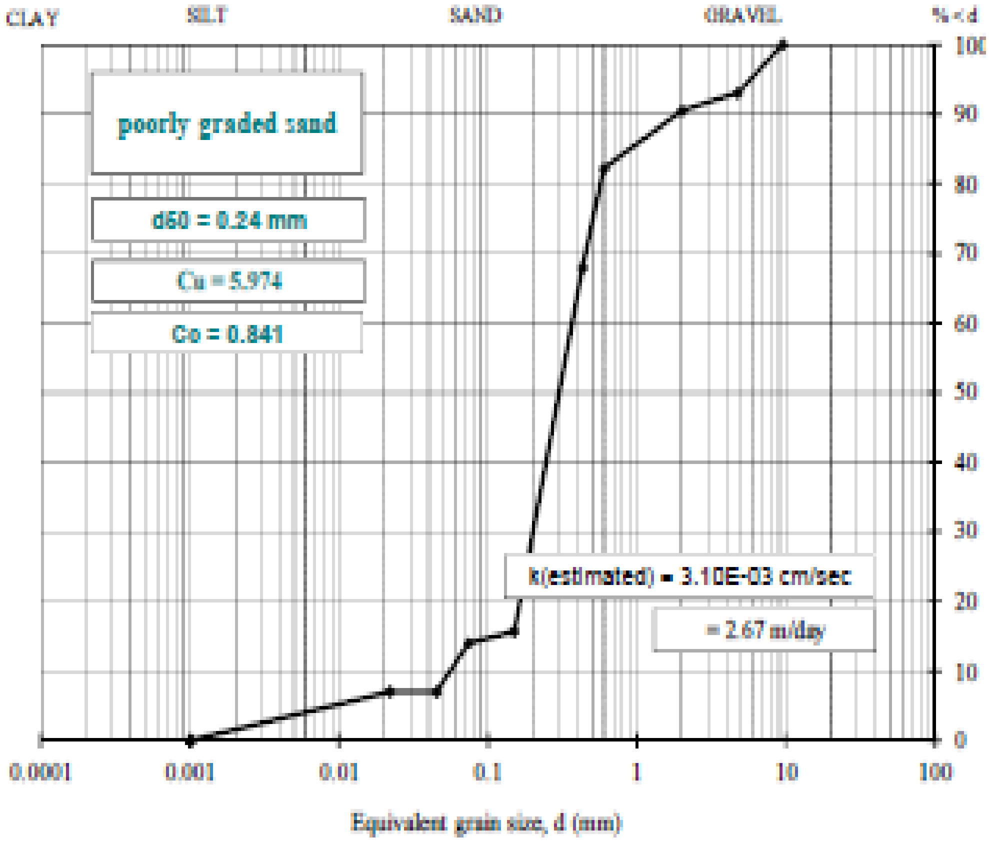
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH1

**Depth** 0.3 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 7.0 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 7.0 | |
| 3/8" | 9.50 | 90.6 | 100.0 | Coarse sand | 2.5 | 79.0 |
| Nr. 4 | 4.75 | 84.3 | 93.0 | Medium sand | 22.6 | |
| Nr. 10 | 2.00 | 82.0 | 90.5 | Fine sand | 53.9 | |
| Nr. 30 | 0.60 | 74.5 | 82.2 | Coarse silt | 7.01 | 9.95 |
| Nr. 40 | 0.43 | 61.5 | 67.9 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 14.2 | 15.7 | | | |
| Nr. 200 | 0.07 | 12.7 | 14.0 | Fine silt | 2.95 | |
| Pan | --- | 0.0 | 0.0 | Clay | 4.06 | 4.06 |

*Percentages relative to entire sample mass



## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

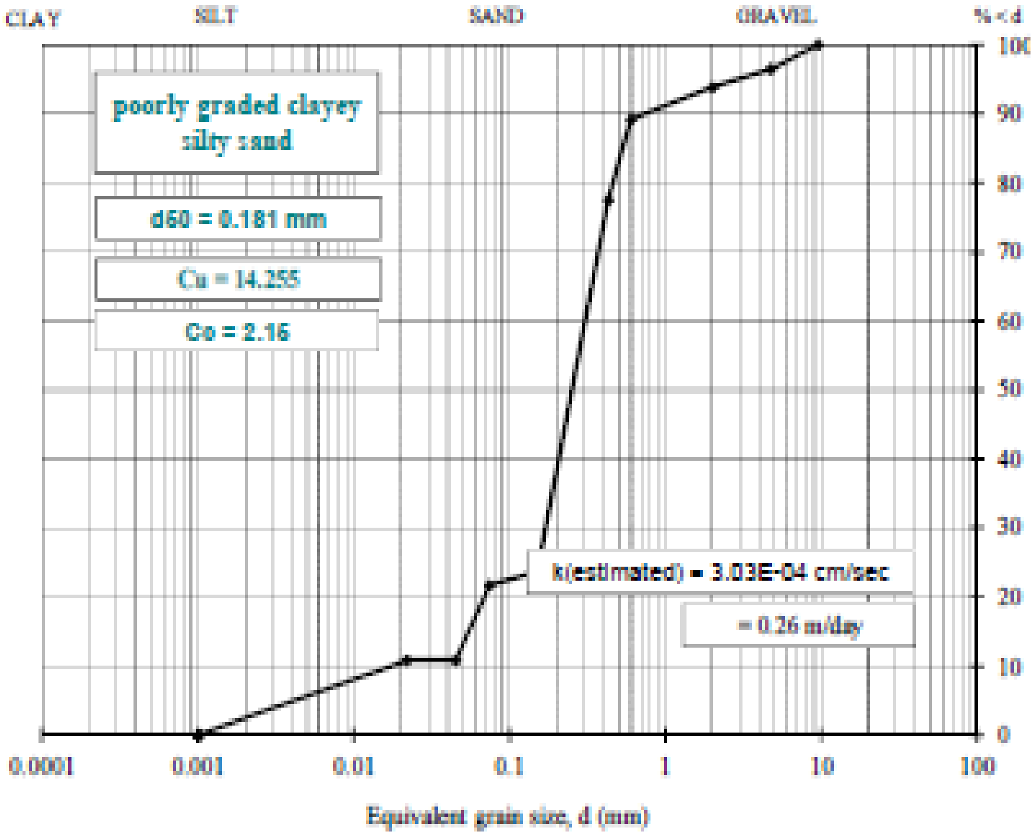
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH1

**Depth** 0.6 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 3.5 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 3.5 | |
| 3/8" | 9.50 | 158.0 | 100.0 | Coarse sand | 2.7 | 74.9 |
| Nr. 4 | 4.75 | 152.5 | 96.5 | Medium sand | 16.4 | |
| Nr. 10 | 2.00 | 148.3 | 93.9 | Fine sand | 55.8 | |
| Nr. 30 | 0.60 | 140.9 | 89.2 | Coarse silt | 10.82 | 15.37 |
| Nr. 40 | 0.43 | 122.4 | 77.5 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 37.4 | 23.7 | | | |
| Nr. 200 | 0.07 | 34.2 | 21.6 | Fine silt | 4.55 | |
| Pan | --- | 0.0 | 0.0 | Clay | 6.27 | 6.27 |

*Percentages relative to entire sample mass



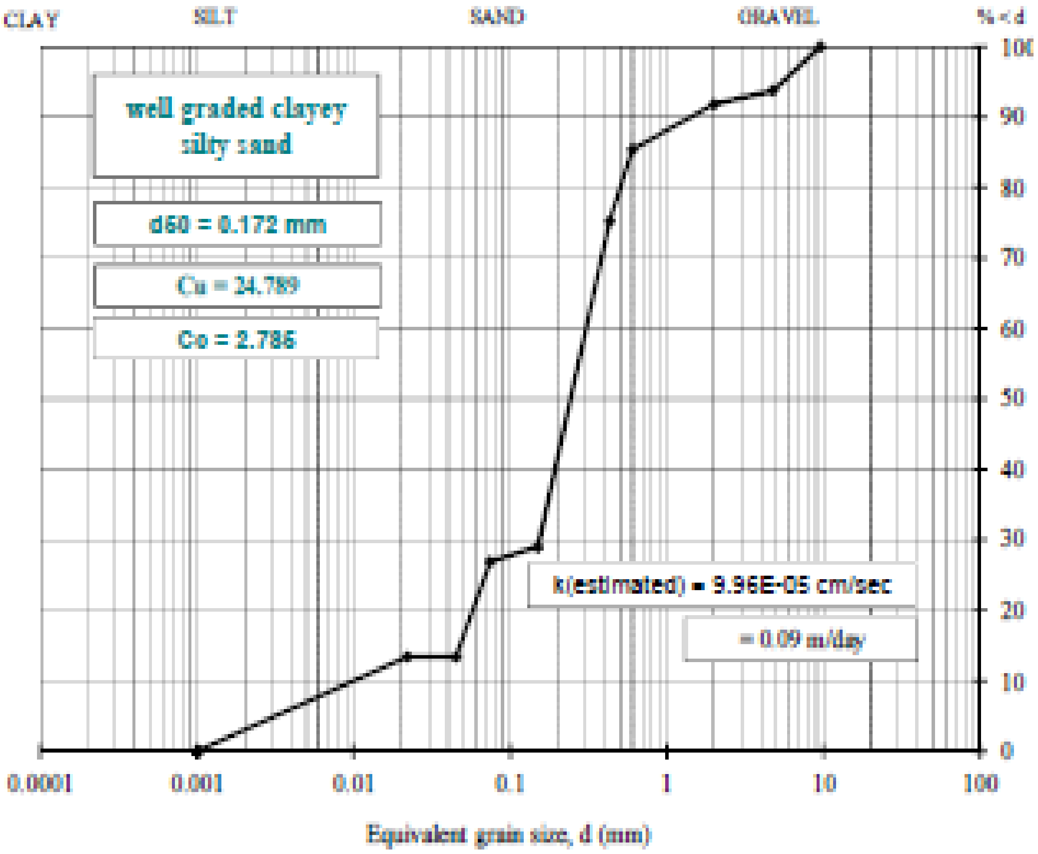
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

**Project:** Master Research-Study- (Eng. Basem Serdah)
**Bore Hole No.** BH1
**Depth** 0.9 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 6.2 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 6.2 | |
| 3/8" | 9.50 | 88.2 | 100.0 | Coarse sand | 1.9 | 66.9 |
| Nr. 4 | 4.75 | 82.7 | 93.8 | Medium sand | 16.7 | |
| Nr. 10 | 2.00 | 81.0 | 91.8 | Fine sand | 48.3 | |
| Nr. 30 | 0.60 | 75.3 | 85.4 | Coarse silt | 13.44 | 19.08 |
| Nr. 40 | 0.43 | 66.3 | 75.2 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 25.6 | 29.0 | | | |
| Nr. 200 | 0.07 | 23.7 | 26.9 | Fine silt | 5.65 | |
| Pan | --- | 0.0 | 0.0 | Clay | 7.79 | 7.79 |

*Percentages relative to entire sample mass



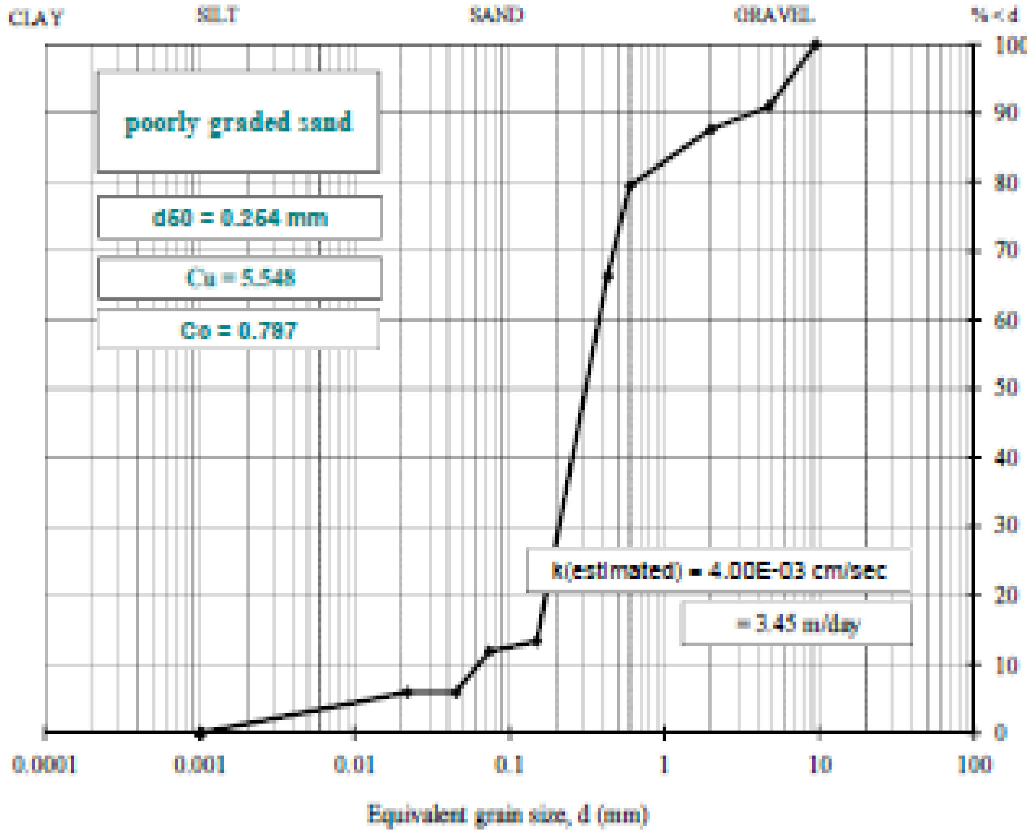
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

**Project:** Master Research-Study- (Eng. Basem Serdah)
**Bore Hole No.** BH1
**Depth** 1.2 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 9.0 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 9.0 | |
| 3/8" | 9.50 | 108.6 | 100.0 | Coarse sand | 3.3 | 79.1 |
| Nr. 4 | 4.75 | 98.8 | 91.0 | Medium sand | 21.4 | |
| Nr. 10 | 2.00 | 95.2 | 87.7 | Fine sand | 54.4 | |
| Nr. 30 | 0.60 | 86.3 | 79.5 | Coarse silt | 5.94 | 8.44 |
| Nr. 40 | 0.43 | 72.0 | 66.3 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 14.5 | 13.4 | | | |
| Nr. 200 | 0.07 | 12.9 | 11.9 | Fine silt | 2.50 | |
| Pan | --- | 0.0 | 0.0 | Clay | 3.44 | 3.44 |

*Percentages relative to entire sample mass



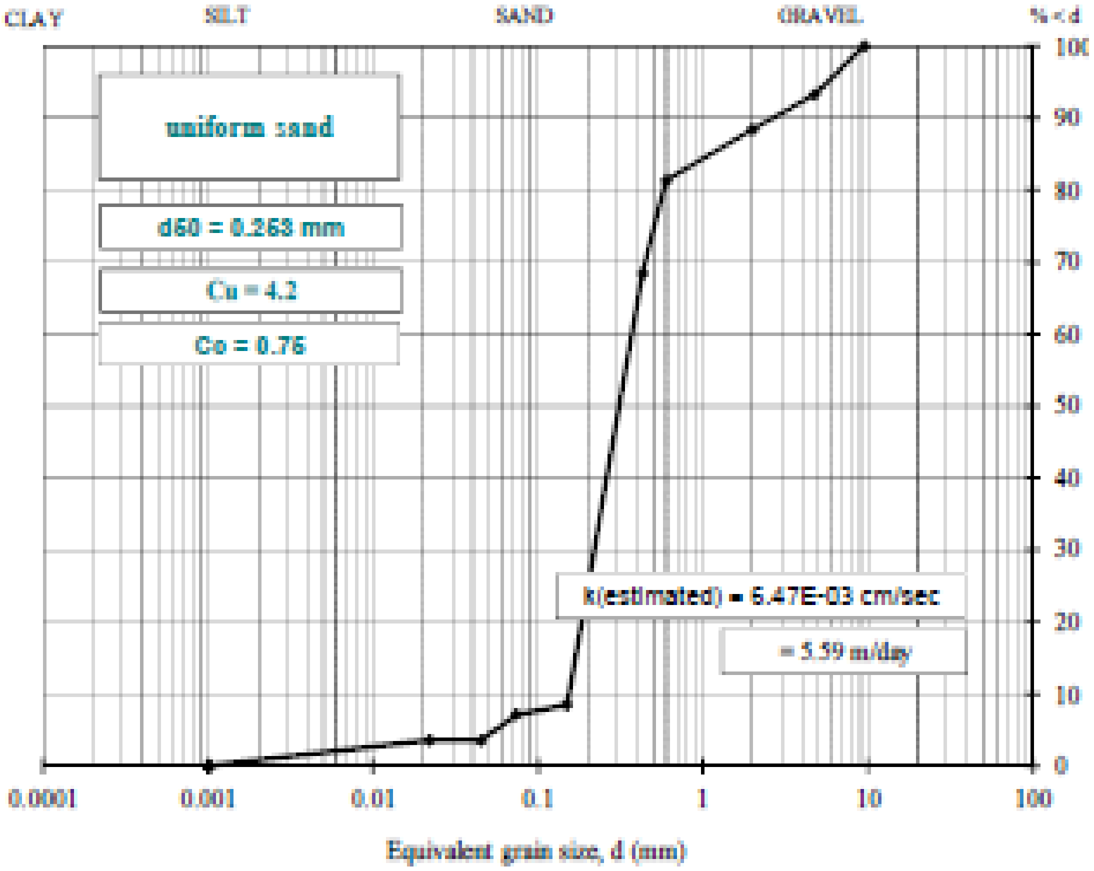
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

**Project:** Master Research-Study- (Eng. Basem Serdah)
**Bore Hole No.** BH1
**Depth** 1.5 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 6.7 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 6.7 | |
| 3/8" | 9.50 | 107.0 | 100.0 | Coarse sand | 4.9 | 86.2 |
| Nr. 4 | 4.75 | 99.8 | 93.3 | Medium sand | 20.0 | |
| Nr. 10 | 2.00 | 94.6 | 88.4 | Fine sand | 61.3 | |
| Nr. 30 | 0.60 | 87.0 | 81.3 | Coarse silt | 3.55 | 5.04 |
| Nr. 40 | 0.43 | 73.2 | 68.4 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 9.1 | 8.5 | | | |
| Nr. 200 | 0.07 | 7.6 | 7.1 | Fine silt | 1.49 | |
| Pan | --- | 0.0 | 0.0 | Clay | 2.06 | 2.06 |

*Percentages relative to entire sample mass



# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

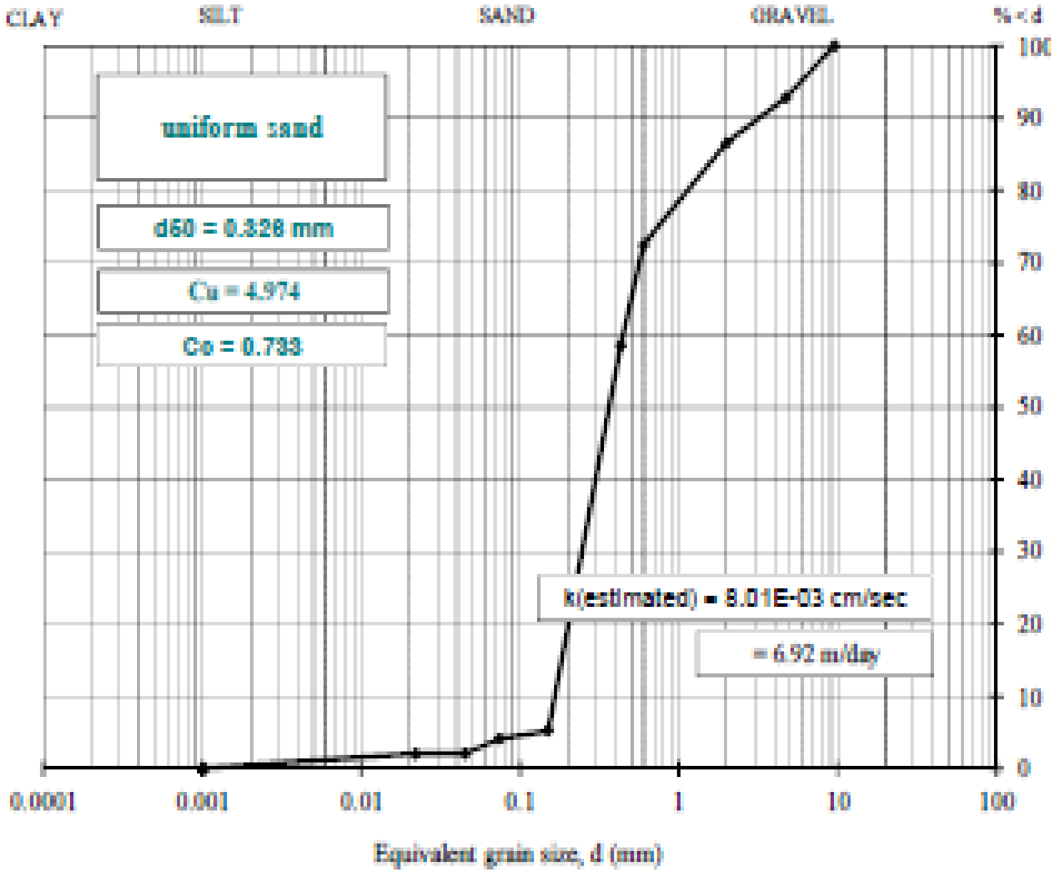
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH1

**Depth** 1.8 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 7.1 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 7.1 | |
| 3/8" | 9.50 | 97.2 | 100.0 | Coarse sand | 6.3 | 88.8 |
| Nr. 4 | 4.75 | 90.3 | 92.9 | Medium sand | 28.1 | |
| Nr. 10 | 2.00 | 84.2 | 86.6 | Fine sand | 54.4 | |
| Nr. 30 | 0.60 | 70.5 | 72.5 | Coarse silt | 2.06 | 2.92 |
| Nr. 40 | 0.43 | 56.9 | 58.5 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 5.1 | 5.2 | | | |
| Nr. 200 | 0.07 | 4.0 | 4.1 | Fine silt | 0.86 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.19 | 1.19 |

*Percentages relative to entire sample mass



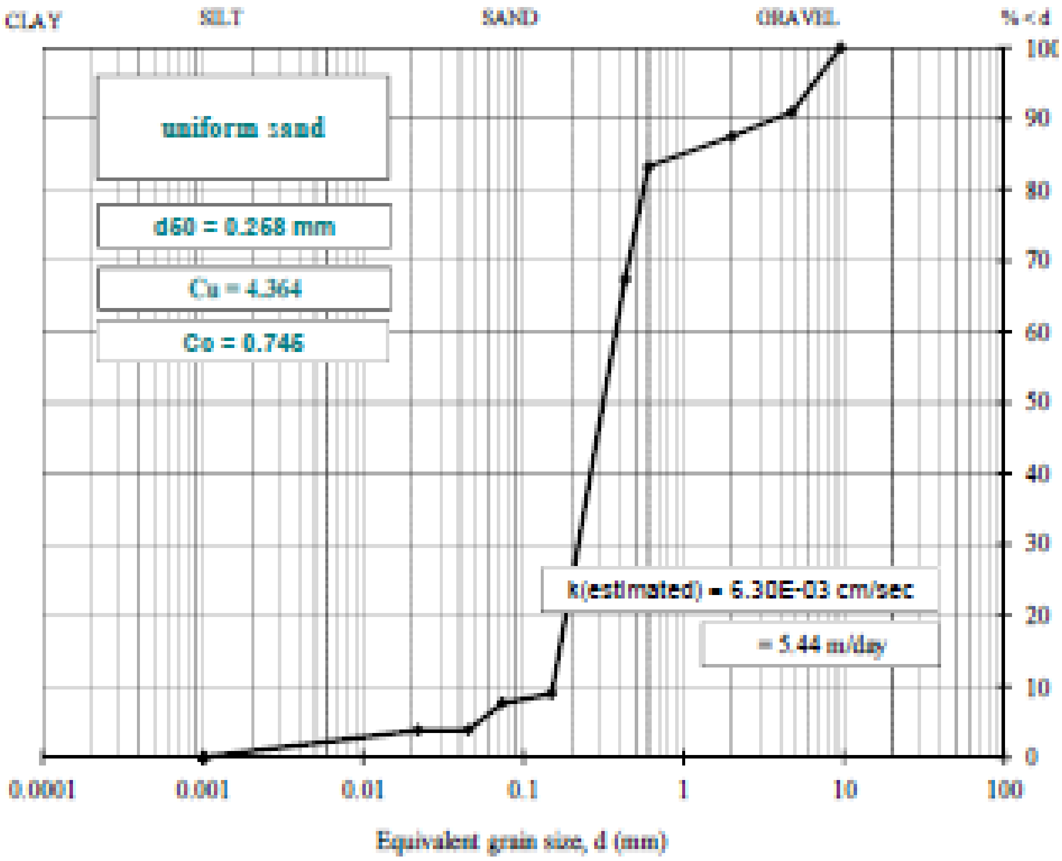
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

**Project:** Master Research-Study- (Eng. Basem Serdah)
**Bore Hole No.** BH1
**Depth** 2.1 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 9.0 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 9.0 | |
| 3/8" | 9.50 | 119.4 | 100.0 | Coarse sand | 3.4 | 83.3 |
| Nr. 4 | 4.75 | 108.6 | 91.0 | Medium sand | 20.2 | |
| Nr. 10 | 2.00 | 104.5 | 87.5 | Fine sand | 59.7 | |
| Nr. 30 | 0.60 | 99.4 | 83.2 | Coarse silt | 3.81 | 5.41 |
| Nr. 40 | 0.43 | 80.4 | 67.3 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 10.7 | 9.0 | | | |
| Nr. 200 | 0.07 | 9.1 | 7.6 | Fine silt | 1.60 | |
| Pan | --- | 0.0 | 0.0 | Clay | 2.21 | 2.21 |

*Percentages relative to entire sample mass



# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

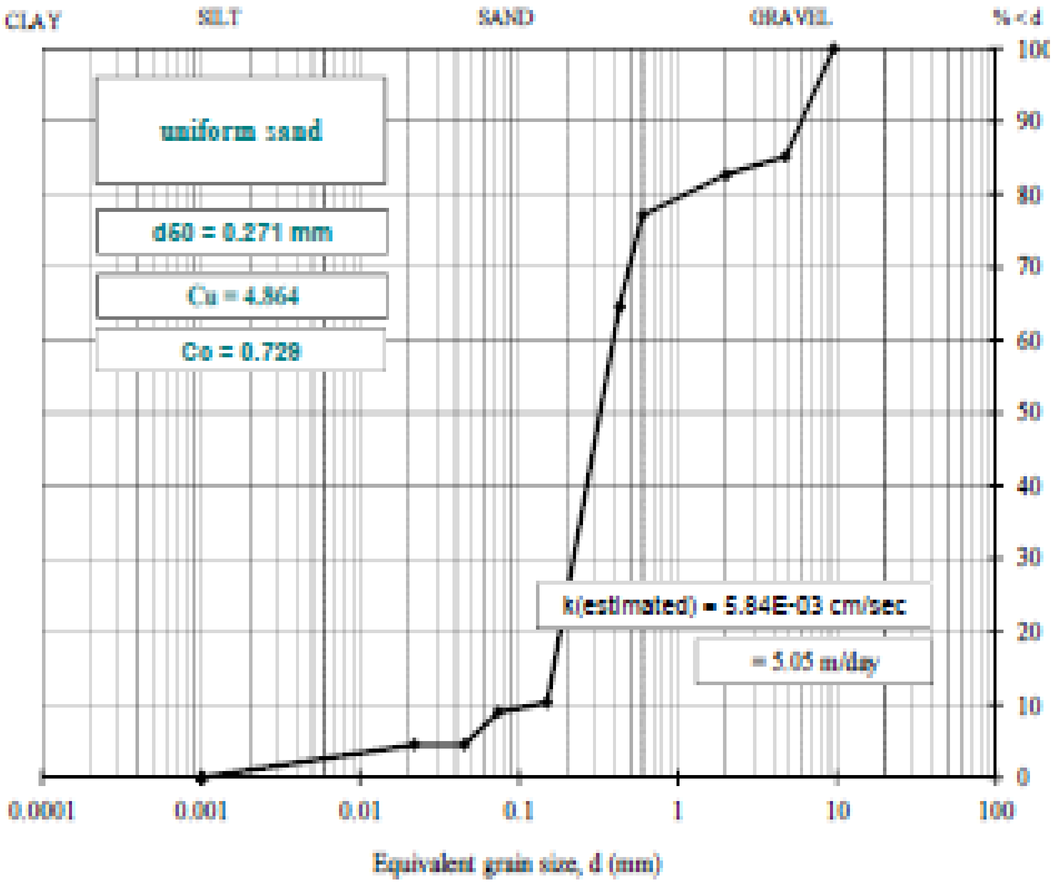
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH1

**Depth** 3.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 14.8 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 14.8 | |
| 3/8" | 9.50 | 114.7 | 100.0 | Coarse sand | 2.5 | 76.2 |
| Nr. 4 | 4.75 | 97.7 | 85.2 | Medium sand | 18.0 | |
| Nr. 10 | 2.00 | 94.8 | 82.7 | Fine sand | 55.6 | |
| Nr. 30 | 0.60 | 88.5 | 77.2 | Coarse silt | 4.49 | 6.38 |
| Nr. 40 | 0.43 | 74.1 | 64.6 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 11.8 | 10.3 | | | |
| Nr. 200 | 0.07 | 10.3 | 9.0 | Fine silt | 1.89 | |
| Pan | --- | 0.0 | 0.0 | Clay | 2.60 | 2.60 |

*Percentages relative to entire sample mass



# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

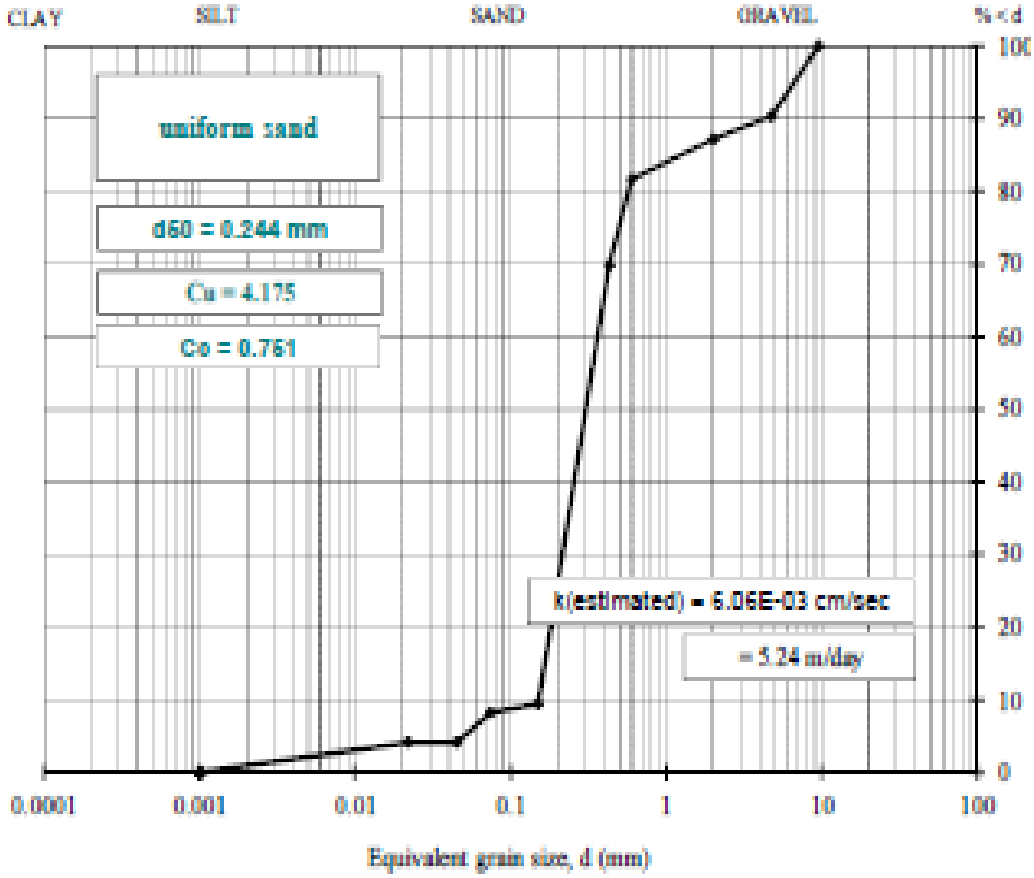
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH1

**Depth** 4.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 9.7 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 9.7 | |
| 3/8" | 9.50 | 97.3 | 100.0 | Coarse sand | 3.2 | 82.1 |
| Nr. 4 | 4.75 | 87.9 | 90.3 | Medium sand | 17.4 | |
| Nr. 10 | 2.00 | 84.8 | 87.2 | Fine sand | 61.6 | |
| Nr. 30 | 0.60 | 79.4 | 81.6 | Coarse silt | 4.11 | 5.84 |
| Nr. 40 | 0.43 | 67.9 | 69.8 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 9.2 | 9.5 | | | |
| Nr. 200 | 0.07 | 8.0 | 8.2 | Fine silt | 1.73 | |
| Pan | --- | 0.0 | 0.0 | Clay | 2.38 | 2.38 |

*Percentages relative to entire sample mass



# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

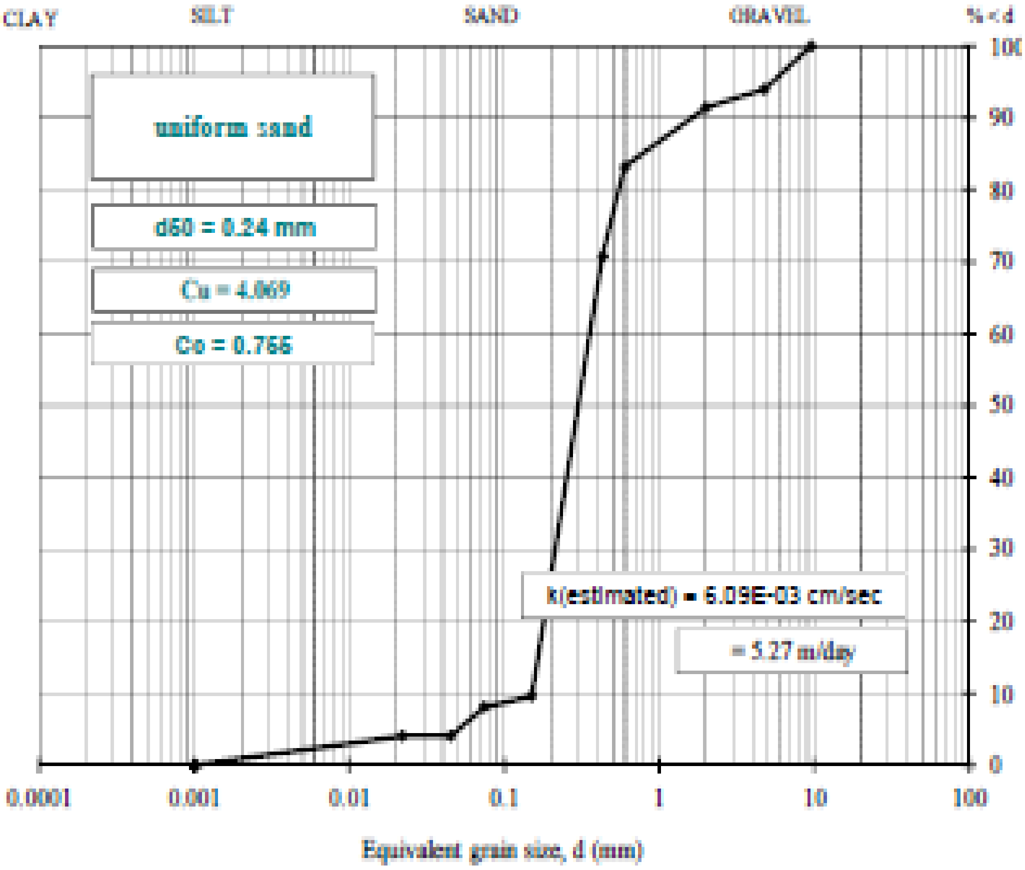
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH1

**Depth** 5.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 6.0 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 6.0 | |
| 3/8" | 9.50 | 107.5 | 100.0 | Coarse sand | 2.5 | 85.9 |
| Nr. 4 | 4.75 | 101.0 | 94.0 | Medium sand | 20.7 | |
| Nr. 10 | 2.00 | 98.3 | 91.4 | Fine sand | 62.7 | |
| Nr. 30 | 0.60 | 89.5 | 83.3 | Coarse silt | 4.05 | 5.75 |
| Nr. 40 | 0.43 | 76.1 | 70.8 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 10.3 | 9.6 | | | |
| Nr. 200 | 0.07 | 8.7 | 8.1 | Fine silt | 1.70 | |
| Pan | --- | 0.0 | 0.0 | Clay | 2.35 | 2.35 |

*Percentages relative to entire sample mass



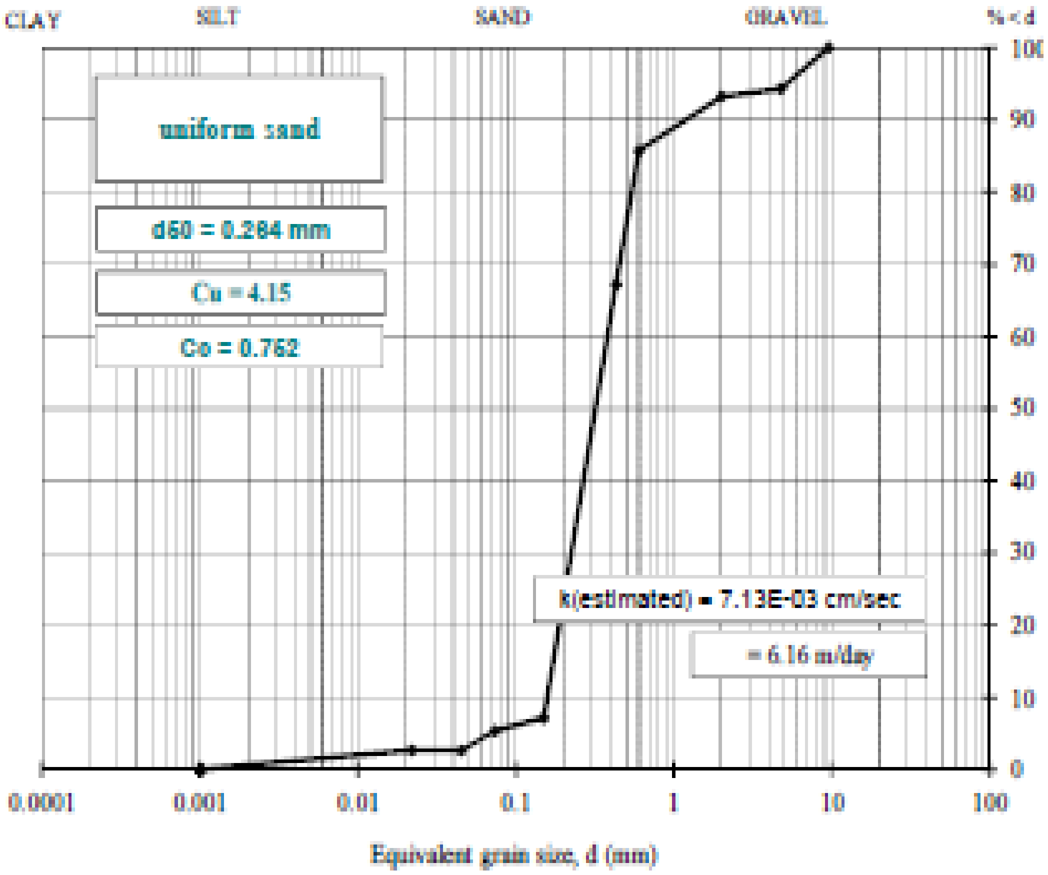
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

**Project:** Master Research-Study- (Eng. Basem Serdah)
**Bore Hole No.** BH1
**Depth** 6.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 5.7 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 5.7 | |
| 3/8" | 9.50 | 173.7 | 100.0 | Coarse sand | 1.1 | 88.9 |
| Nr. 4 | 4.75 | 163.8 | 94.3 | Medium sand | 26.0 | |
| Nr. 10 | 2.00 | 161.9 | 93.2 | Fine sand | 61.8 | |
| Nr. 30 | 0.60 | 148.9 | 85.7 | Coarse silt | 2.68 | 3.80 |
| Nr. 40 | 0.43 | 116.7 | 67.2 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 12.4 | 7.1 | | | |
| Nr. 200 | 0.07 | 9.3 | 5.4 | Fine silt | 1.13 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.55 | 1.55 |

*Percentages relative to entire sample mass



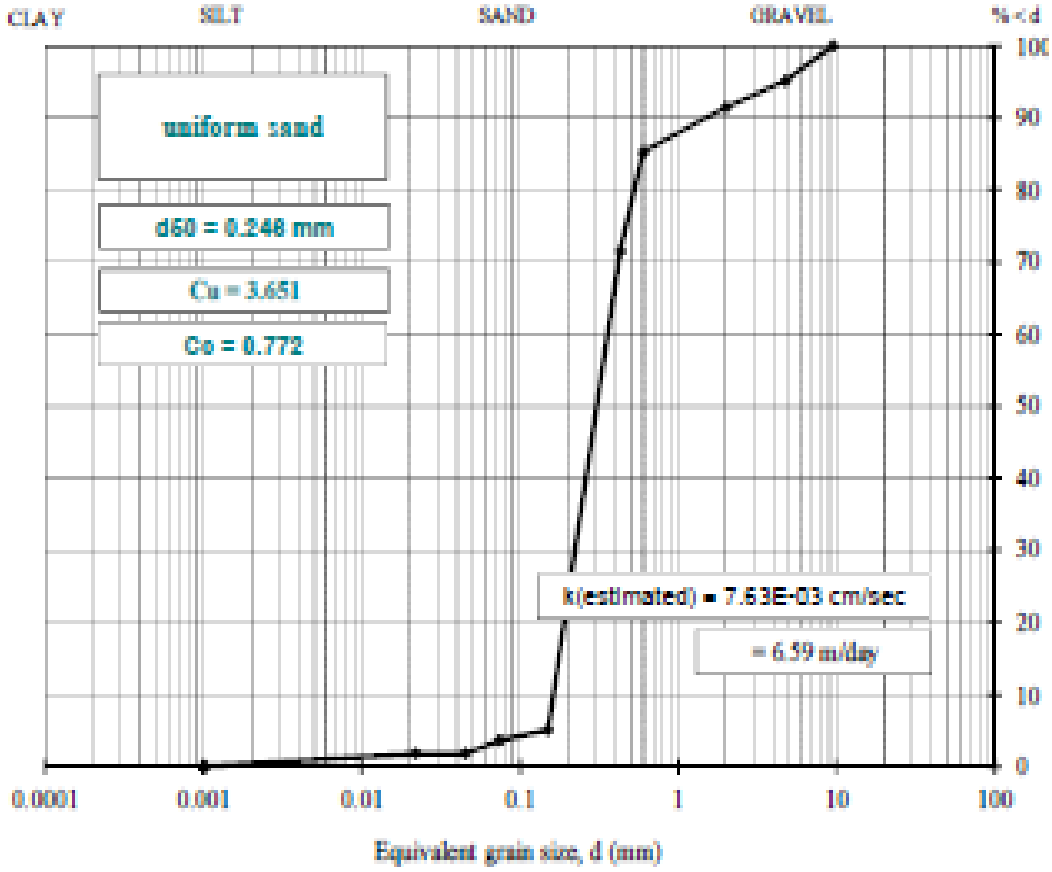
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH1 |
| **Depth** | 7.0 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 4.9 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 4.9 | |
| 3/8" | 9.50 | 144.1 | 100.0 | Coarse sand | 3.7 | 91.5 |
| Nr. 4 | 4.75 | 137.1 | 95.1 | Medium sand | 19.9 | |
| Nr. 10 | 2.00 | 131.8 | 91.5 | Fine sand | 67.9 | |
| Nr. 30 | 0.60 | 122.9 | 85.3 | Coarse silt | 1.80 | 2.56 |
| Nr. 40 | 0.43 | 103.1 | 71.5 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 7.3 | 5.1 | | | |
| Nr. 200 | 0.07 | 5.2 | 3.6 | Fine silt | 0.76 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.05 | 1.05 |

*Percentages relative to entire sample mass



# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

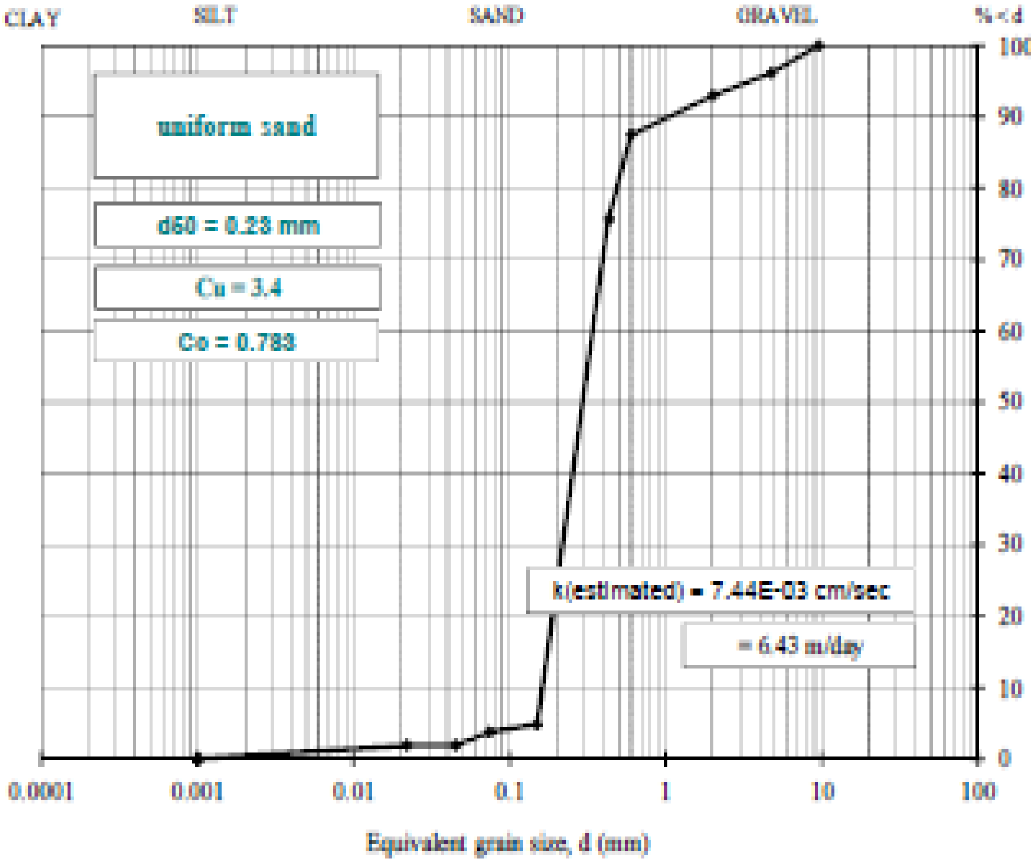
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH1

**Depth** 8.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 3.8 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 3.8 | |
| 3/8" | 9.50 | 101.4 | 100.0 | Coarse sand | 3.2 | 92.4 |
| Nr. 4 | 4.75 | 97.5 | 96.2 | Medium sand | 17.4 | |
| Nr. 10 | 2.00 | 94.3 | 93.0 | Fine sand | 71.9 | |
| Nr. 30 | 0.60 | 88.7 | 87.5 | Coarse silt | 1.87 | 2.66 |
| Nr. 40 | 0.43 | 76.7 | 75.6 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 4.9 | 4.8 | | | |
| Nr. 200 | 0.07 | 3.8 | 3.7 | Fine silt | 0.79 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.09 | 1.09 |

*Percentages relative to entire sample mass



# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

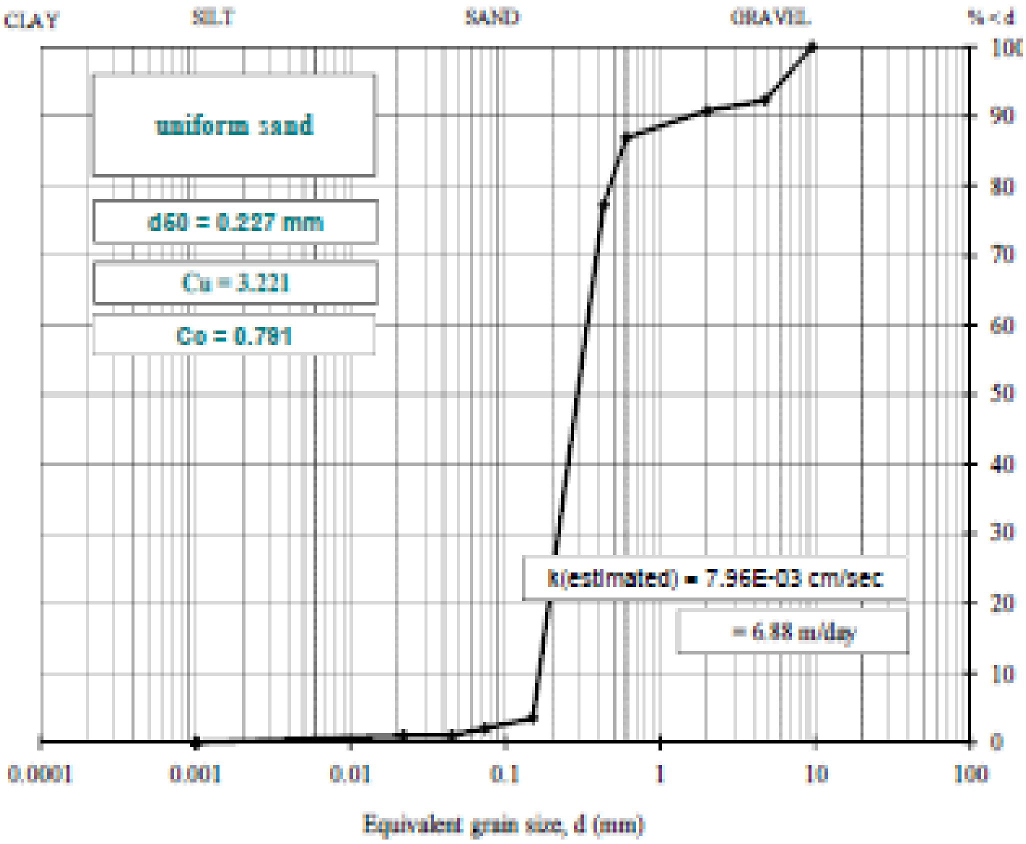
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH1

**Depth** 9.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 7.7 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 7.7 | |
| 3/8" | 9.50 | 104.5 | 100.0 | Coarse sand | 1.5 | 90.3 |
| Nr. 4 | 4.75 | 96.5 | 92.3 | Medium sand | 13.6 | |
| Nr. 10 | 2.00 | 94.9 | 90.8 | Fine sand | 75.2 | |
| Nr. 30 | 0.60 | 90.8 | 86.9 | Coarse silt | 1.00 | 1.43 |
| Nr. 40 | 0.43 | 80.7 | 77.2 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 3.6 | 3.4 | | | |
| Nr. 200 | 0.07 | 2.1 | 2.0 | Fine silt | 0.42 | |
| Pan | --- | 0.0 | 0.0 | Clay | 0.58 | 0.58 |

*Percentages relative to entire sample mass



## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

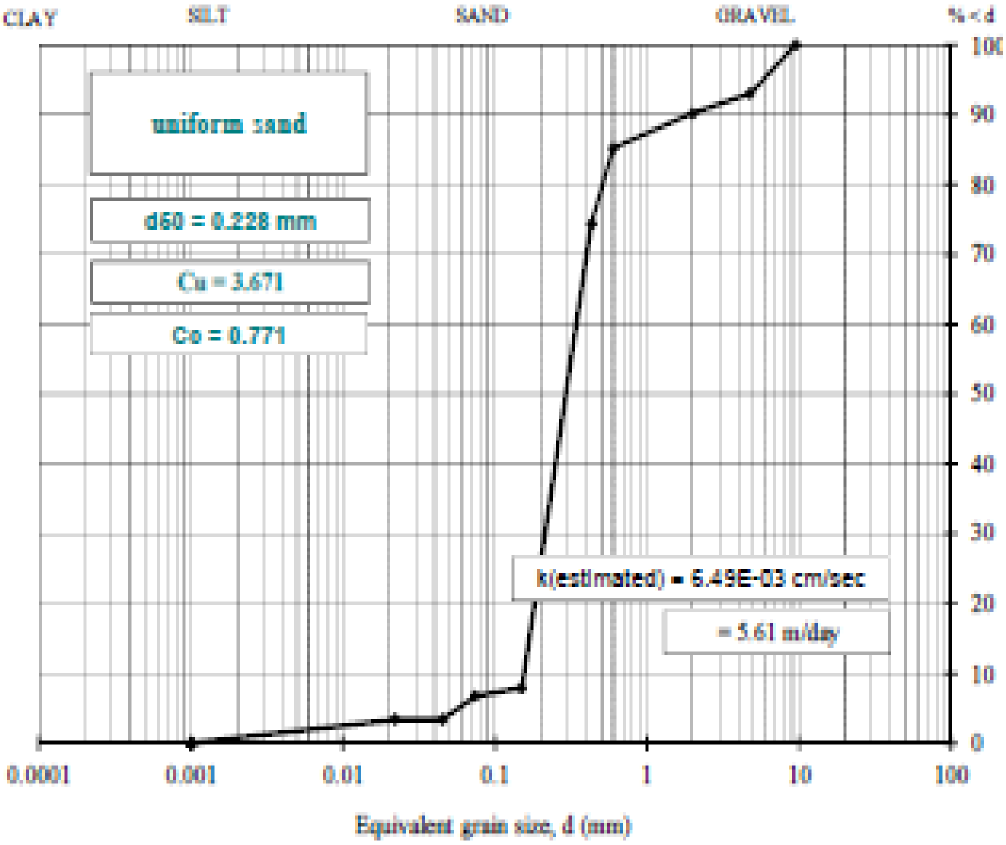
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH1

**Depth** 10.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 7.0 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 7.0 | |
| 3/8" | 9.50 | 120.3 | 100.0 | Coarse sand | 2.8 | 86.3 |
| Nr. 4 | 4.75 | 111.9 | 93.0 | Medium sand | 15.8 | |
| Nr. 10 | 2.00 | 108.5 | 90.2 | Fine sand | 67.7 | |
| Nr. 30 | 0.60 | 102.5 | 85.2 | Coarse silt | 3.37 | 4.78 |
| Nr. 40 | 0.43 | 89.5 | 74.4 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 9.5 | 7.9 | | | |
| Nr. 200 | 0.07 | 8.1 | 6.7 | Fine silt | 1.42 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.95 | 1.95 |

*Percentages relative to entire sample mass



# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

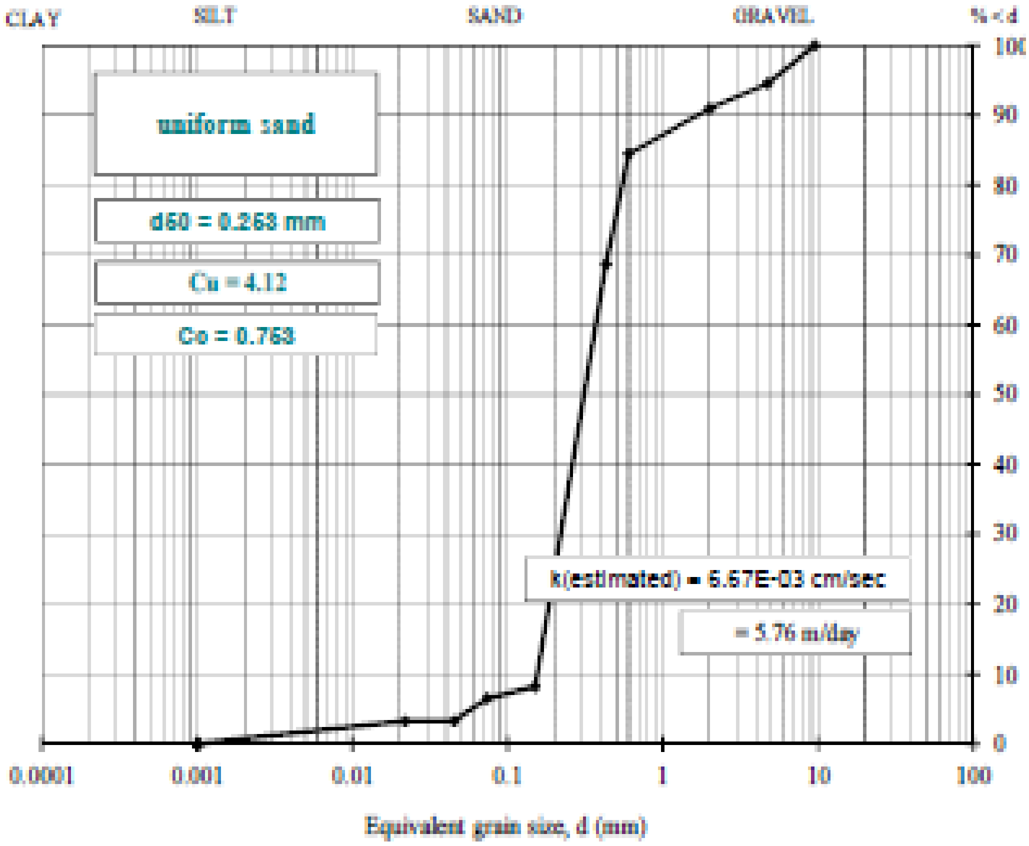
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH1

**Depth** 11.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 5.5 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 5.5 | |
| 3/8" | 9.50 | 114.9 | 100.0 | Coarse sand | 3.6 | 88.0 |
| Nr. 4 | 4.75 | 108.6 | 94.5 | Medium sand | 22.3 | |
| Nr. 10 | 2.00 | 104.5 | 90.9 | Fine sand | 62.1 | |
| Nr. 30 | 0.60 | 97.0 | 84.4 | Coarse silt | 3.26 | 4.64 |
| Nr. 40 | 0.43 | 78.9 | 68.7 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 9.4 | 8.2 | | | |
| Nr. 200 | 0.07 | 7.5 | 6.5 | Fine silt | 1.37 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.89 | 1.89 |

*Percentages relative to entire sample mass



## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

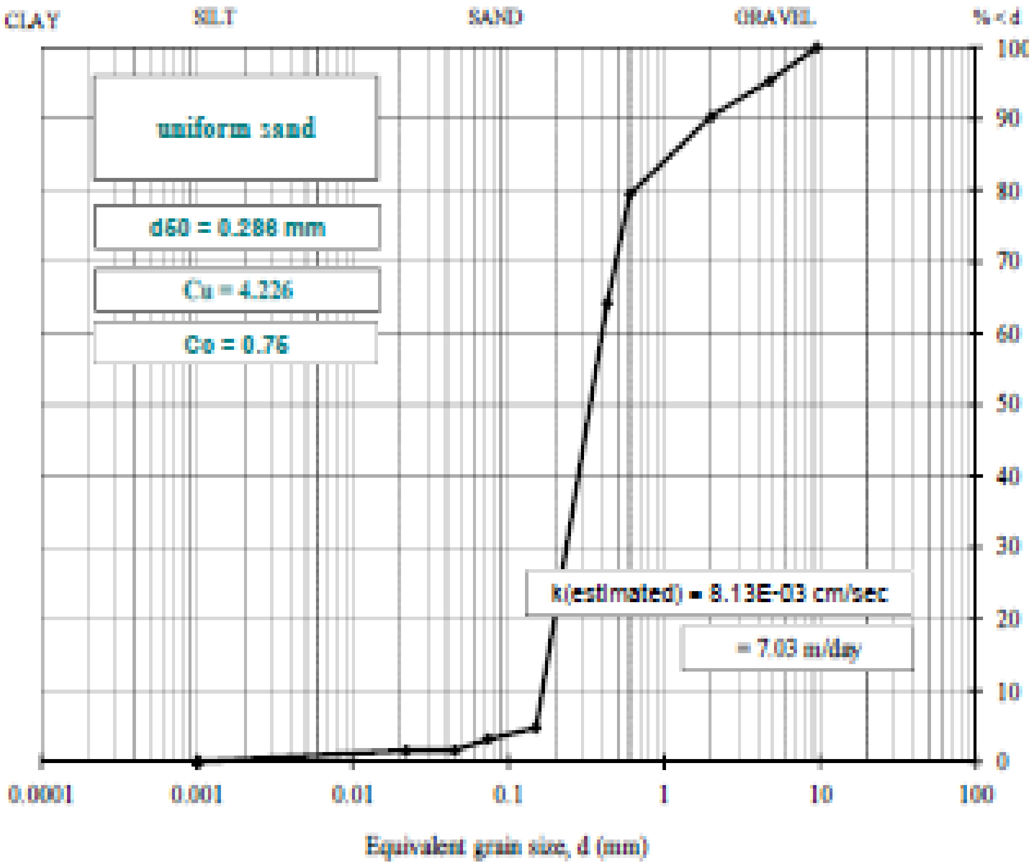
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH1

**Depth** 12.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 4.7 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 4.7 | |
| 3/8" | 9.50 | 86.0 | 100.0 | Coarse sand | 5.0 | 92.2 |
| Nr. 4 | 4.75 | 82.0 | 95.3 | Medium sand | 26.2 | |
| Nr. 10 | 2.00 | 77.7 | 90.3 | Fine sand | 61.0 | |
| Nr. 30 | 0.60 | 68.3 | 79.4 | Coarse silt | 1.57 | 2.23 |
| Nr. 40 | 0.43 | 55.2 | 64.2 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 4.1 | 4.8 | | | |
| Nr. 200 | 0.07 | 2.7 | 3.1 | Fine silt | 0.66 | |
| Pan | --- | 0.0 | 0.0 | Clay | 0.91 | 0.91 |

*Percentages relative to entire sample mass



## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

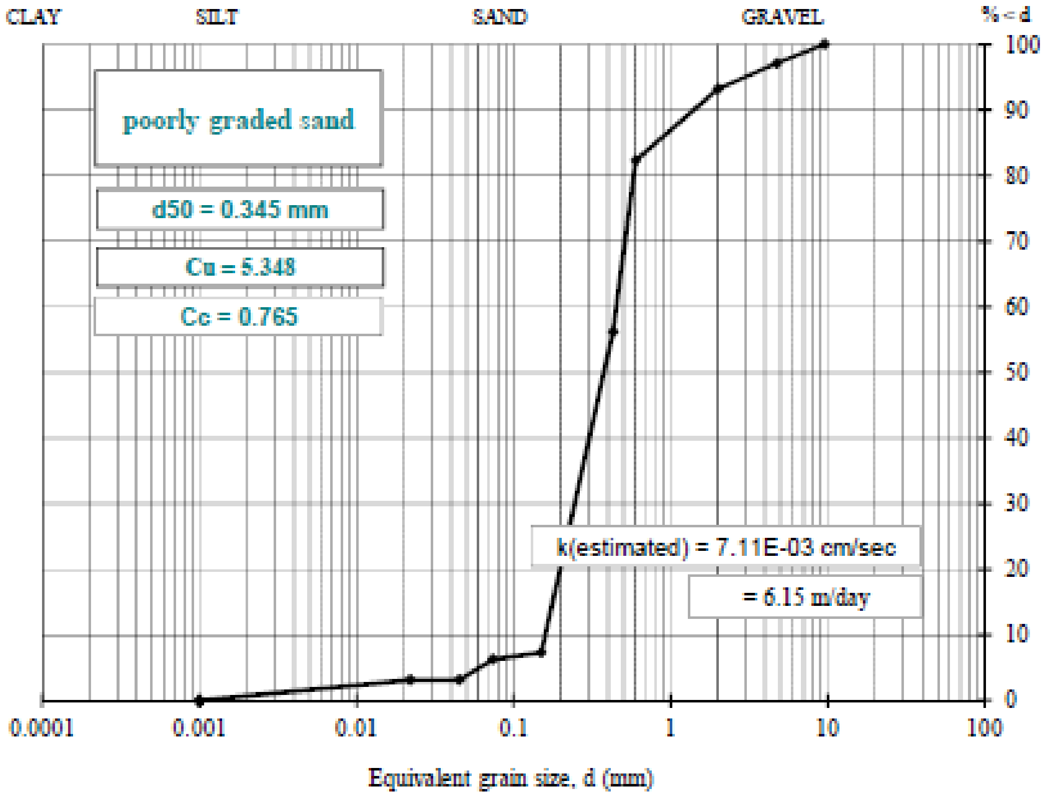
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH2

**Depth** 0.3 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 2.9 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 2.9 | |
| 3/8" | 9.50 | 125.7 | 100.0 | Coarse sand | 3.9 | 90.9 |
| Nr. 4 | 4.75 | 122.1 | 97.1 | Medium sand | 37.0 | |
| Nr. 10 | 2.00 | 117.2 | 93.2 | Fine sand | 50.0 | |
| Nr. 30 | 0.60 | 103.5 | 82.3 | Coarse silt | 3.14 | 4.46 |
| Nr. 40 | 0.43 | 70.7 | 56.2 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 9.2 | 7.3 | | | |
| Nr. 200 | 0.07 | 7.9 | 6.3 | Fine silt | 1.32 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.82 | 1.82 |

*Percentages relative to entire sample mass



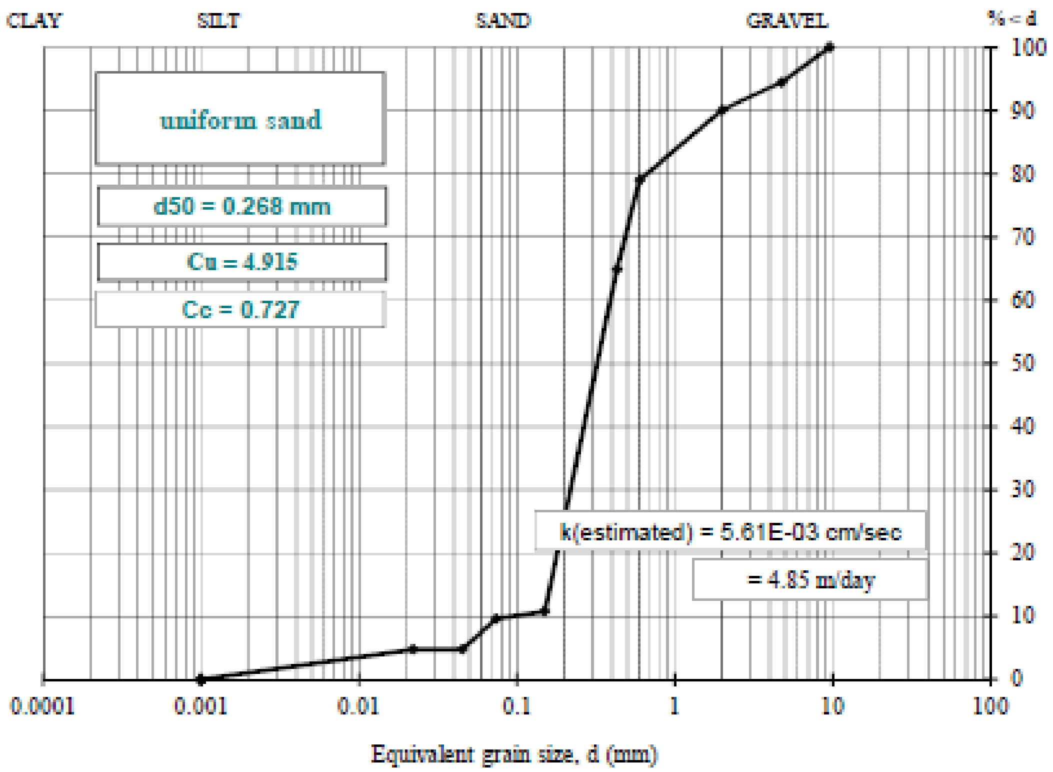
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH2 |
| **Depth** | 0.6 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 5.6 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 5.6 | |
| 3/8" | 9.50 | 120.7 | 100.0 | Coarse sand | 4.3 | 84.8 |
| Nr. 4 | 4.75 | 114.0 | 94.4 | Medium sand | 25.3 | |
| Nr. 10 | 2.00 | 108.8 | 90.1 | Fine sand | 55.3 | |
| Nr. 30 | 0.60 | 95.4 | 79.0 | Coarse silt | 4.81 | 6.83 |
| Nr. 40 | 0.43 | 78.3 | 64.9 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 13.0 | 10.8 | | | |
| Nr. 200 | 0.07 | 11.6 | 9.6 | Fine silt | 2.02 | |
| Pan | --- | 0.0 | 0.0 | Clay | 2.79 | 2.79 |

*Percentages relative to entire sample mass



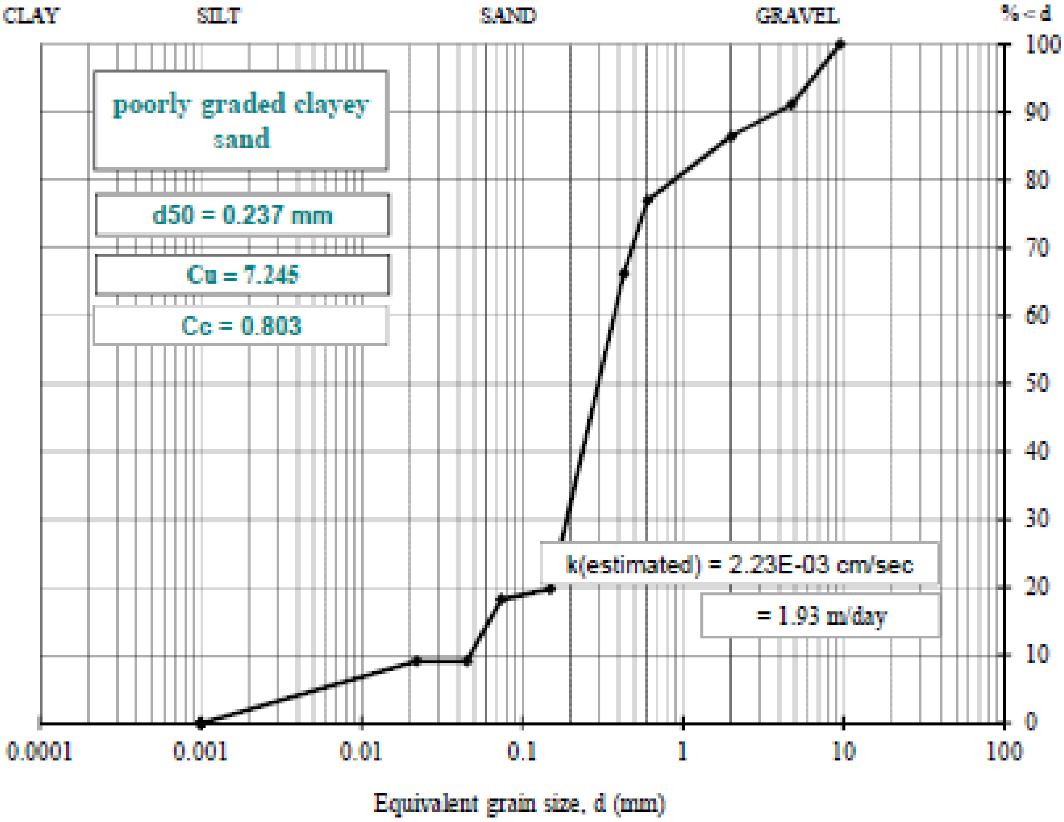
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH2 |
| **Depth** | 0.9 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 8.9 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 8.9 | |
| 3/8" | 9.50 | 125.0 | 100.0 | Coarse sand | 4.6 | 72.9 |
| Nr. 4 | 4.75 | 113.9 | 91.1 | Medium sand | 20.2 | |
| Nr. 10 | 2.00 | 108.1 | 86.5 | Fine sand | 48.0 | |
| Nr. 30 | 0.60 | 96.2 | 77.0 | Coarse silt | 9.12 | 12.95 |
| Nr. 40 | 0.43 | 82.8 | 66.2 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 24.7 | 19.8 | | | |
| Nr. 200 | 0.07 | 22.8 | 18.2 | Fine silt | 3.83 | |
| Pan | --- | 0.0 | 0.0 | Clay | 5.29 | 5.29 |

*Percentages relative to entire sample mass



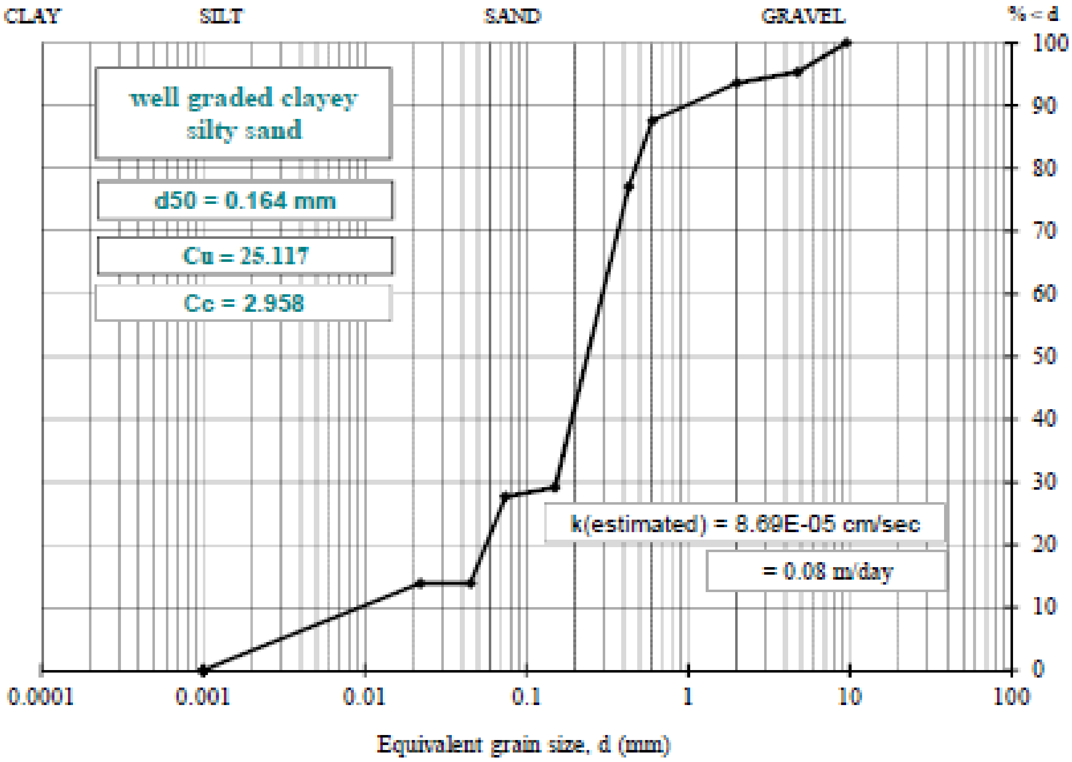
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH2 |
| **Depth** | 1.2 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 4.6 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 4.6 | |
| 3/8" | 9.50 | 195.7 | 100.0 | Coarse sand | 1.7 | 67.7 |
| Nr. 4 | 4.75 | 186.6 | 95.4 | Medium sand | 16.6 | |
| Nr. 10 | 2.00 | 183.2 | 93.6 | Fine sand | 49.4 | |
| Nr. 30 | 0.60 | 171.4 | 87.6 | Coarse silt | 13.85 | 19.67 |
| Nr. 40 | 0.43 | 150.8 | 77.1 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 57.1 | 29.2 | | | |
| Nr. 200 | 0.07 | 54.2 | 27.7 | Fine silt | 5.82 | |
| Pan | --- | 0.0 | 0.0 | Clay | 8.03 | 8.03 |

*Percentages relative to entire sample mass



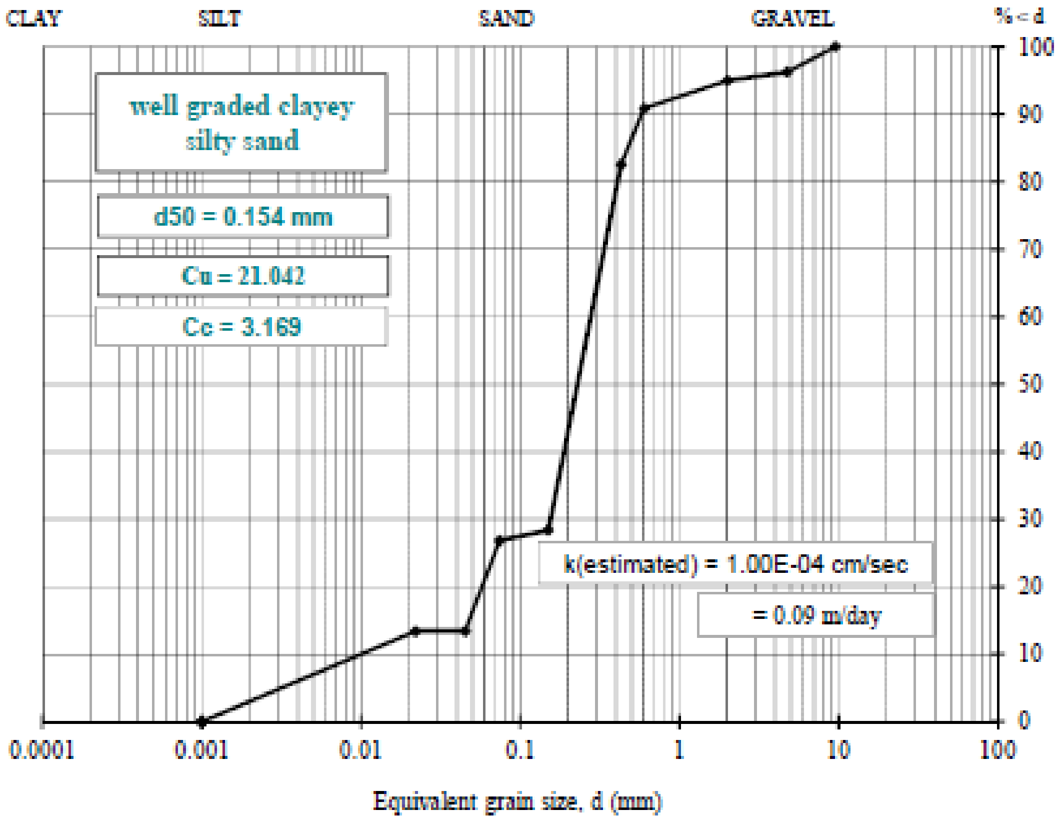
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH2 |
| **Depth** | 1.5 m |

| **Mechanical (sieve) analysis** | | | | **Soil Type** | **%** | **Tot. %** |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 3.7 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 3.7 | |
| 3/8" | 9.50 | 161.0 | 100.0 | Coarse sand | 1.2 | 69.4 |
| Nr. 4 | 4.75 | 155.0 | 96.3 | Medium sand | 12.4 | |
| Nr. 10 | 2.00 | 153.0 | 95.0 | Fine sand | 55.8 | |
| Nr. 30 | 0.60 | 146.3 | 90.9 | Coarse silt | 13.42 | 19.06 |
| Nr. 40 | 0.43 | 133.0 | 82.6 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 45.7 | 28.4 | | | |
| Nr. 200 | 0.07 | 43.2 | 26.8 | Fine silt | 5.64 | |
| Pan | --- | 0.0 | 0.0 | Clay | 7.78 | 7.78 |

*Percentages relative to entire sample mass



# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

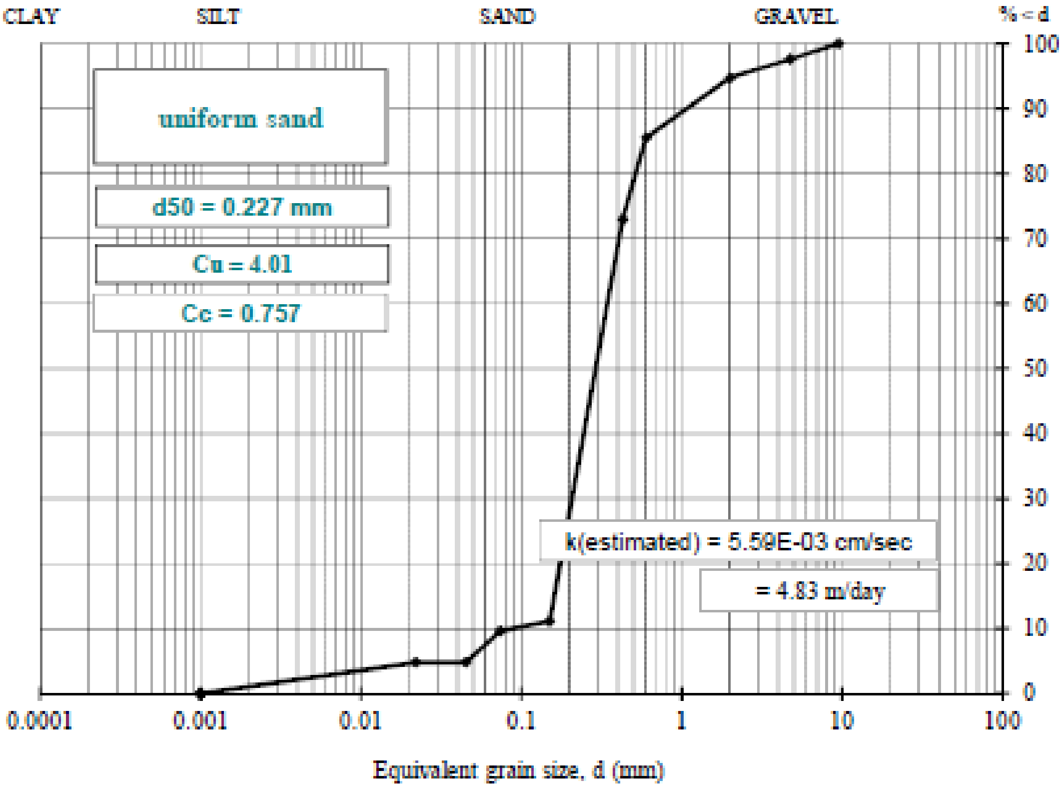
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH2

**Depth** 1.8 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 2.4 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 2.4 | |
| 3/8" | 9.50 | 121.7 | 100.0 | Coarse sand | 2.9 | 88.0 |
| Nr. 4 | 4.75 | 118.8 | 97.6 | Medium sand | 21.8 | |
| Nr. 10 | 2.00 | 115.3 | 94.7 | Fine sand | 63.4 | |
| Nr. 30 | 0.60 | 104.1 | 85.5 | Coarse silt | 4.81 | 6.83 |
| Nr. 40 | 0.43 | 88.8 | 73.0 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 13.5 | 11.1 | | | |
| Nr. 200 | 0.07 | 11.7 | 9.6 | Fine silt | 2.02 | |
| Pan | --- | 0.0 | 0.0 | Clay | 2.79 | 2.79 |

*Percentages relative to entire sample mass



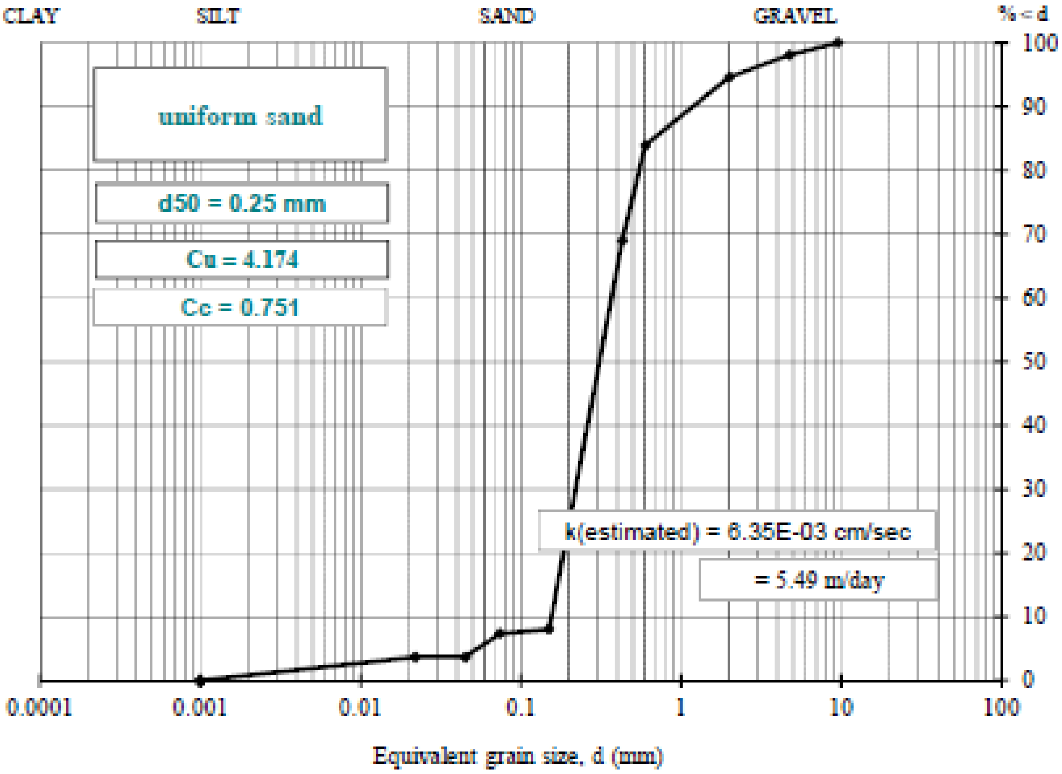
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH2 |
| **Depth** | 2.1 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 1.9 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 1.9 | |
| 3/8" | 9.50 | 87.7 | 100.0 | Coarse sand | 3.4 | 90.6 |
| Nr. 4 | 4.75 | 86.0 | 98.1 | Medium sand | 25.7 | |
| Nr. 10 | 2.00 | 83.0 | 94.6 | Fine sand | 61.6 | |
| Nr. 30 | 0.60 | 73.6 | 83.9 | Coarse silt | 3.71 | 5.26 |
| Nr. 40 | 0.43 | 60.5 | 69.0 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 7.1 | 8.1 | | | |
| Nr. 200 | 0.07 | 6.5 | 7.4 | Fine silt | 1.56 | |
| Pan | --- | 0.0 | 0.0 | Clay | 2.15 | 2.15 |

*Percentages relative to entire sample mass



## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

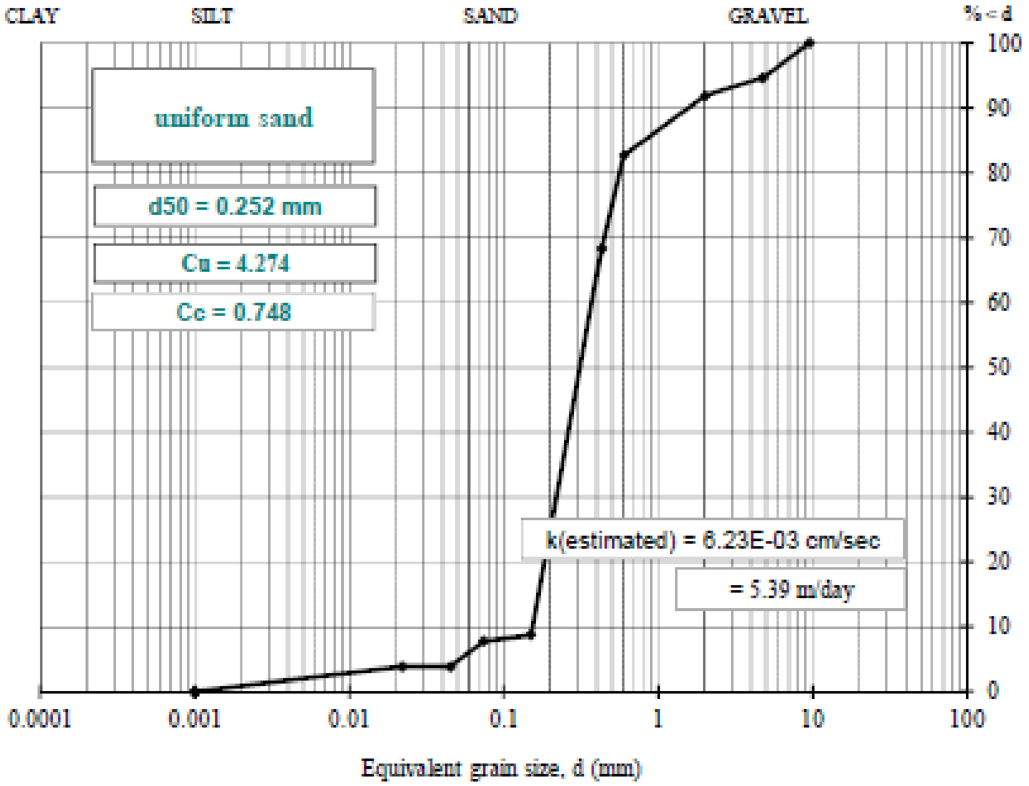
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH2

**Depth** 3.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 5.4 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 5.4 | |
| 3/8" | 9.50 | 101.7 | 100.0 | Coarse sand | 2.8 | 86.8 |
| Nr. 4 | 4.75 | 96.2 | 94.6 | Medium sand | 23.5 | |
| Nr. 10 | 2.00 | 93.4 | 91.8 | Fine sand | 60.6 | |
| Nr. 30 | 0.60 | 84.1 | 82.7 | Coarse silt | 3.88 | 5.52 |
| Nr. 40 | 0.43 | 69.5 | 68.3 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 8.9 | 8.8 | | | |
| Nr. 200 | 0.07 | 7.9 | 7.8 | Fine silt | 1.63 | |
| Pan | --- | 0.0 | 0.0 | Clay | 2.25 | 2.25 |

*Percentages relative to entire sample mass



## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

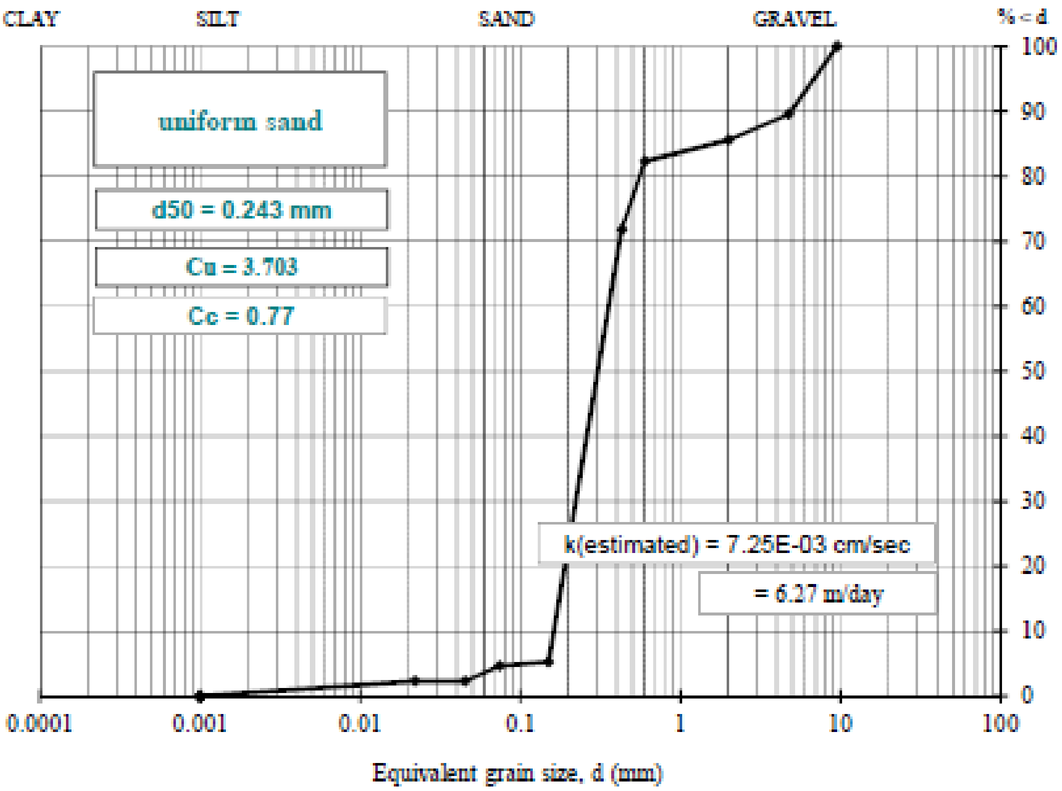
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH2

**Depth** 4.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 10.4 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 10.4 | |
| 3/8" | 9.50 | 122.9 | 100.0 | Coarse sand | 4.0 | 84.9 |
| Nr. 4 | 4.75 | 110.1 | 89.6 | Medium sand | 13.8 | |
| Nr. 10 | 2.00 | 105.2 | 85.6 | Fine sand | 67.2 | |
| Nr. 30 | 0.60 | 101.2 | 82.3 | Coarse silt | 2.32 | 3.29 |
| Nr. 40 | 0.43 | 88.3 | 71.8 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 6.5 | 5.3 | | | |
| Nr. 200 | 0.07 | 5.7 | 4.6 | Fine silt | 0.97 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.34 | 1.34 |

*Percentages relative to entire sample mass



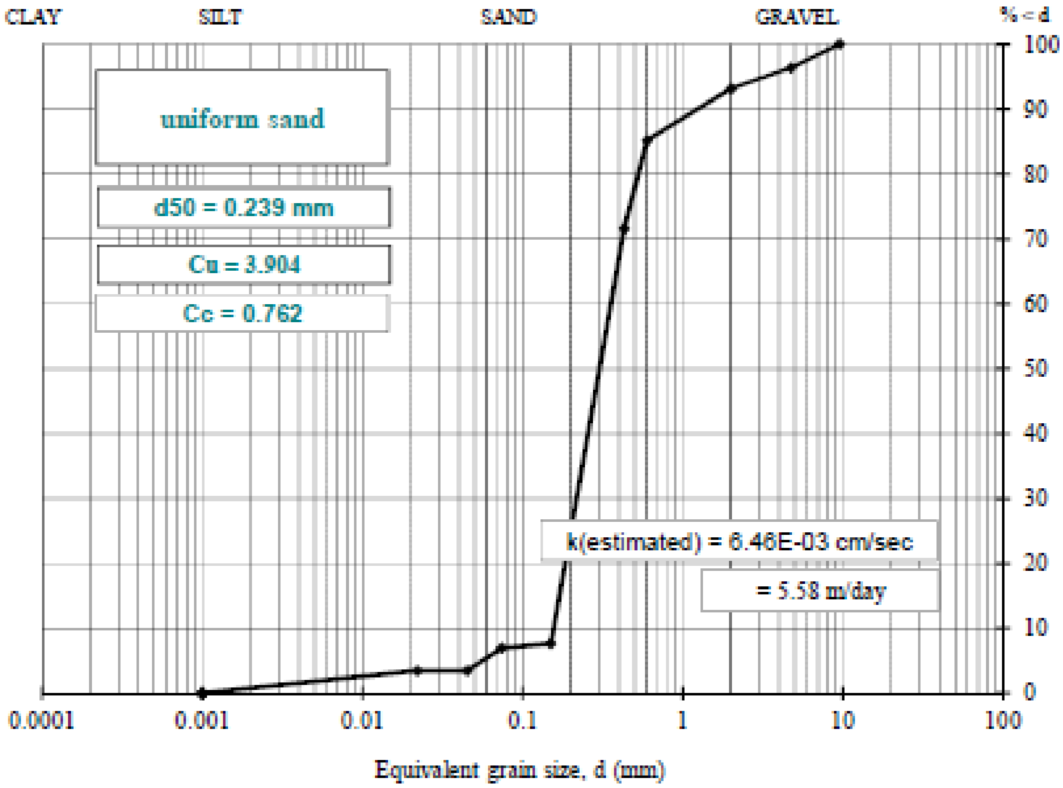
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH2 |
| **Depth** | 5.0 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 3.6 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 3.6 | |
| 3/8" | 9.50 | 127.7 | 100.0 | Coarse sand | 3.2 | 89.4 |
| Nr. 4 | 4.75 | 123.1 | 96.4 | Medium sand | 21.6 | |
| Nr. 10 | 2.00 | 119.0 | 93.2 | Fine sand | 64.6 | |
| Nr. 30 | 0.60 | 108.8 | 85.2 | Coarse silt | 3.48 | 4.95 |
| Nr. 40 | 0.43 | 91.4 | 71.6 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 9.8 | 7.7 | | | |
| Nr. 200 | 0.07 | 8.9 | 7.0 | Fine silt | 1.46 | |
| Pan | --- | 0.0 | 0.0 | Clay | 2.02 | 2.02 |

*Percentages relative to entire sample mass



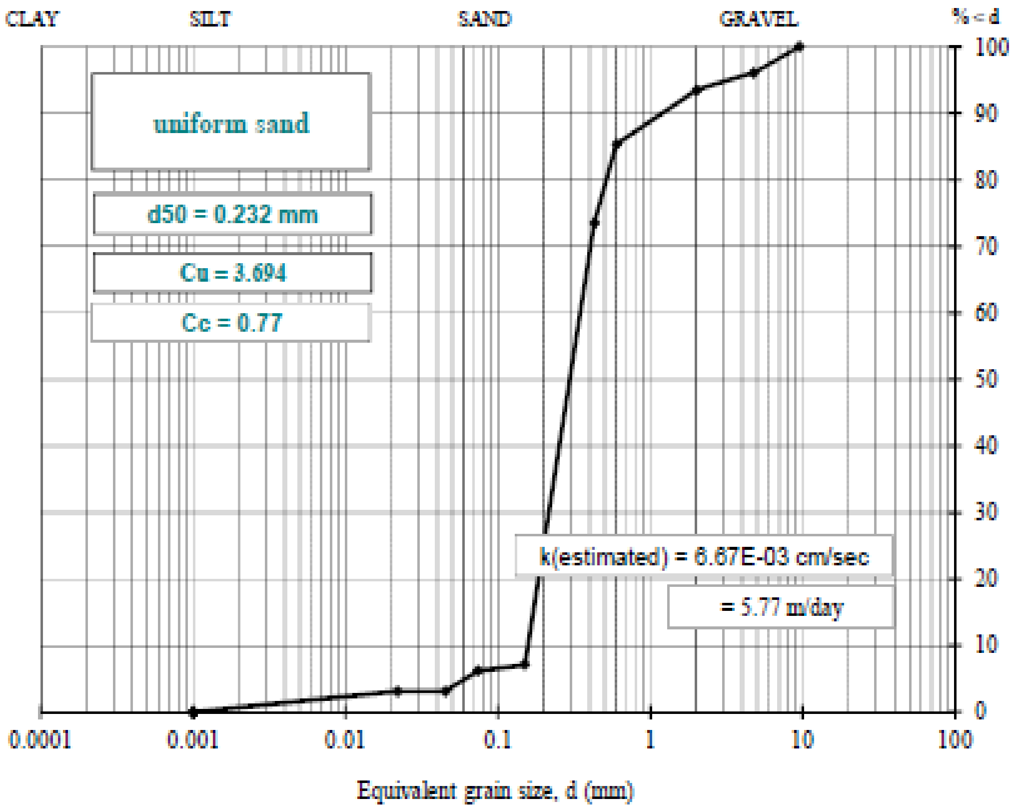
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH2 |
| **Depth** | 6.0 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 3.9 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 3.9 | |
| 3/8" | 9.50 | 99.8 | 100.0 | Coarse sand | 2.6 | 89.9 |
| Nr. 4 | 4.75 | 95.9 | 96.1 | Medium sand | 19.9 | |
| Nr. 10 | 2.00 | 93.3 | 93.5 | Fine sand | 67.3 | |
| Nr. 30 | 0.60 | 85.2 | 85.4 | Coarse silt | 3.11 | 4.41 |
| Nr. 40 | 0.43 | 73.4 | 73.5 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 7.1 | 7.1 | | | |
| Nr. 200 | 0.07 | 6.2 | 6.2 | Fine silt | 1.31 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.80 | 1.80 |

*Percentages relative to entire sample mass



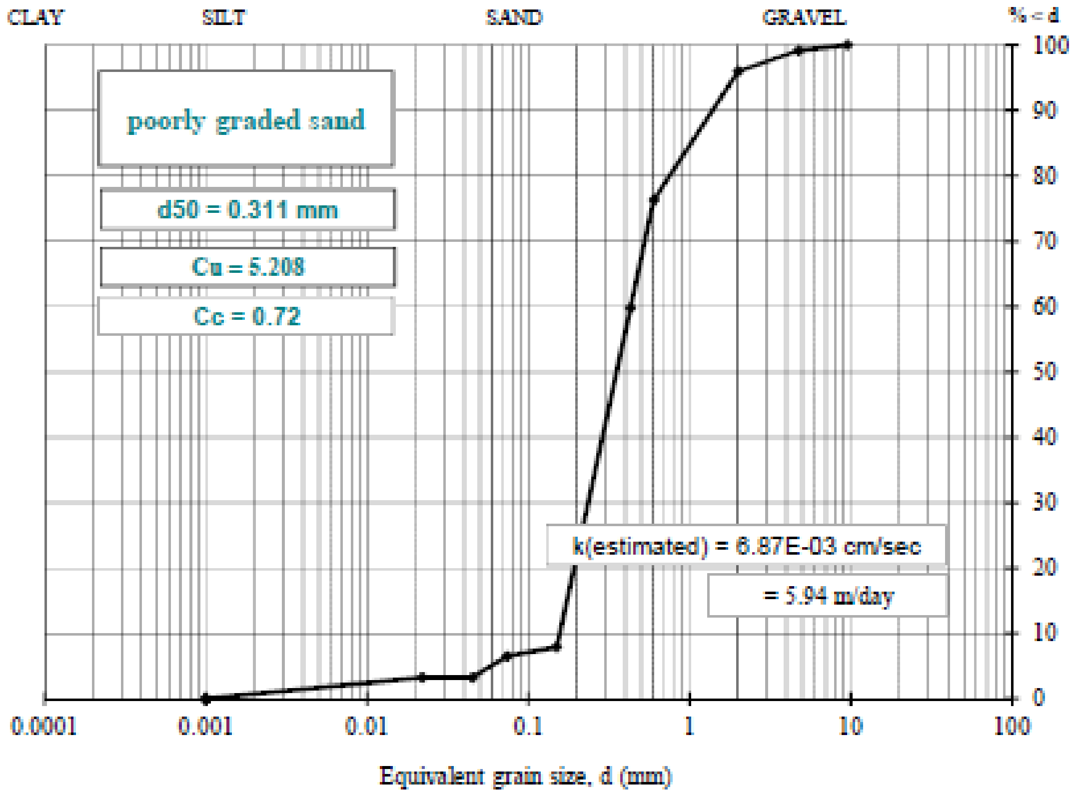
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH2 |
| **Depth** | 7.0 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 0.8 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 0.8 | |
| 3/8" | 9.50 | 94.5 | 100.0 | Coarse sand | 3.2 | 92.6 |
| Nr. 4 | 4.75 | 93.7 | 99.2 | Medium sand | 36.2 | |
| Nr. 10 | 2.00 | 90.7 | 96.0 | Fine sand | 53.2 | |
| Nr. 30 | 0.60 | 72.1 | 76.3 | Coarse silt | 3.28 | 4.66 |
| Nr. 40 | 0.43 | 56.5 | 59.8 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 7.5 | 7.9 | | | |
| Nr. 200 | 0.07 | 6.2 | 6.6 | Fine silt | 1.38 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.90 | 1.90 |

*Percentages relative to entire sample mass



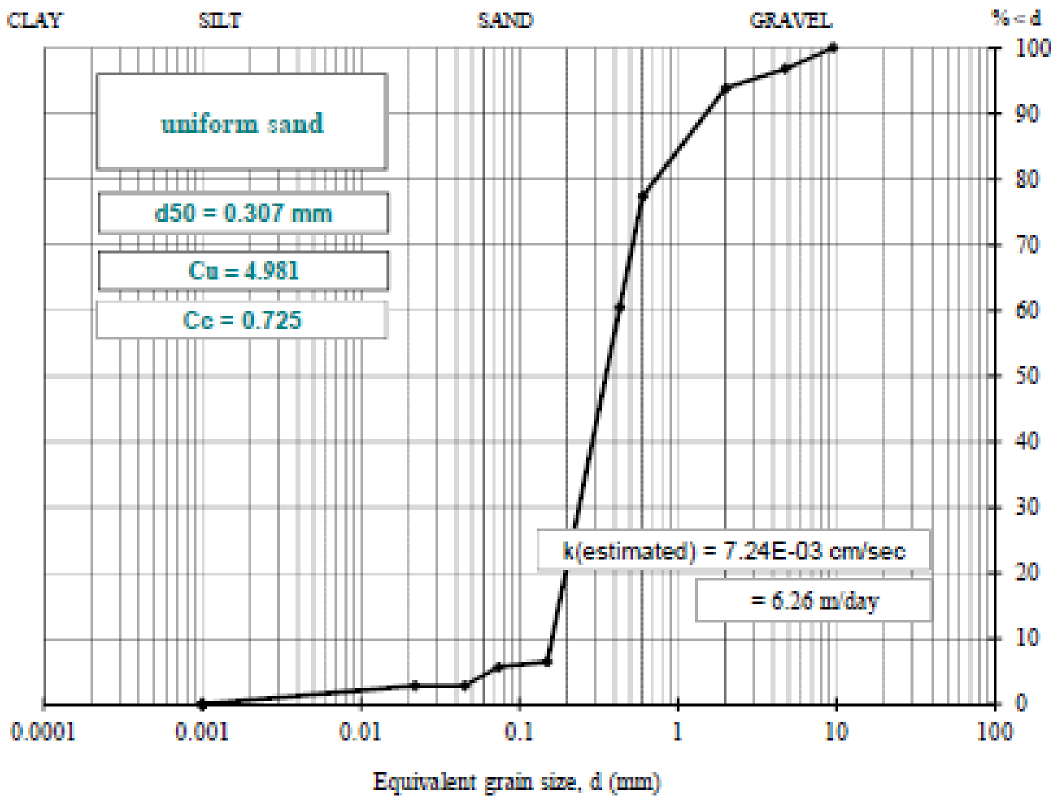
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH2 |
| **Depth** | 8.0 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 3.2 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 3.2 | |
| 3/8" | 9.50 | 146.9 | 100.0 | Coarse sand | 2.9 | 91.2 |
| Nr. 4 | 4.75 | 142.2 | 96.8 | Medium sand | 33.4 | |
| Nr. 10 | 2.00 | 137.9 | 93.9 | Fine sand | 54.8 | |
| Nr. 30 | 0.60 | 113.7 | 77.4 | Coarse silt | 2.83 | 4.01 |
| Nr. 40 | 0.43 | 88.8 | 60.4 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 9.5 | 6.5 | | | |
| Nr. 200 | 0.07 | 8.3 | 5.7 | Fine silt | 1.19 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.64 | 1.64 |

*Percentages relative to entire sample mass



## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

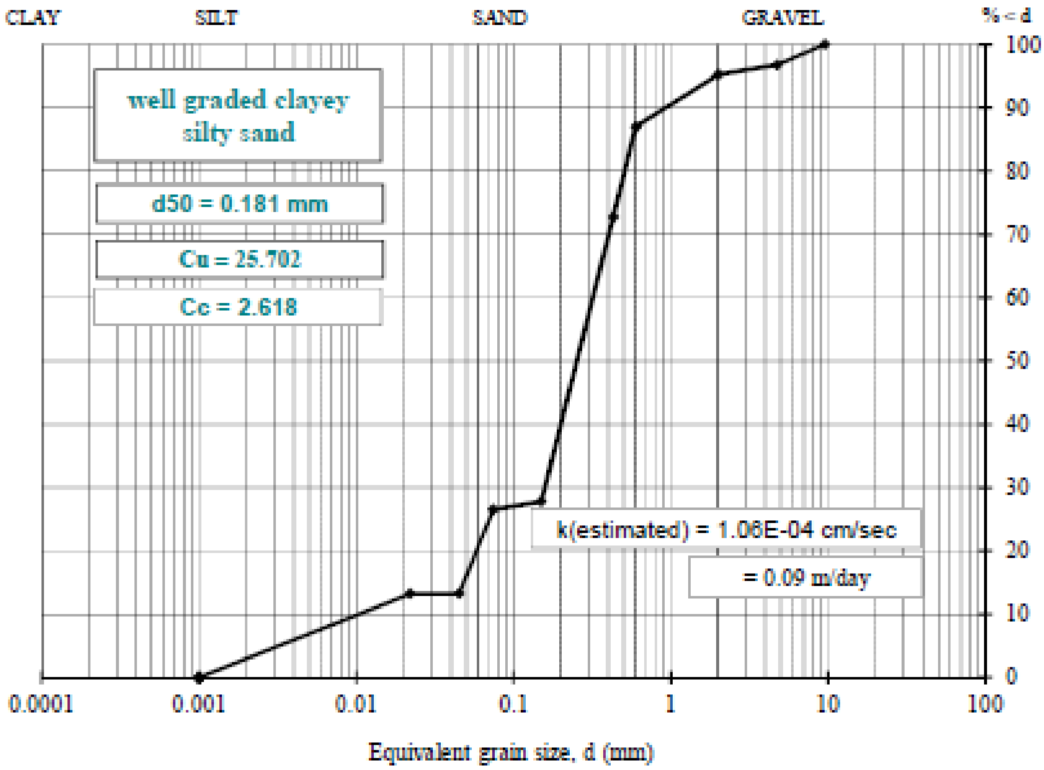
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH2

**Depth** 9.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 3.2 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 3.2 | |
| 3/8" | 9.50 | 180.0 | 100.0 | Coarse sand | 1.6 | 70.3 |
| Nr. 4 | 4.75 | 174.2 | 96.8 | Medium sand | 22.5 | |
| Nr. 10 | 2.00 | 171.4 | 95.2 | Fine sand | 46.2 | |
| Nr. 30 | 0.60 | 156.6 | 87.0 | Coarse silt | 13.25 | 18.82 |
| Nr. 40 | 0.43 | 130.9 | 72.7 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 50.0 | 27.8 | | | |
| Nr. 200 | 0.07 | 47.7 | 26.5 | Fine silt | 5.57 | |
| Pan | --- | 0.0 | 0.0 | Clay | 7.68 | 7.68 |

*Percentages relative to entire sample mass



# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

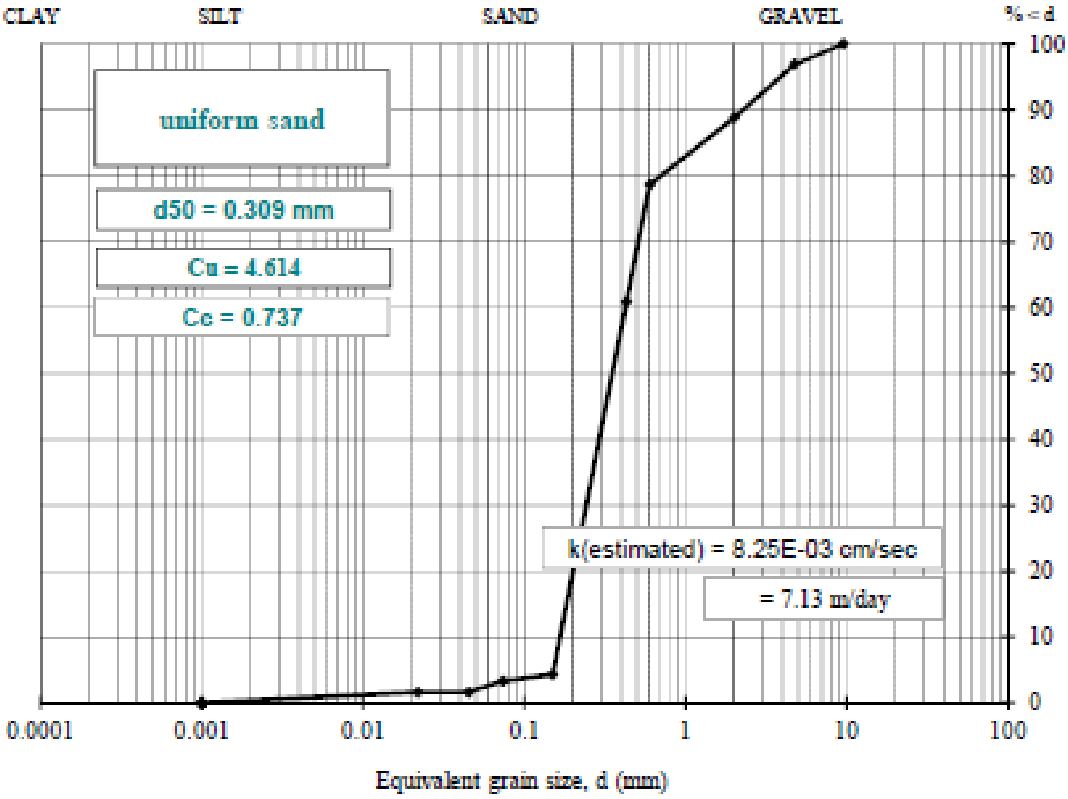
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH2

**Depth** 10.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 3.0 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 3.0 | |
| 3/8" | 9.50 | 115.4 | 100.0 | Coarse sand | 8.1 | 93.7 |
| Nr. 4 | 4.75 | 111.9 | 97.0 | Medium sand | 28.0 | |
| Nr. 10 | 2.00 | 102.5 | 88.8 | Fine sand | 57.5 | |
| Nr. 30 | 0.60 | 90.8 | 78.7 | Coarse silt | 1.65 | 2.34 |
| Nr. 40 | 0.43 | 70.2 | 60.8 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 5.0 | 4.3 | | | |
| Nr. 200 | 0.07 | 3.8 | 3.3 | Fine silt | 0.69 | |
| Pan | --- | 0.0 | 0.0 | Clay | 0.95 | 0.95 |

*Percentages relative to entire sample mass



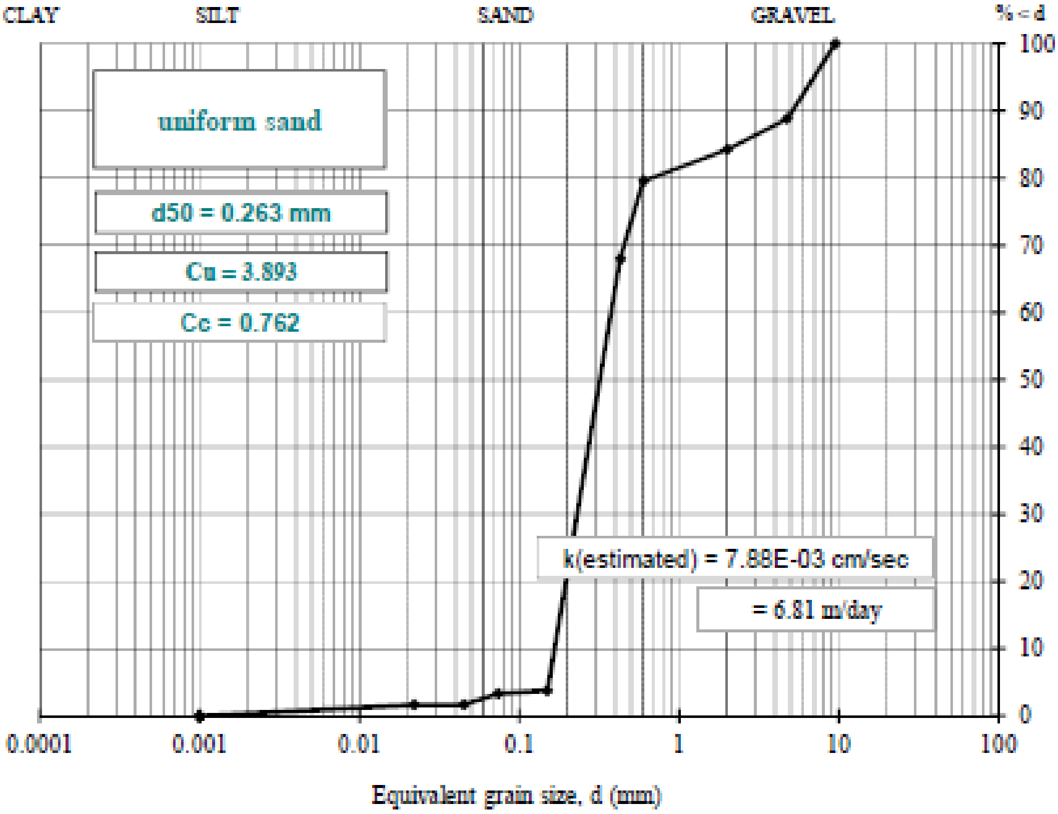
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH2 |
| **Depth** | 11.0 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 11.2 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 11.2 | |
| 3/8" | 9.50 | 120.8 | 100.0 | Coarse sand | 4.6 | 85.5 |
| Nr. 4 | 4.75 | 107.3 | 88.8 | Medium sand | 16.2 | |
| Nr. 10 | 2.00 | 101.8 | 84.3 | Fine sand | 64.7 | |
| Nr. 30 | 0.60 | 96.1 | 79.6 | Coarse silt | 1.66 | 2.35 |
| Nr. 40 | 0.43 | 82.2 | 68.0 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 4.6 | 3.8 | | | |
| Nr. 200 | 0.07 | 4.0 | 3.3 | Fine silt | 0.70 | |
| Pan | --- | 0.0 | 0.0 | Clay | 0.96 | 0.96 |

*Percentages relative to entire sample mass



# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

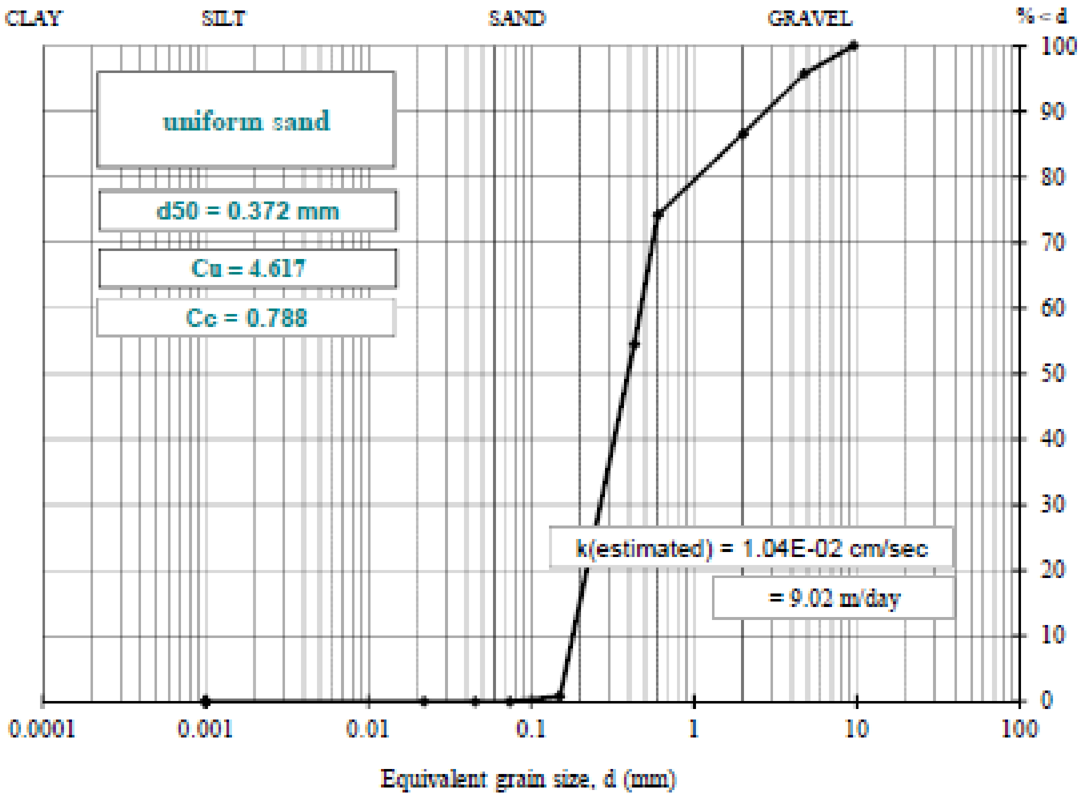
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH2

**Depth** 12.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 4.2 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 4.2 | |
| 3/8" | 9.50 | 103.8 | 100.0 | Coarse sand | 9.2 | 95.8 |
| Nr. 4 | 4.75 | 99.4 | 95.8 | Medium sand | 32.1 | |
| Nr. 10 | 2.00 | 89.9 | 86.6 | Fine sand | 54.5 | |
| Nr. 30 | 0.60 | 77.0 | 74.2 | Coarse silt | 0.00 | 0.00 |
| Nr. 40 | 0.43 | 56.6 | 54.5 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 0.8 | 0.8 | | | |
| Nr. 200 | 0.07 | 0.0 | 0.0 | Fine silt | 0.00 | |
| Pan | --- | 0.0 | 0.0 | Clay | 0.00 | 0.00 |

*Percentages relative to entire sample mass



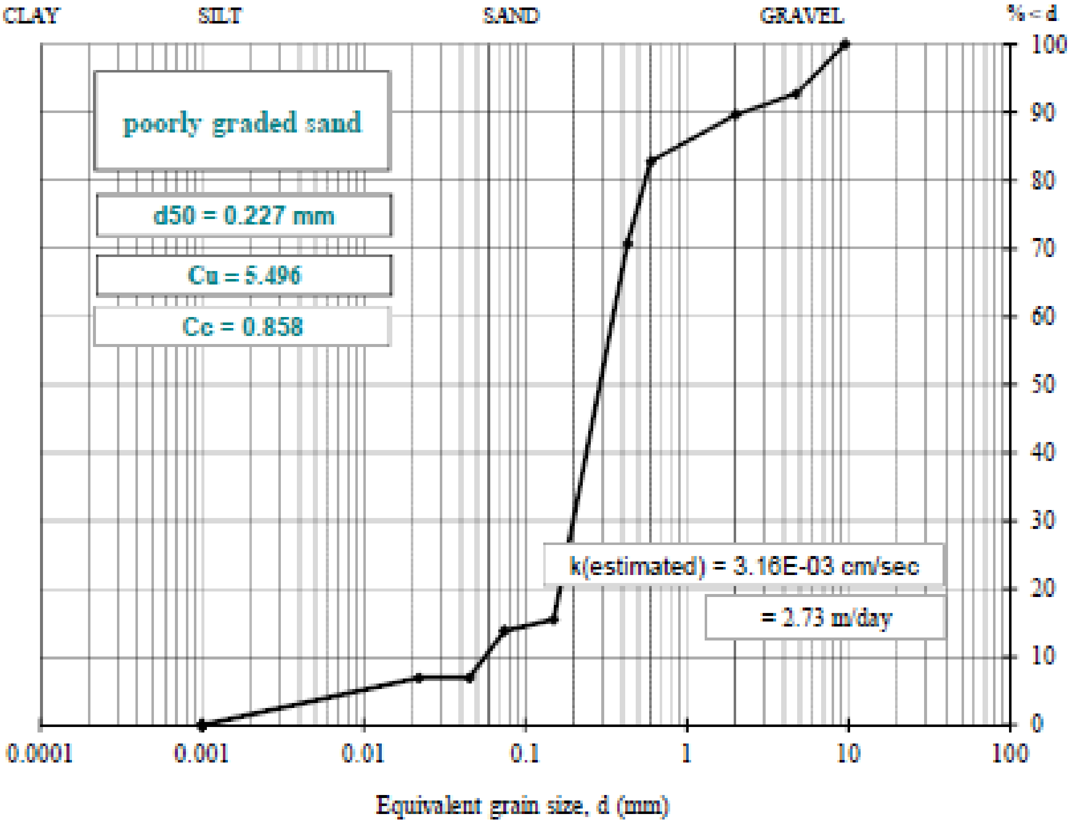
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH3 |
| **Depth** | 0.3 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 7.2 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 7.2 | |
| 3/8" | 9.50 | 118.7 | 100.0 | Coarse sand | 3.1 | 78.9 |
| Nr. 4 | 4.75 | 110.1 | 92.8 | Medium sand | 19.0 | |
| Nr. 10 | 2.00 | 106.4 | 89.6 | Fine sand | 56.9 | |
| Nr. 30 | 0.60 | 98.3 | 82.8 | Coarse silt | 6.91 | 9.81 |
| Nr. 40 | 0.43 | 83.9 | 70.7 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 18.4 | 15.5 | | | |
| Nr. 200 | 0.07 | 16.4 | 13.8 | Fine silt | 2.90 | |
| Pan | --- | 0.0 | 0.0 | Clay | 4.00 | 4.00 |

*Percentages relative to entire sample mass



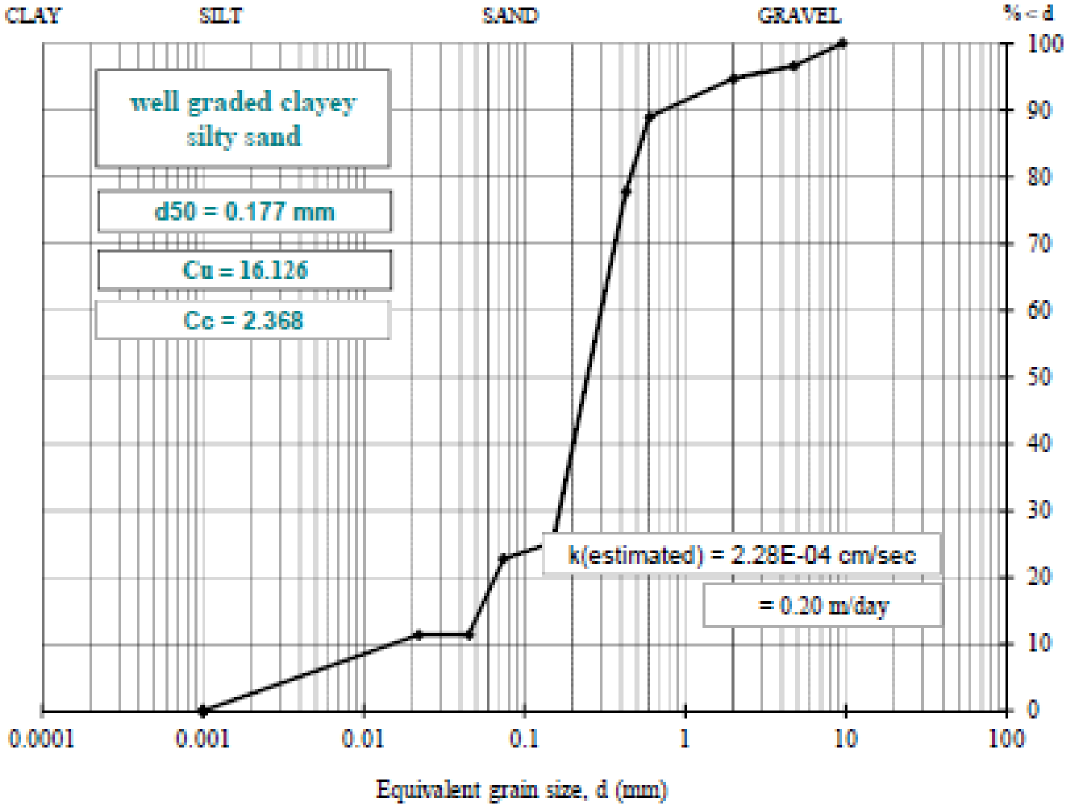
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH3 |
| **Depth** | 0.6 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 3.4 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 3.4 | |
| 3/8" | 9.50 | 133.0 | 100.0 | Coarse sand | 1.9 | 73.8 |
| Nr. 4 | 4.75 | 128.5 | 96.6 | Medium sand | 16.9 | |
| Nr. 10 | 2.00 | 126.0 | 94.7 | Fine sand | 55.0 | |
| Nr. 30 | 0.60 | 118.4 | 89.0 | Coarse silt | 11.39 | 16.18 |
| Nr. 40 | 0.43 | 103.5 | 77.8 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 33.6 | 25.3 | | | |
| Nr. 200 | 0.07 | 30.3 | 22.8 | Fine silt | 4.79 | |
| Pan | --- | 0.0 | 0.0 | Clay | 6.60 | 6.60 |

*Percentages relative to entire sample mass



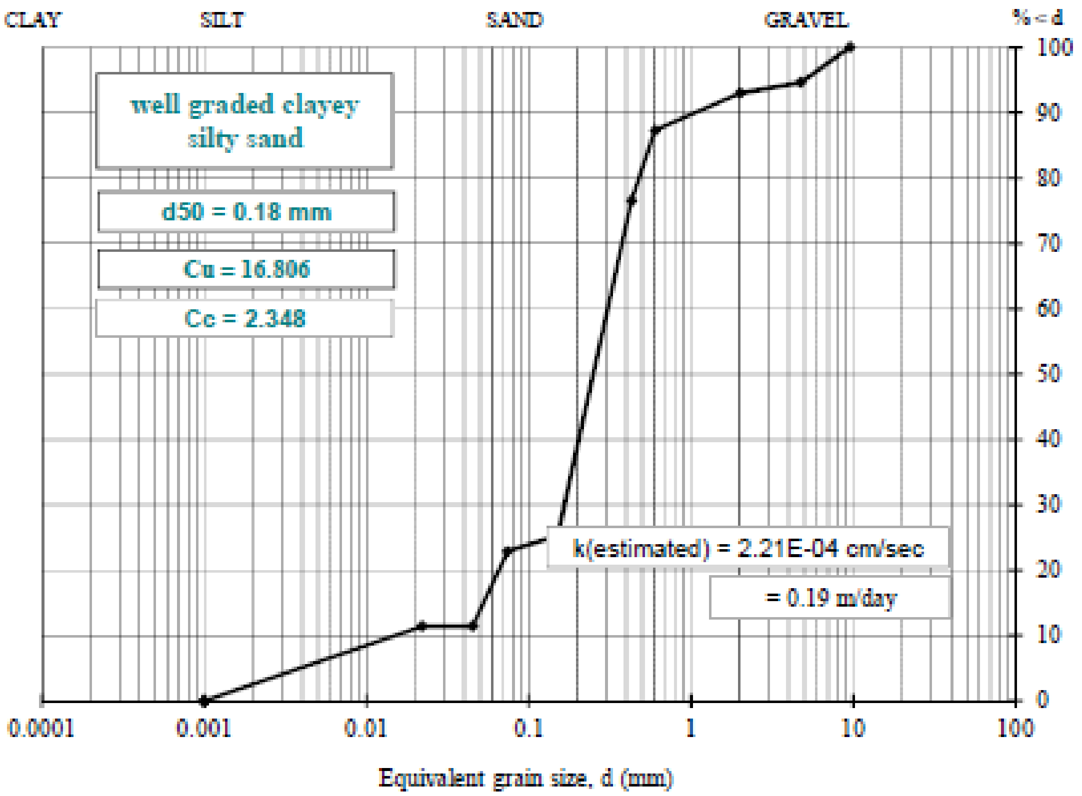
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH3 |
| **Depth** | 0.9 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 5.4 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 5.4 | |
| 3/8" | 9.50 | 181.2 | 100.0 | Coarse sand | 1.7 | 71.7 |
| Nr. 4 | 4.75 | 171.5 | 94.6 | Medium sand | 16.4 | |
| Nr. 10 | 2.00 | 168.5 | 93.0 | Fine sand | 53.6 | |
| Nr. 30 | 0.60 | 158.2 | 87.3 | Coarse silt | 11.45 | 16.26 |
| Nr. 40 | 0.43 | 138.7 | 76.5 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 45.7 | 25.2 | | | |
| Nr. 200 | 0.07 | 41.5 | 22.9 | Fine silt | 4.81 | |
| Pan | --- | 0.0 | 0.0 | Clay | 6.64 | 6.64 |

*Percentages relative to entire sample mass



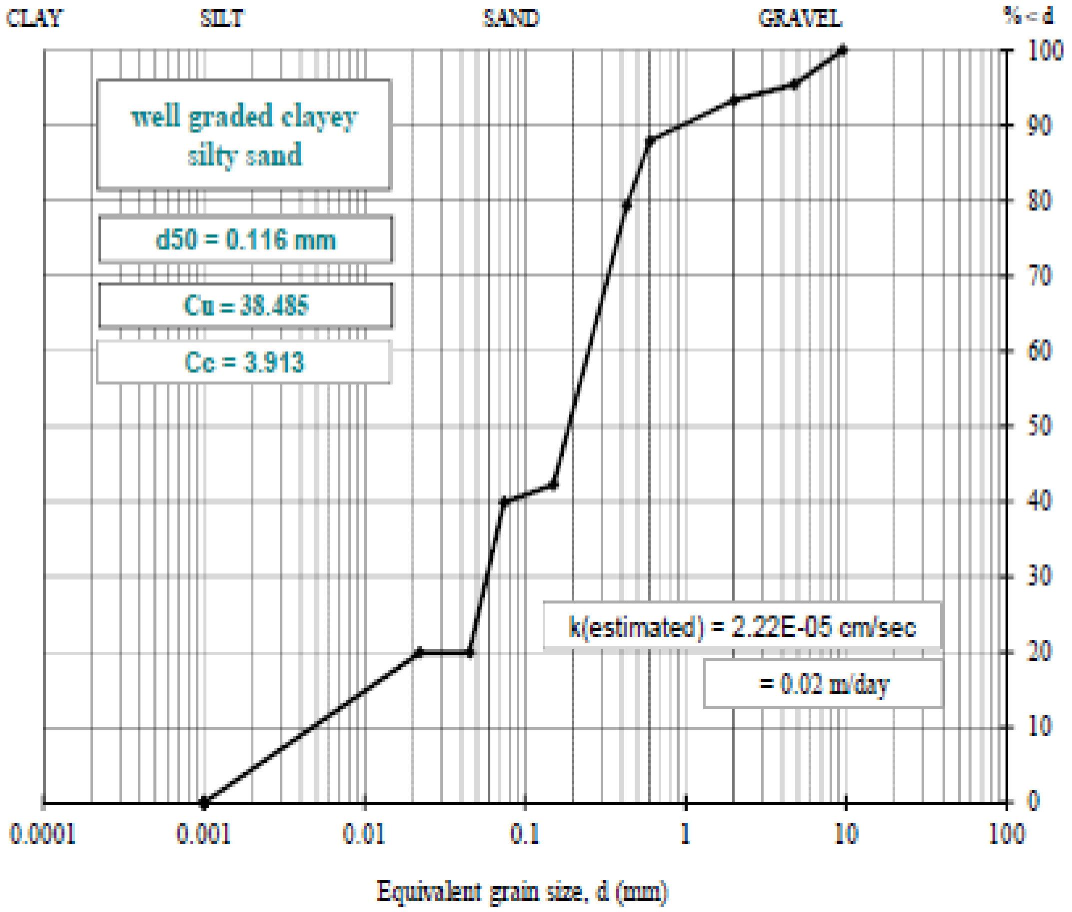
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH3 |
| **Depth** | 1.2 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 4.5 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 4.5 | |
| 3/8" | 9.50 | 108.1 | 100.0 | Coarse sand | 2.1 | 55.6 |
| Nr. 4 | 4.75 | 103.2 | 95.5 | Medium sand | 14.0 | |
| Nr. 10 | 2.00 | 100.9 | 93.3 | Fine sand | 39.5 | |
| Nr. 30 | 0.60 | 95.1 | 88.0 | Coarse silt | 19.94 | 28.31 |
| Nr. 40 | 0.43 | 85.8 | 79.4 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 45.6 | 42.2 | | | |
| Nr. 200 | 0.07 | 43.1 | 39.9 | Fine silt | 8.38 | |
| Pan | --- | 0.0 | 0.0 | Clay | 11.56 | 11.56 |

*Percentages relative to entire sample mass



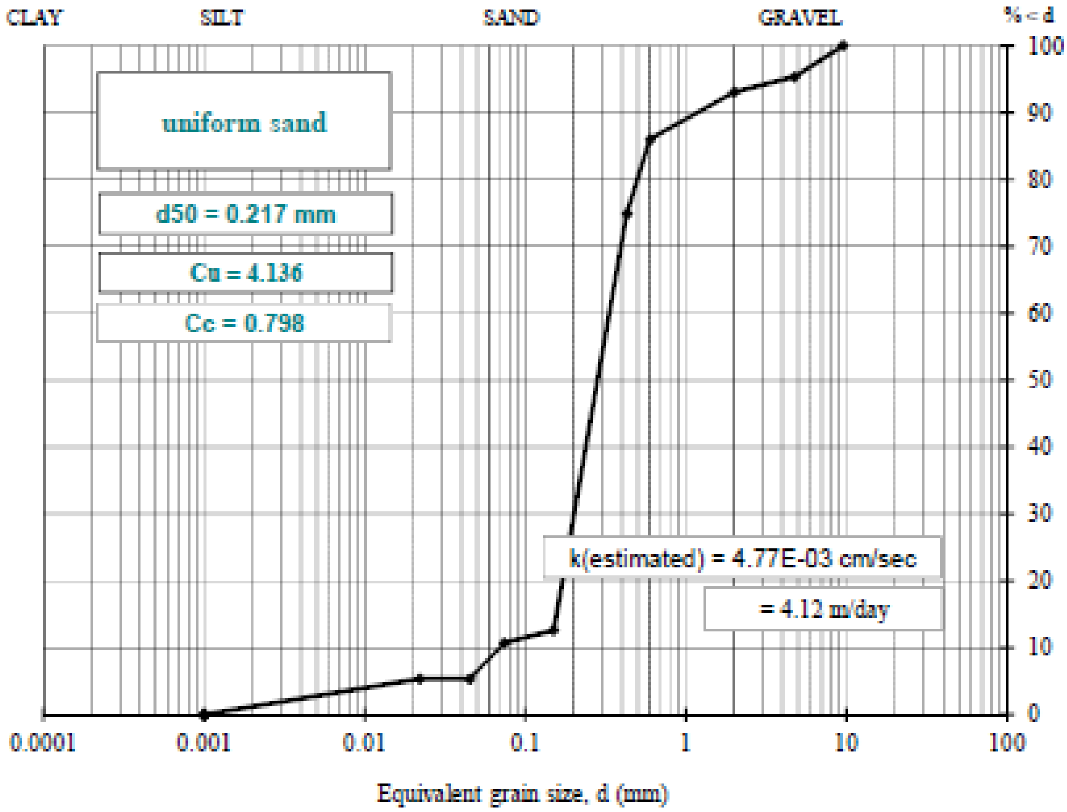
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH3 |
| **Depth** | 1.5 m |

| **Mechanical (sieve) analysis** | | | | **Soil Type** | **%** | **Tot. %** |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 4.7 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 4.7 | |
| 3/8" | 9.50 | 105.2 | 100.0 | Coarse sand | 2.3 | 84.6 |
| Nr. 4 | 4.75 | 100.3 | 95.3 | Medium sand | 18.2 | |
| Nr. 10 | 2.00 | 97.9 | 93.1 | Fine sand | 64.2 | |
| Nr. 30 | 0.60 | 90.5 | 86.0 | Coarse silt | 5.37 | 7.63 |
| Nr. 40 | 0.43 | 78.8 | 74.9 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 13.3 | 12.6 | | | |
| Nr. 200 | 0.07 | 11.3 | 10.7 | Fine silt | 2.26 | |
| Pan | --- | 0.0 | 0.0 | Clay | 3.11 | 3.11 |

*Percentages relative to entire sample mass



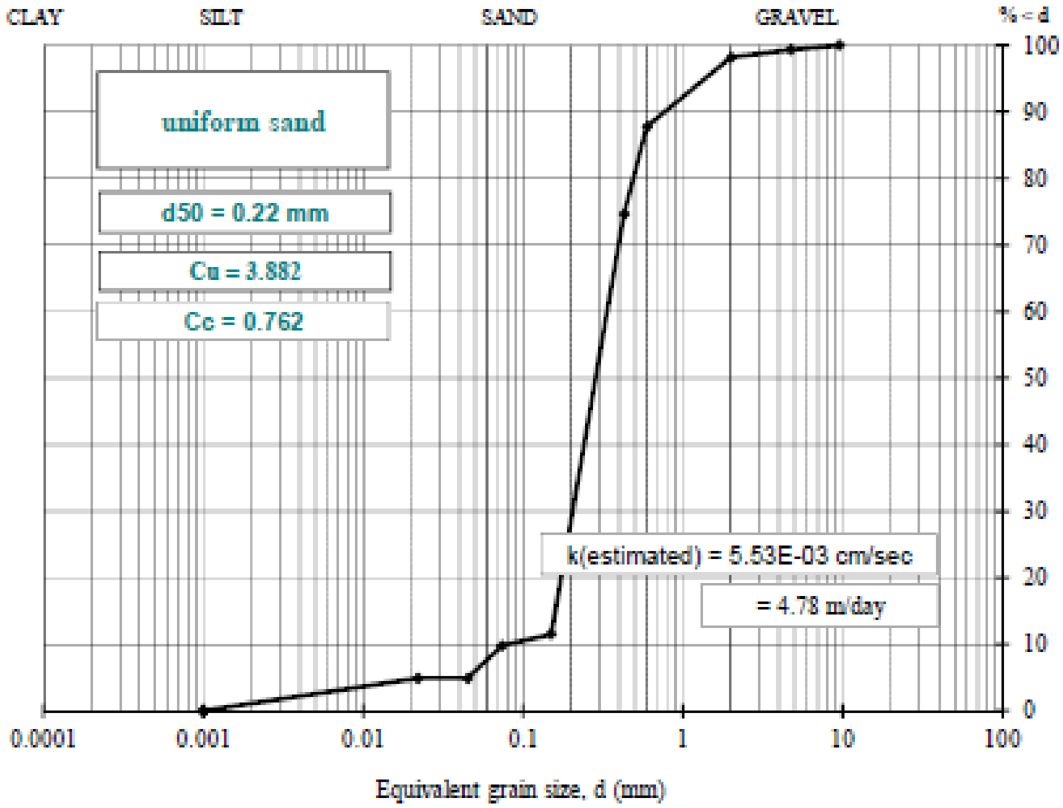
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH3 |
| **Depth** | 1.8 m |

| **Mechanical (sieve) analysis** | | | | **Soil Type** | **%** | **Tot. %** |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 0.7 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 0.7 | |
| 3/8" | 9.50 | 105.9 | 100.0 | Coarse sand | 1.1 | 89.5 |
| Nr. 4 | 4.75 | 105.2 | 99.3 | Medium sand | 23.5 | |
| Nr. 10 | 2.00 | 104.0 | 98.2 | Fine sand | 64.9 | |
| Nr. 30 | 0.60 | 93.0 | 87.8 | Coarse silt | 4.91 | 6.97 |
| Nr. 40 | 0.43 | 79.1 | 74.7 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 12.2 | 11.5 | | | |
| Nr. 200 | 0.07 | 10.4 | 9.8 | Fine silt | 2.06 | |
| Pan | --- | 0.0 | 0.0 | Clay | 2.85 | 2.85 |

*Percentages relative to entire sample mass



# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

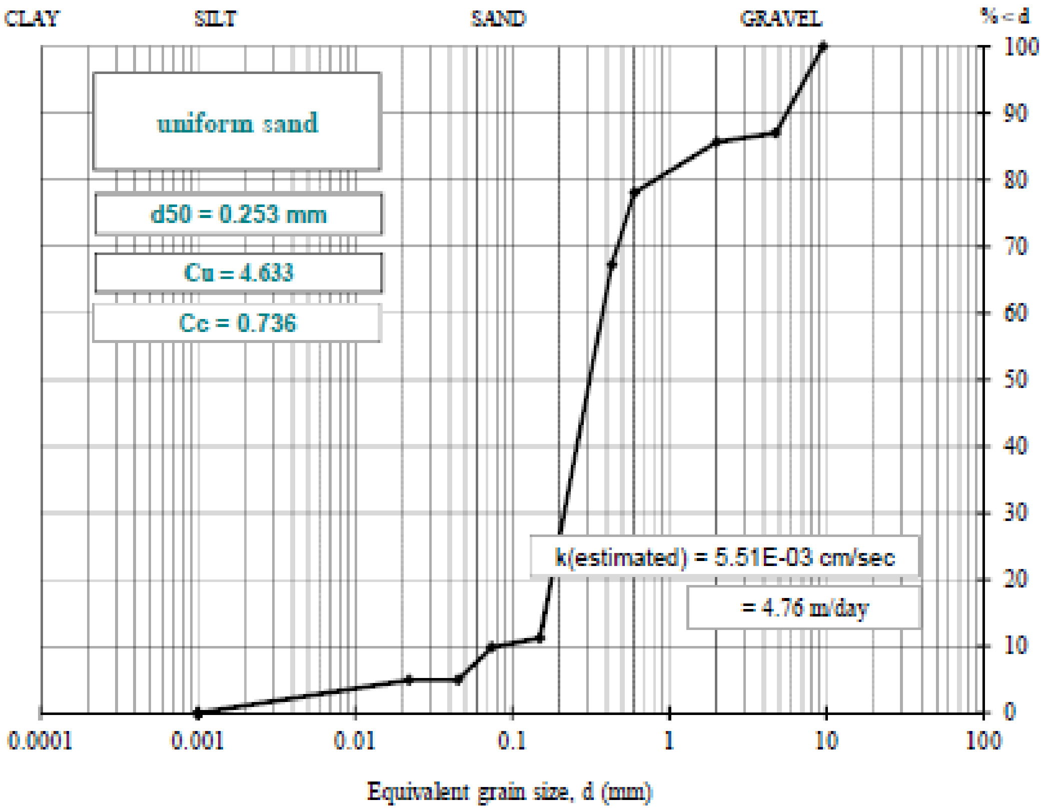
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH3

**Depth** 2.1 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 13.0 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 13.0 | |
| 3/8" | 9.50 | 88.0 | 100.0 | Coarse sand | 1.4 | 77.2 |
| Nr. 4 | 4.75 | 76.6 | 87.0 | Medium sand | 18.4 | |
| Nr. 10 | 2.00 | 75.4 | 85.7 | Fine sand | 57.4 | |
| Nr. 30 | 0.60 | 68.7 | 78.1 | Coarse silt | 4.94 | 7.02 |
| Nr. 40 | 0.43 | 59.2 | 67.3 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 9.9 | 11.3 | | | |
| Nr. 200 | 0.07 | 8.7 | 9.9 | Fine silt | 2.08 | |
| Pan | --- | 0.0 | 0.0 | Clay | 2.87 | 2.87 |

*Percentages relative to entire sample mass



# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

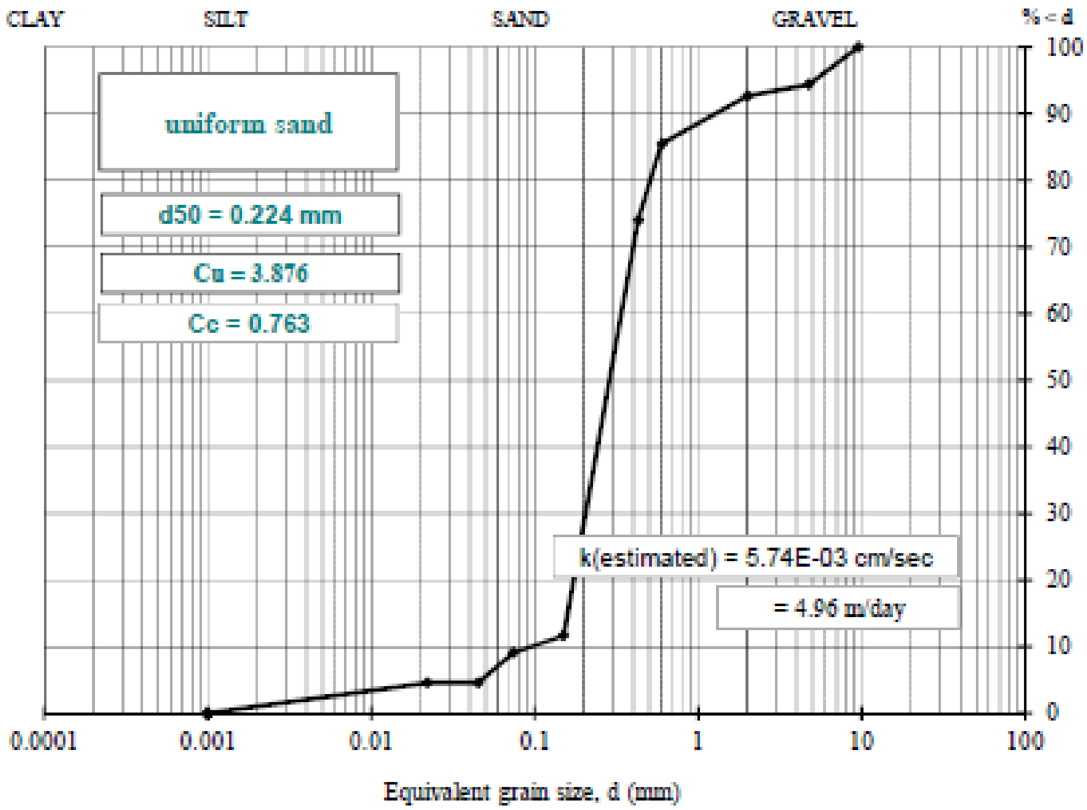
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH3

**Depth** 3.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 5.6 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 5.6 | |
| 3/8" | 9.50 | 98.7 | 100.0 | Coarse sand | 1.7 | 85.3 |
| Nr. 4 | 4.75 | 93.2 | 94.4 | Medium sand | 18.6 | |
| Nr. 10 | 2.00 | 91.5 | 92.7 | Fine sand | 64.9 | |
| Nr. 30 | 0.60 | 84.4 | 85.5 | Coarse silt | 4.56 | 6.48 |
| Nr. 40 | 0.43 | 73.1 | 74.1 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 11.5 | 11.7 | | | |
| Nr. 200 | 0.07 | 9.0 | 9.1 | Fine silt | 1.92 | |
| Pan | --- | 0.0 | 0.0 | Clay | 2.64 | 2.64 |

*Percentages relative to entire sample mass



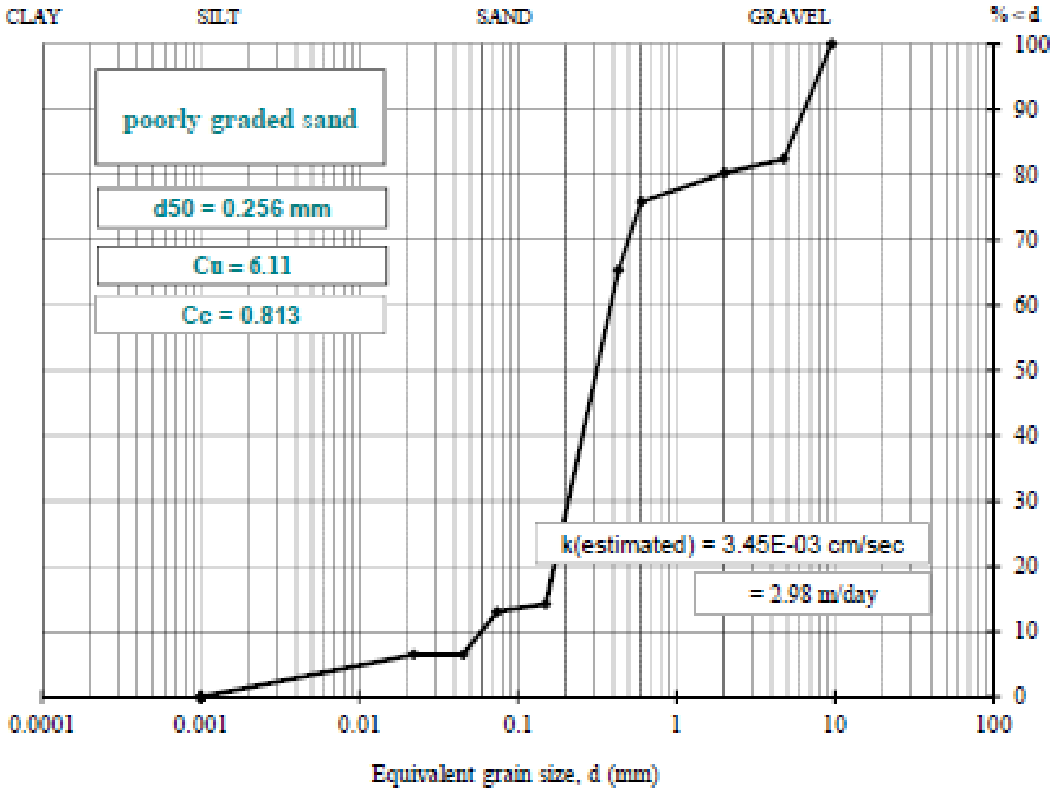
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH3 |
| **Depth** | 4.0 m |

| **Mechanical (sieve) analysis** | | | | **Soil Type** | **%** | **Tot. %** |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 17.6 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 17.6 | |
| 3/8" | 9.50 | 131.2 | 100.0 | Coarse sand | 2.1 | 69.4 |
| Nr. 4 | 4.75 | 108.1 | 82.4 | Medium sand | 14.9 | |
| Nr. 10 | 2.00 | 105.3 | 80.3 | Fine sand | 52.4 | |
| Nr. 30 | 0.60 | 99.5 | 75.8 | Coarse silt | 6.52 | 9.26 |
| Nr. 40 | 0.43 | 85.8 | 65.4 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 18.7 | 14.3 | | | |
| Nr. 200 | 0.07 | 17.1 | 13.0 | Fine silt | 2.74 | |
| Pan | --- | 0.0 | 0.0 | Clay | 3.78 | 3.78 |

*Percentages relative to entire sample mass



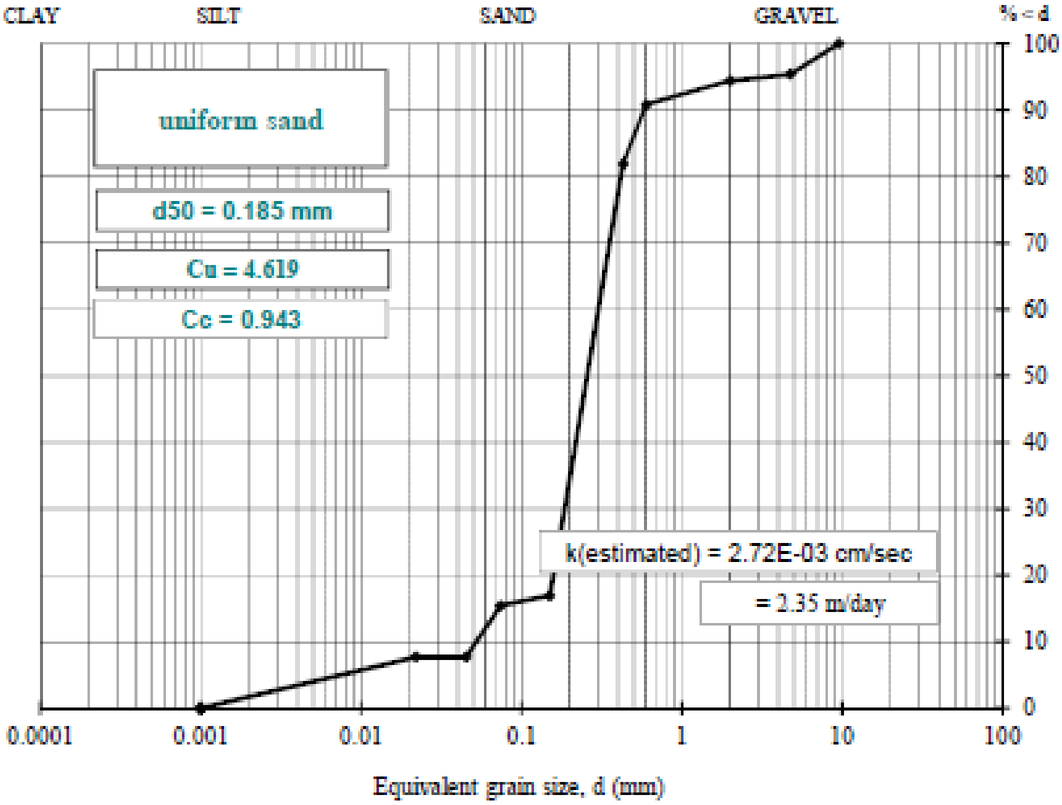
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH3 |
| **Depth** | 5.0 m |

| **Mechanical (sieve) analysis** | | | | **Soil Type** | **%** | **Tot. %** |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 4.6 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 4.6 | |
| 3/8" | 9.50 | 102.3 | 100.0 | Coarse sand | 1.0 | 80.0 |
| Nr. 4 | 4.75 | 97.6 | 95.4 | Medium sand | 12.5 | |
| Nr. 10 | 2.00 | 96.6 | 94.4 | Fine sand | 66.5 | |
| Nr. 30 | 0.60 | 92.9 | 90.8 | Coarse silt | 7.72 | 10.97 |
| Nr. 40 | 0.43 | 83.8 | 81.9 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 17.3 | 16.9 | | | |
| Nr. 200 | 0.07 | 15.8 | 15.4 | Fine silt | 3.25 | |
| Pan | --- | 0.0 | 0.0 | Clay | 4.48 | 4.48 |

*Percentages relative to entire sample mass



# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

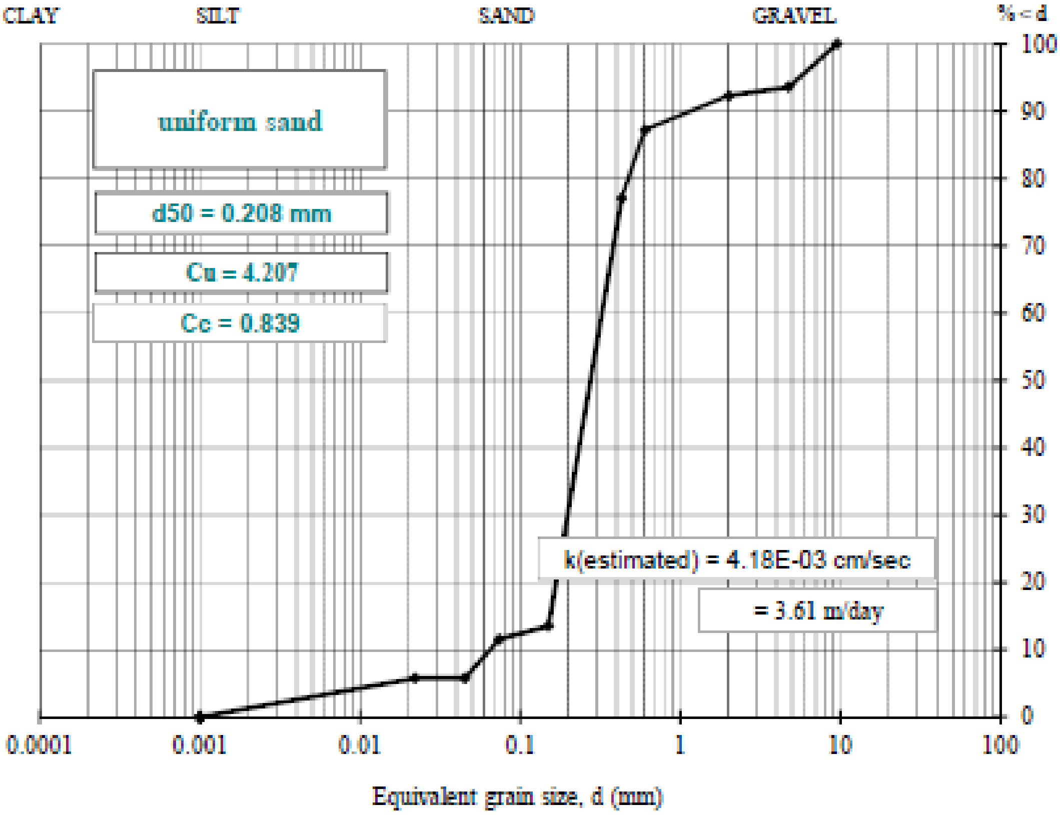
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH3

**Depth** 6.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 6.4 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 6.4 | |
| 3/8" | 9.50 | 106.3 | 100.0 | Coarse sand | 1.3 | 82.0 |
| Nr. 4 | 4.75 | 99.5 | 93.6 | Medium sand | 15.2 | |
| Nr. 10 | 2.00 | 98.1 | 92.3 | Fine sand | 65.5 | |
| Nr. 30 | 0.60 | 92.7 | 87.2 | Coarse silt | 5.79 | 8.22 |
| Nr. 40 | 0.43 | 81.9 | 77.0 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 14.4 | 13.5 | | | |
| Nr. 200 | 0.07 | 12.3 | 11.6 | Fine silt | 2.43 | |
| Pan | --- | 0.0 | 0.0 | Clay | 3.35 | 3.35 |

*Percentages relative to entire sample mass



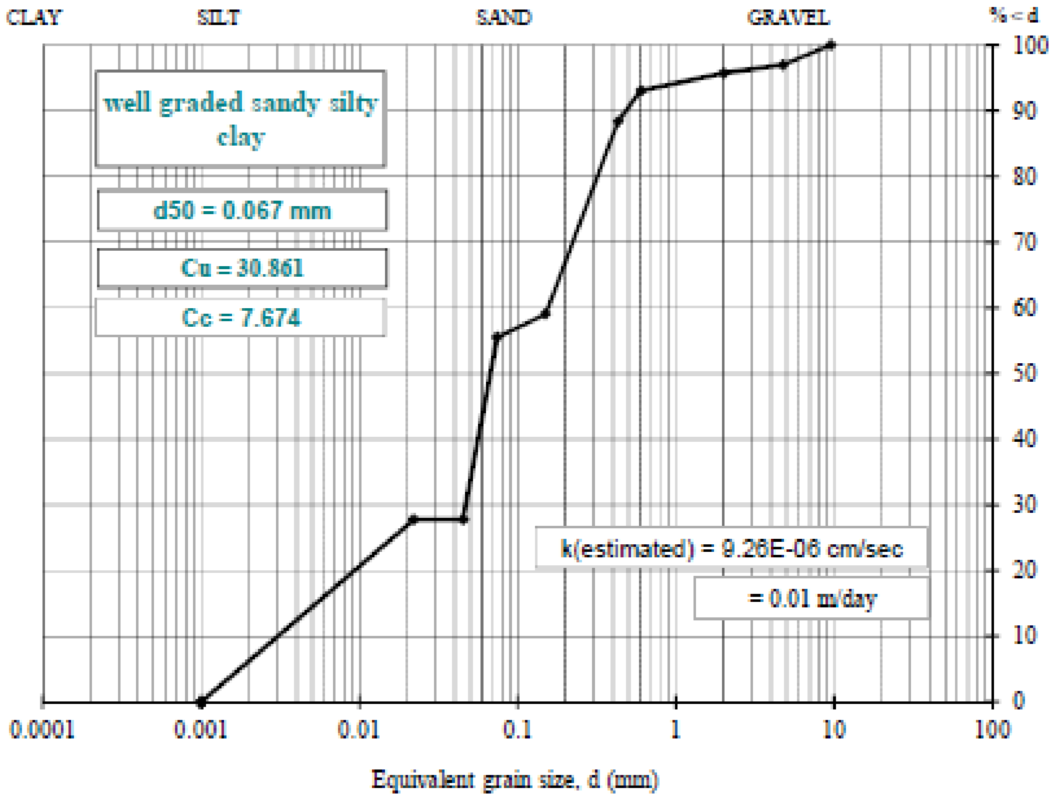
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH3 |
| **Depth** | 7.0 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 3.0 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 3.0 | |
| 3/8" | 9.50 | 140.4 | 100.0 | Coarse sand | 1.3 | 41.5 |
| Nr. 4 | 4.75 | 136.2 | 97.0 | Medium sand | 7.3 | |
| Nr. 10 | 2.00 | 134.4 | 95.7 | Fine sand | 32.8 | |
| Nr. 30 | 0.60 | 130.7 | 93.1 | Coarse silt | 27.78 | 39.45 |
| Nr. 40 | 0.43 | 124.1 | 88.4 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 82.9 | 59.0 | | | |
| Nr. 200 | 0.07 | 78.0 | 55.6 | Fine silt | 11.68 | |
| Pan | --- | 0.0 | 0.0 | Clay | 16.10 | 16.10 |

*Percentages relative to entire sample mass



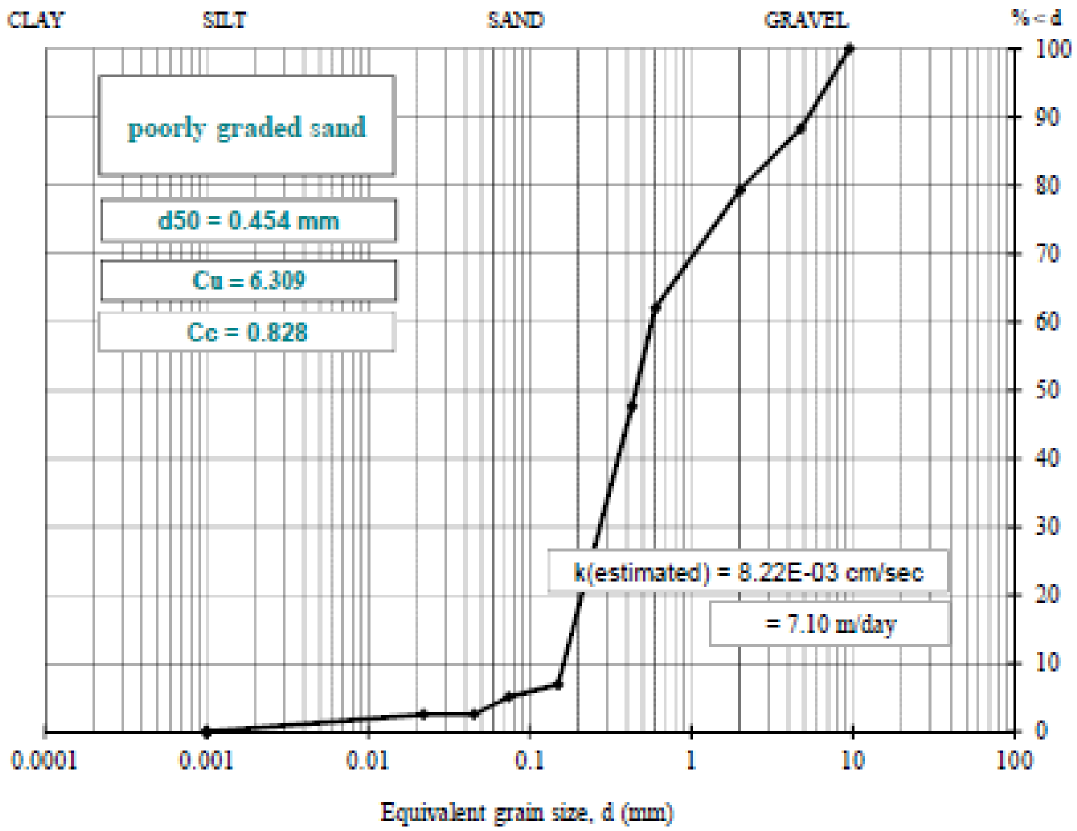
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH3 |
| **Depth** | 8.0 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 11.7 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 11.7 | |
| 3/8" | 9.50 | 92.3 | 100.0 | Coarse sand | 9.0 | 83.2 |
| Nr. 4 | 4.75 | 81.5 | 88.3 | Medium sand | 31.6 | |
| Nr. 10 | 2.00 | 73.2 | 79.3 | Fine sand | 42.6 | |
| Nr. 30 | 0.60 | 57.3 | 62.1 | Coarse silt | 2.55 | 3.62 |
| Nr. 40 | 0.43 | 44.0 | 47.7 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 6.4 | 6.9 | | | |
| Nr. 200 | 0.07 | 4.7 | 5.1 | Fine silt | 1.07 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.48 | 1.48 |

*Percentages relative to entire sample mass



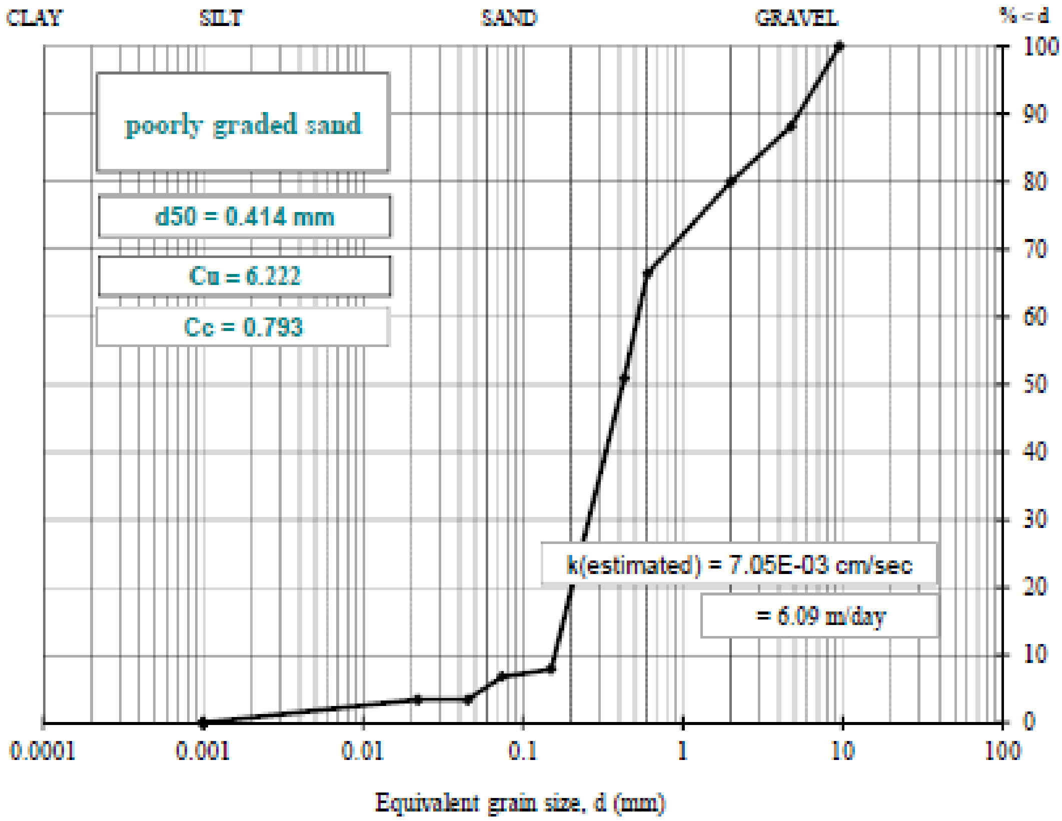
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

**Project:** Master Research-Study- (Eng. Basem Serdah)
**Bore Hole No.** BH3
**Depth** 9.0 m

<table>
<tr><th colspan="4">Mechanical (sieve) analysis</th><th>Soil Type</th><th>%</th><th>Tot. %</th></tr>
<tr><td rowspan="3">Sieve Number</td><td rowspan="3">Sieve mesh opening, mm</td><td rowspan="3">Mass passing, g</td><td rowspan="3">Percent passing, %</td><td>Coarse gravel</td><td>0.0</td><td rowspan="3">11.8</td></tr>
<tr><td>Medium gravel</td><td>0.0</td></tr>
<tr><td>Fine gravel</td><td>11.8</td></tr>
<tr><td>3/8"</td><td>9.50</td><td>118.6</td><td>100.0</td><td>Coarse sand</td><td>8.2</td><td rowspan="3">81.4</td></tr>
<tr><td>Nr. 4</td><td>4.75</td><td>104.6</td><td>88.2</td><td>Medium sand</td><td>29.1</td></tr>
<tr><td>Nr. 10</td><td>2.00</td><td>94.9</td><td>80.0</td><td>Fine sand</td><td>44.1</td></tr>
<tr><td>Nr. 30</td><td>0.60</td><td>78.8</td><td>66.4</td><td>Coarse silt</td><td>3.41</td><td rowspan="4">4.85</td></tr>
<tr><td>Nr. 40</td><td>0.43</td><td>60.4</td><td>50.9</td><td rowspan="2">Medium silt</td><td rowspan="2">0.00</td></tr>
<tr><td>Nr. 100</td><td>0.15</td><td>9.4</td><td>7.9</td></tr>
<tr><td>Nr. 200</td><td>0.07</td><td>8.1</td><td>6.8</td><td>Fine silt</td><td>1.44</td></tr>
<tr><td>Pan</td><td>---</td><td>0.0</td><td>0.0</td><td>Clay</td><td>1.98</td><td>1.98</td></tr>
</table>

*Percentages relative to entire sample mass



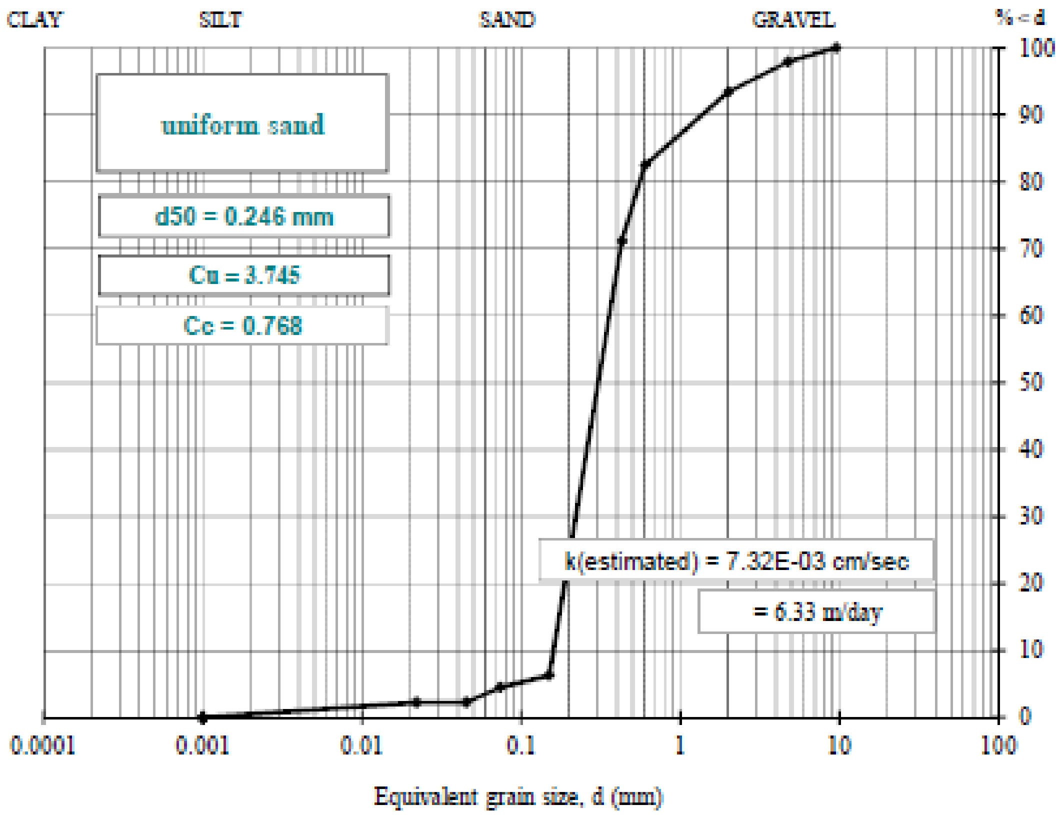
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH3 |
| **Depth** | 10.0 m |

| **Mechanical (sieve) analysis** | | | | **Soil Type** | **%** | **Tot. %** |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 2.1 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 2.1 | |
| 3/8" | 9.50 | 106.7 | 100.0 | Coarse sand | 4.5 | 93.4 |
| Nr. 4 | 4.75 | 104.5 | 97.9 | Medium sand | 22.3 | |
| Nr. 10 | 2.00 | 99.7 | 93.4 | Fine sand | 66.6 | |
| Nr. 30 | 0.60 | 88.0 | 82.5 | Coarse silt | 2.25 | 3.19 |
| Nr. 40 | 0.43 | 75.9 | 71.1 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 6.7 | 6.3 | | | |
| Nr. 200 | 0.07 | 4.8 | 4.5 | Fine silt | 0.95 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.30 | 1.30 |

*Percentages relative to entire sample mass



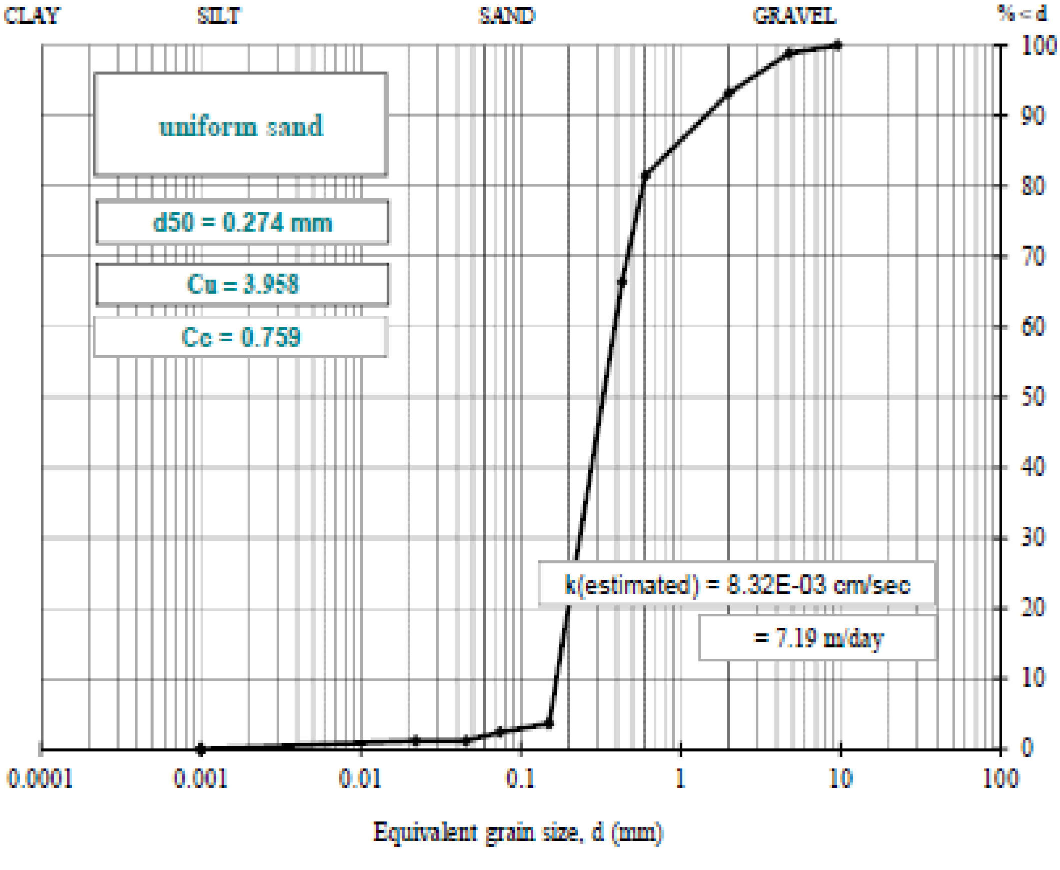
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH3 |
| **Depth** | 11.0 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 1.1 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 1.1 | |
| 3/8" | 9.50 | 96.0 | 100.0 | Coarse sand | 5.6 | 96.5 |
| Nr. 4 | 4.75 | 94.9 | 98.9 | Medium sand | 26.9 | |
| Nr. 10 | 2.00 | 89.5 | 93.2 | Fine sand | 64.0 | |
| Nr. 30 | 0.60 | 78.2 | 81.5 | Coarse silt | 1.20 | 1.70 |
| Nr. 40 | 0.43 | 63.7 | 66.4 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 3.5 | 3.6 | | | |
| Nr. 200 | 0.07 | 2.3 | 2.4 | Fine silt | 0.50 | |
| Pan | --- | 0.0 | 0.0 | Clay | 0.69 | 0.69 |

*Percentages relative to entire sample mass



# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

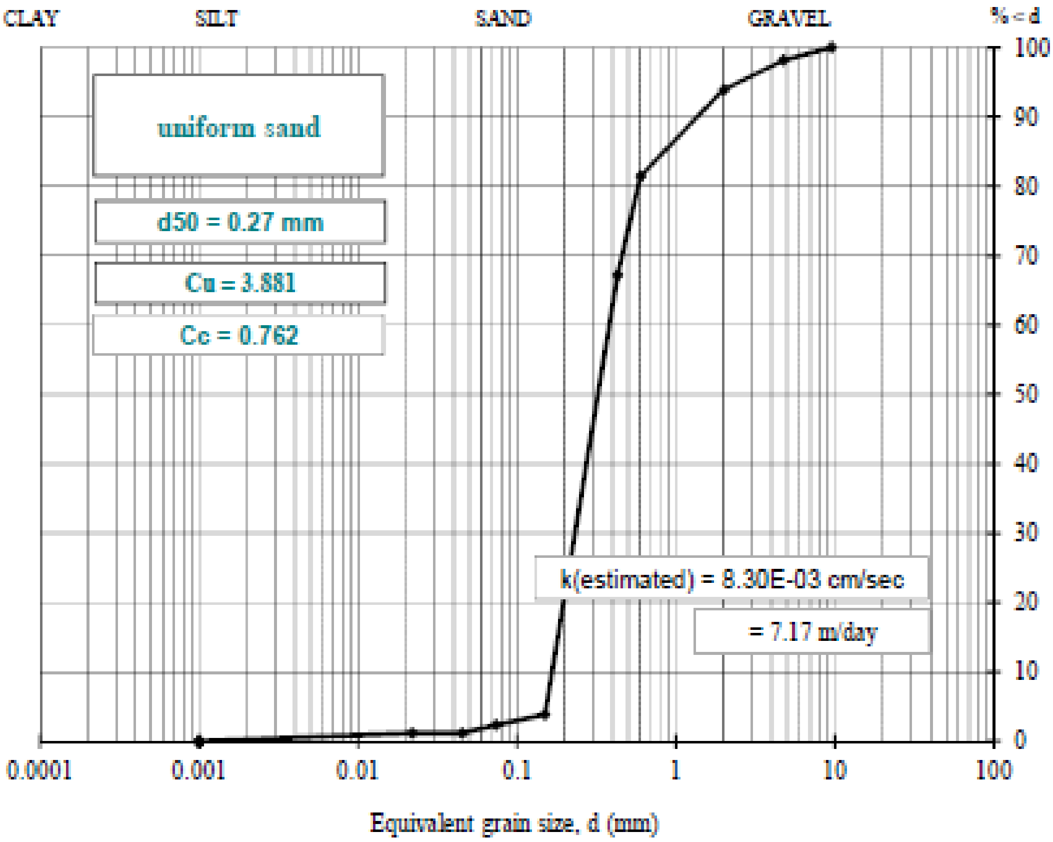
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH3

**Depth** 12.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 1.9 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 1.9 | |
| 3/8" | 9.50 | 85.7 | 100.0 | Coarse sand | 4.2 | 95.8 |
| Nr. 4 | 4.75 | 84.1 | 98.1 | Medium sand | 26.7 | |
| Nr. 10 | 2.00 | 80.5 | 93.9 | Fine sand | 64.9 | |
| Nr. 30 | 0.60 | 69.8 | 81.4 | Coarse silt | 1.17 | 1.66 |
| Nr. 40 | 0.43 | 57.6 | 67.2 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 3.3 | 3.9 | | | |
| Nr. 200 | 0.07 | 2.0 | 2.3 | Fine silt | 0.49 | |
| Pan | --- | 0.0 | 0.0 | Clay | 0.68 | 0.68 |

*Percentages relative to entire sample mass



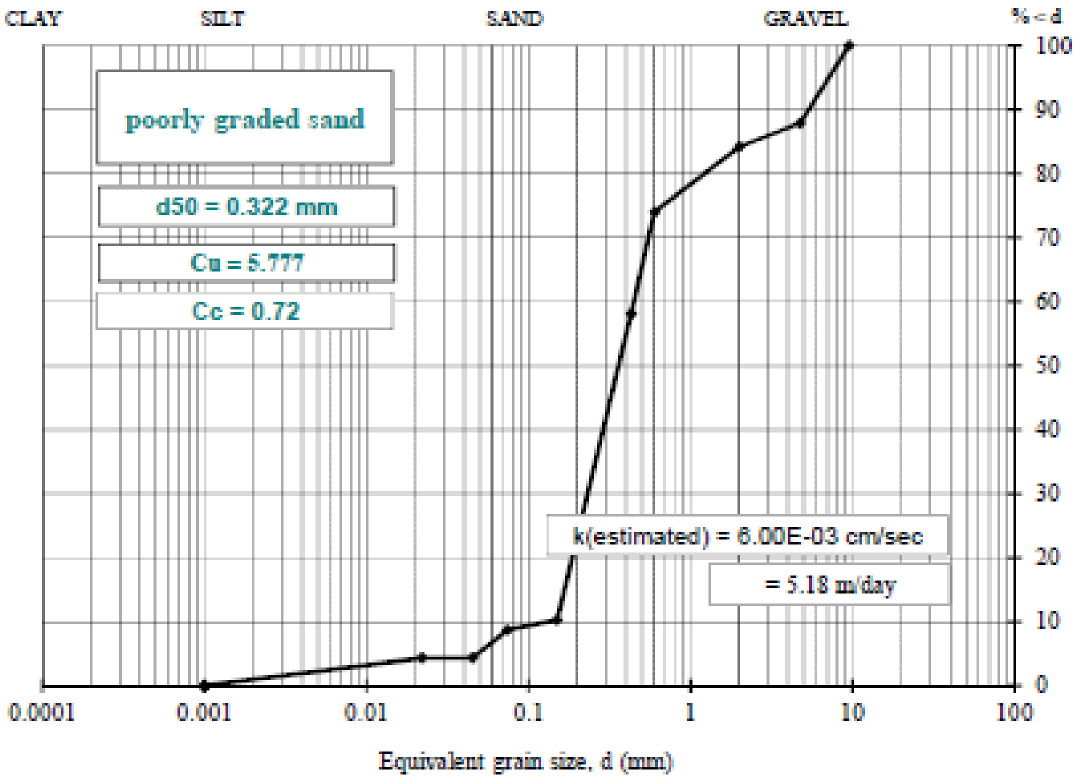
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH4 |
| **Depth** | 0.3 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 12.1 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 12.1 | |
| 3/8" | 9.50 | 97.4 | 100.0 | Coarse sand | 3.7 | 79.2 |
| Nr. 4 | 4.75 | 85.6 | 87.9 | Medium sand | 26.1 | |
| Nr. 10 | 2.00 | 82.0 | 84.2 | Fine sand | 49.4 | |
| Nr. 30 | 0.60 | 72.1 | 74.0 | Coarse silt | 4.36 | 6.20 |
| Nr. 40 | 0.43 | 56.6 | 58.1 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 10.0 | 10.3 | | | |
| Nr. 200 | 0.07 | 8.5 | 8.7 | Fine silt | 1.83 | |
| Pan | --- | 0.0 | 0.0 | Clay | 2.53 | 2.53 |

*Percentages relative to entire sample mass



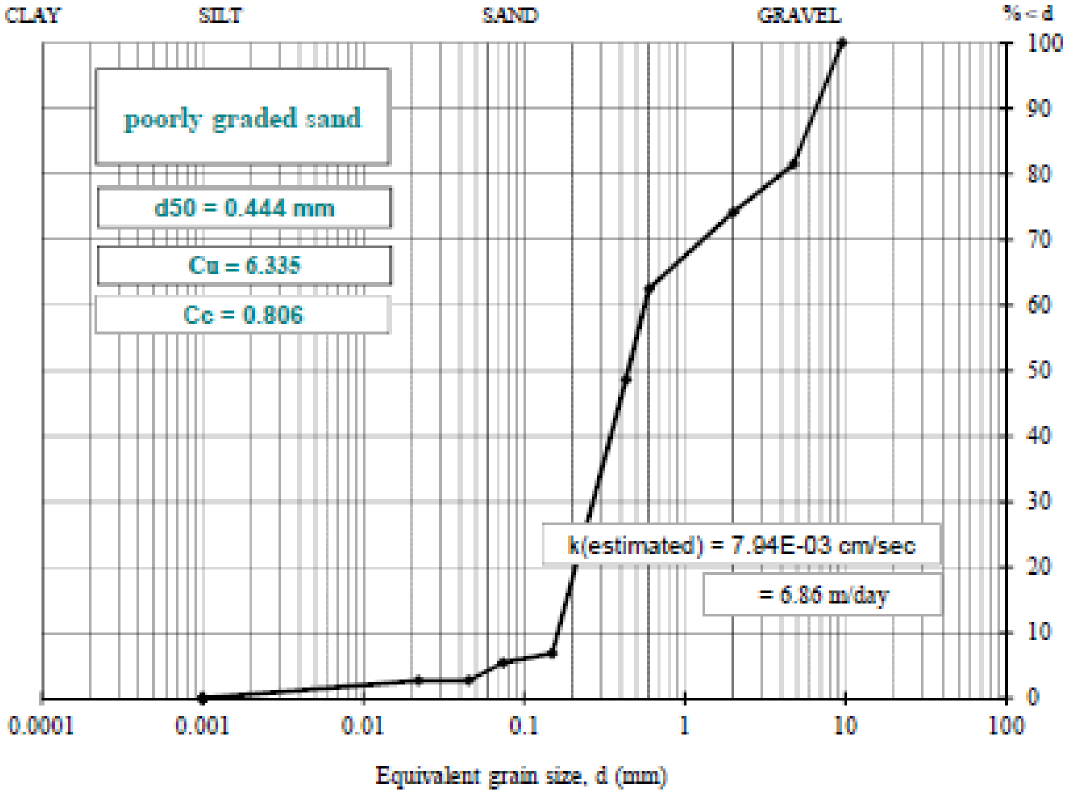
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH4 |
| **Depth** | 0.6 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 18.5 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 18.5 | |
| 3/8" | 9.50 | 104.9 | 100.0 | Coarse sand | 7.3 | 76.1 |
| Nr. 4 | 4.75 | 85.5 | 81.5 | Medium sand | 25.5 | |
| Nr. 10 | 2.00 | 77.8 | 74.2 | Fine sand | 43.2 | |
| Nr. 30 | 0.60 | 65.6 | 62.5 | Coarse silt | 2.72 | 3.86 |
| Nr. 40 | 0.43 | 51.0 | 48.6 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 7.2 | 6.9 | | | |
| Nr. 200 | 0.07 | 5.7 | 5.4 | Fine silt | 1.14 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.57 | 1.57 |

*Percentages relative to entire sample mass



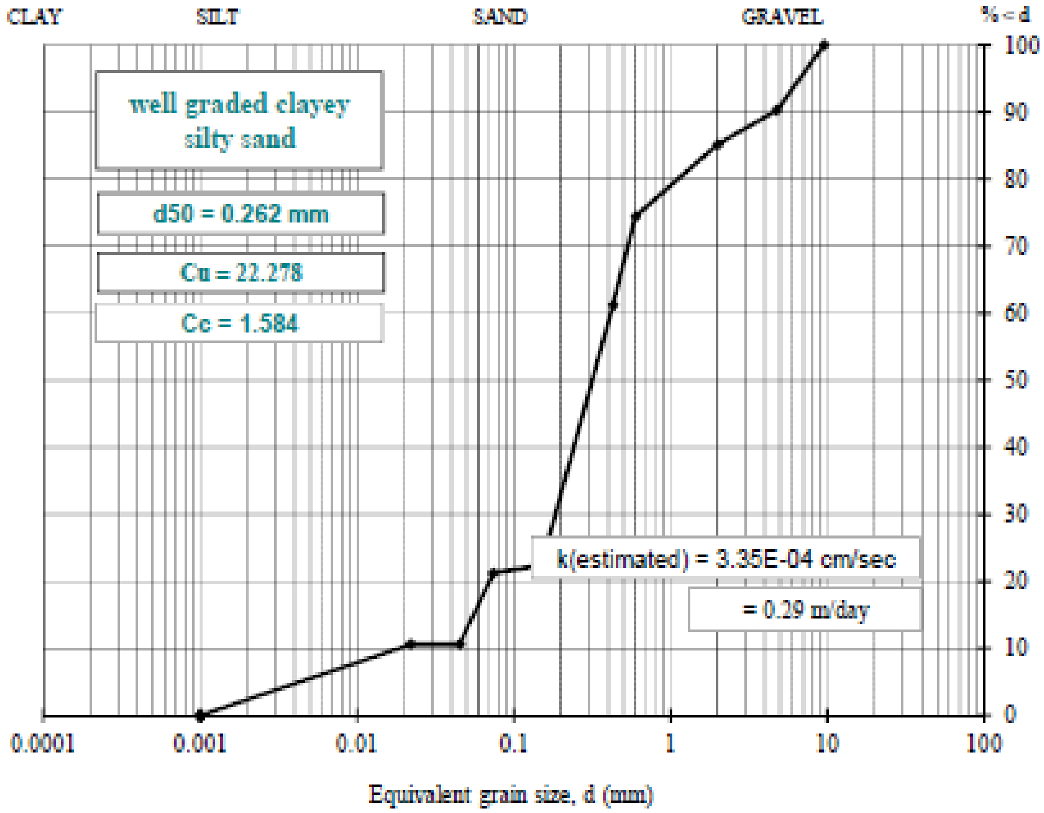
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH4 |
| **Depth** | 0.9 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 9.8 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 9.8 | |
| 3/8" | 9.50 | 131.2 | 100.0 | Coarse sand | 5.0 | 69.0 |
| Nr. 4 | 4.75 | 118.4 | 90.2 | Medium sand | 24.0 | |
| Nr. 10 | 2.00 | 111.8 | 85.2 | Fine sand | 39.9 | |
| Nr. 30 | 0.60 | 97.7 | 74.5 | Coarse silt | 10.63 | 15.10 |
| Nr. 40 | 0.43 | 80.3 | 61.2 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 29.4 | 22.4 | | | |
| Nr. 200 | 0.07 | 27.9 | 21.3 | Fine silt | 4.47 | |
| Pan | --- | 0.0 | 0.0 | Clay | 6.16 | 6.16 |

*Percentages relative to entire sample mass



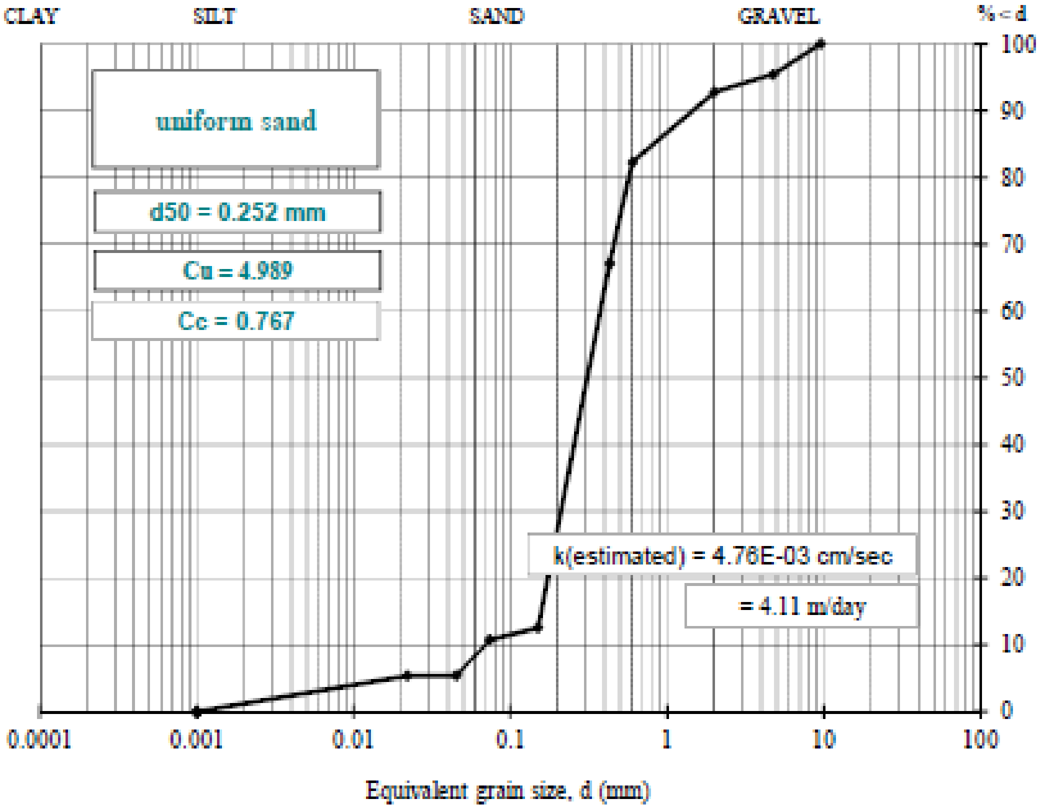
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH4 |
| **Depth** | 1.2 m |

| **Mechanical (sieve) analysis** | | | | **Soil Type** | **%** | **Tot. %** |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 4.6 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 4.6 | |
| 3/8" | 9.50 | 105.0 | 100.0 | Coarse sand | 2.7 | 84.7 |
| Nr. 4 | 4.75 | 100.2 | 95.4 | Medium sand | 25.6 | |
| Nr. 10 | 2.00 | 97.4 | 92.8 | Fine sand | 56.4 | |
| Nr. 30 | 0.60 | 86.4 | 82.3 | Coarse silt | 5.38 | 7.64 |
| Nr. 40 | 0.43 | 70.5 | 67.1 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 13.2 | 12.6 | | | |
| Nr. 200 | 0.07 | 11.3 | 10.8 | Fine silt | 2.26 | |
| Pan | --- | 0.0 | 0.0 | Clay | 3.12 | 3.12 |

*Percentages relative to entire sample mass



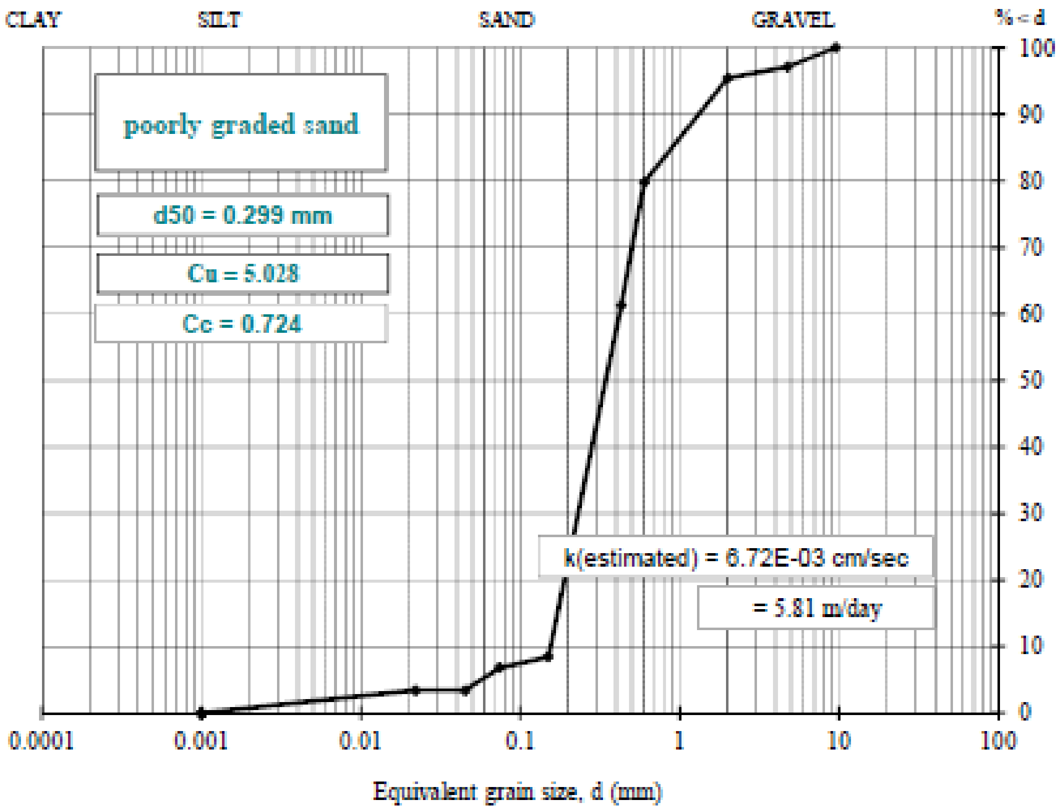
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH4 |
| **Depth** | 1.5 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 2.9 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 2.9 | |
| 3/8" | 9.50 | 121.7 | 100.0 | Coarse sand | 1.6 | 90.3 |
| Nr. 4 | 4.75 | 118.2 | 97.1 | Medium sand | 34.2 | |
| Nr. 10 | 2.00 | 116.2 | 95.5 | Fine sand | 54.5 | |
| Nr. 30 | 0.60 | 97.1 | 79.8 | Coarse silt | 3.41 | 4.84 |
| Nr. 40 | 0.43 | 74.6 | 61.3 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 10.3 | 8.5 | | | |
| Nr. 200 | 0.07 | 8.3 | 6.8 | Fine silt | 1.43 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.98 | 1.98 |

*Percentages relative to entire sample mass



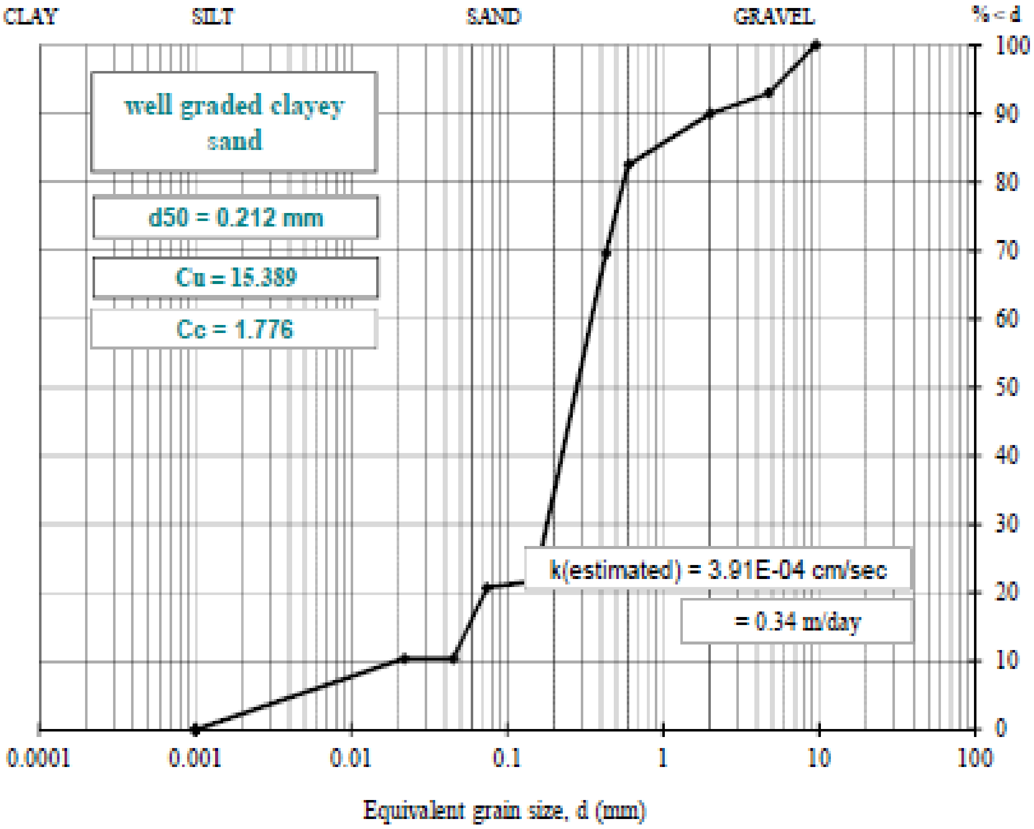
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH4 |
| **Depth** | 1.8 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 7.0 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 7.0 | |
| 3/8" | 9.50 | 131.3 | 100.0 | Coarse sand | 3.0 | 72.3 |
| Nr. 4 | 4.75 | 122.1 | 93.0 | Medium sand | 20.4 | |
| Nr. 10 | 2.00 | 118.2 | 90.0 | Fine sand | 48.9 | |
| Nr. 30 | 0.60 | 108.4 | 82.6 | Coarse silt | 10.36 | 14.71 |
| Nr. 40 | 0.43 | 91.4 | 69.6 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 28.5 | 21.7 | | | |
| Nr. 200 | 0.07 | 27.2 | 20.7 | Fine silt | 4.35 | |
| Pan | --- | 0.0 | 0.0 | Clay | 6.00 | 6.00 |

*Percentages relative to entire sample mass



## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

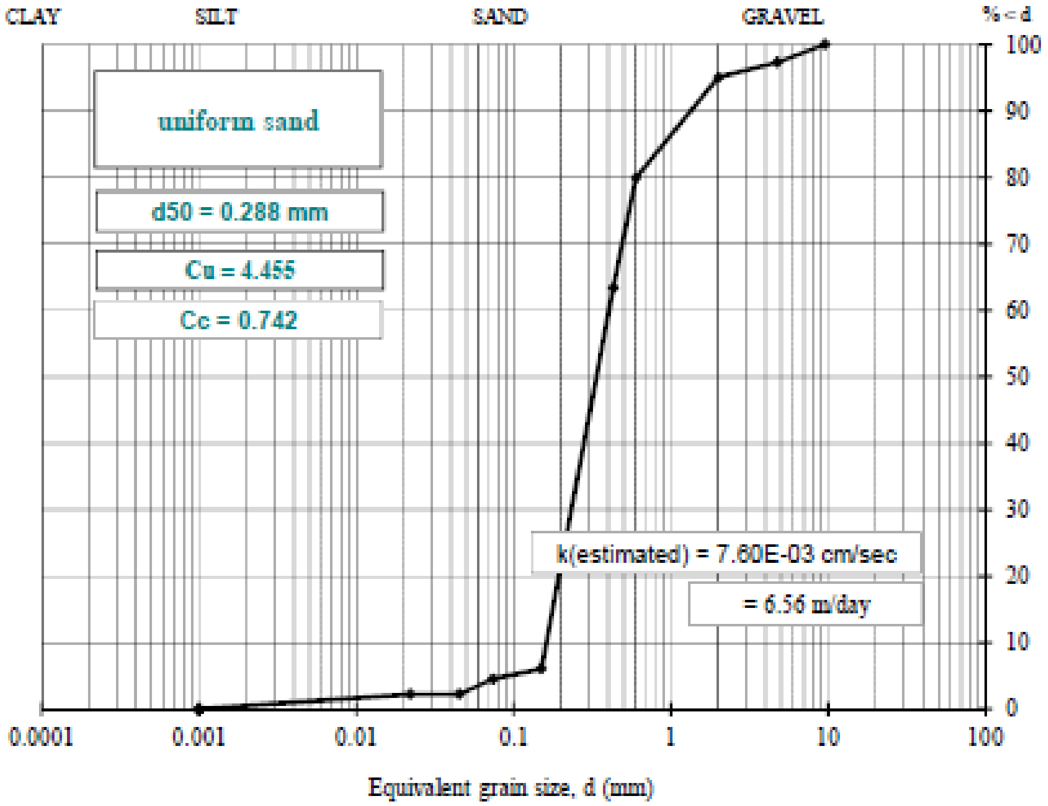
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH4

**Depth** 2.1 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 2.7 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 2.7 | |
| 3/8" | 9.50 | 97.3 | 100.0 | Coarse sand | 2.3 | 92.8 |
| Nr. 4 | 4.75 | 94.7 | 97.3 | Medium sand | 31.7 | |
| Nr. 10 | 2.00 | 92.5 | 95.1 | Fine sand | 58.9 | |
| Nr. 30 | 0.60 | 77.8 | 80.0 | Coarse silt | 2.26 | 3.21 |
| Nr. 40 | 0.43 | 61.7 | 63.4 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 5.9 | 6.1 | | | |
| Nr. 200 | 0.07 | 4.4 | 4.5 | Fine silt | 0.95 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.31 | 1.31 |

*Percentages relative to entire sample mass



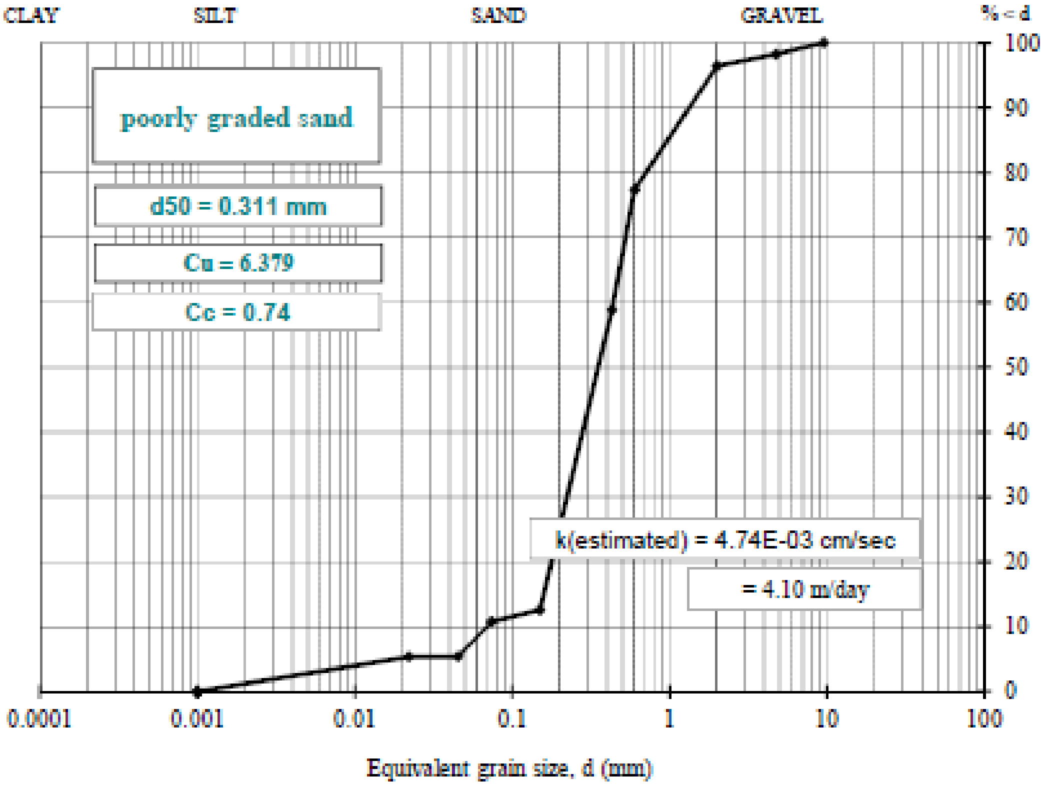
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH4 |
| **Depth** | 3.0 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 1.7 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 1.7 | |
| 3/8" | 9.50 | 103.9 | 100.0 | Coarse sand | 1.8 | 87.5 |
| Nr. 4 | 4.75 | 102.1 | 98.3 | Medium sand | 37.6 | |
| Nr. 10 | 2.00 | 100.2 | 96.4 | Fine sand | 48.0 | |
| Nr. 30 | 0.60 | 80.4 | 77.4 | Coarse silt | 5.39 | 7.66 |
| Nr. 40 | 0.43 | 61.1 | 58.8 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 13.1 | 12.6 | | | |
| Nr. 200 | 0.07 | 11.2 | 10.8 | Fine silt | 2.27 | |
| Pan | --- | 0.0 | 0.0 | Clay | 3.12 | 3.12 |

*Percentages relative to entire sample mass



# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

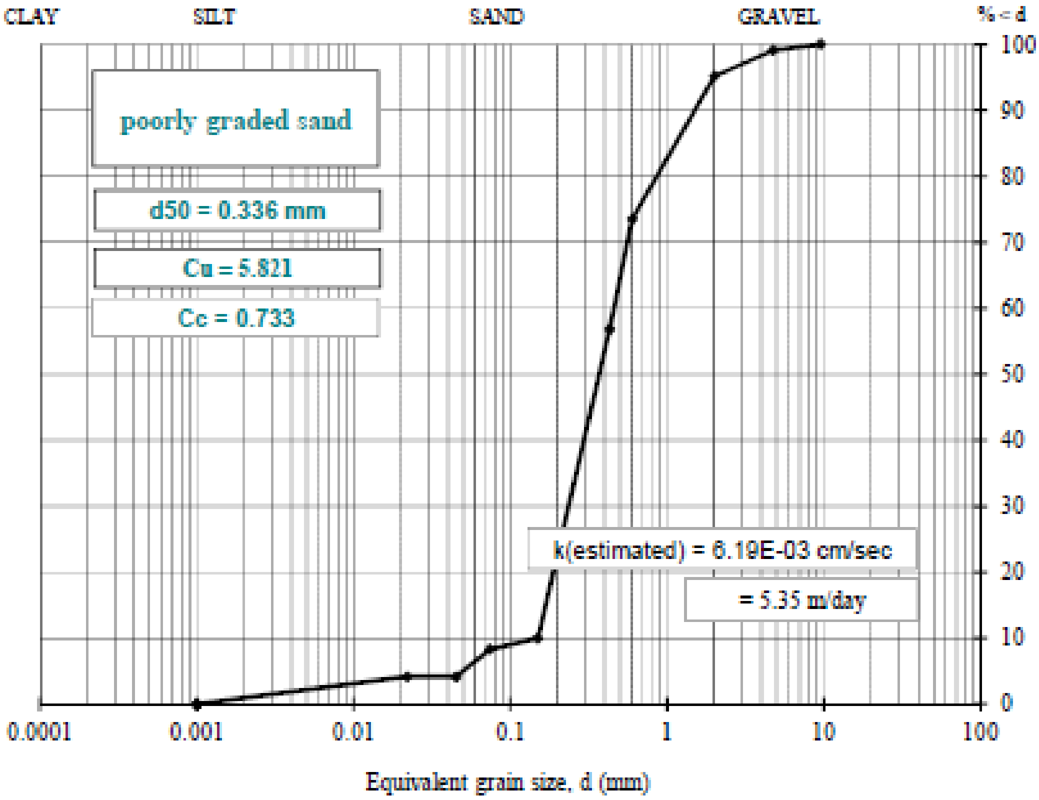
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH4

**Depth** 4.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 0.9 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 0.9 | |
| 3/8" | 9.50 | 101.2 | 100.0 | Coarse sand | 4.0 | 90.8 |
| Nr. 4 | 4.75 | 100.3 | 99.1 | Medium sand | 38.3 | |
| Nr. 10 | 2.00 | 96.3 | 95.2 | Fine sand | 48.5 | |
| Nr. 30 | 0.60 | 74.4 | 73.5 | Coarse silt | 4.15 | 5.89 |
| Nr. 40 | 0.43 | 57.5 | 56.8 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 10.1 | 10.0 | | | |
| Nr. 200 | 0.07 | 8.4 | 8.3 | Fine silt | 1.74 | |
| Pan | --- | 0.0 | 0.0 | Clay | 2.41 | 2.41 |

*Percentages relative to entire sample mass



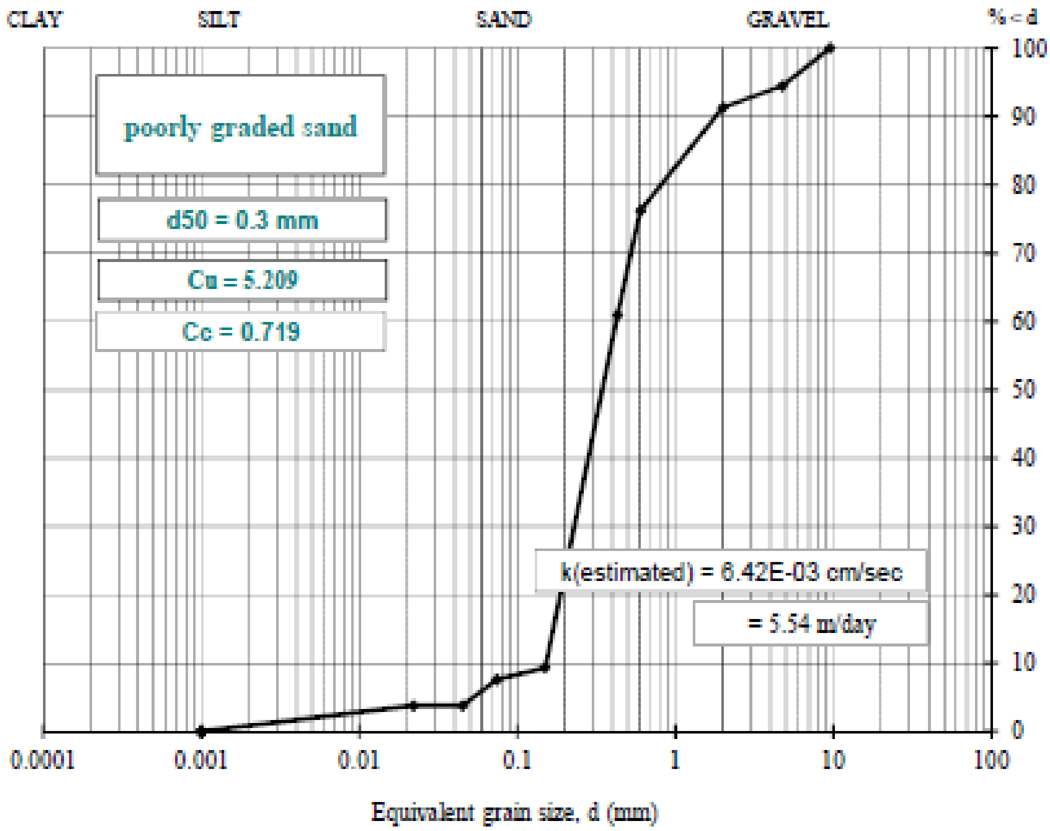
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH4 |
| **Depth** | 5.0 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 5.5 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 5.5 | |
| 3/8" | 9.50 | 92.1 | 100.0 | Coarse sand | 3.1 | 86.9 |
| Nr. 4 | 4.75 | 87.0 | 94.5 | Medium sand | 30.4 | |
| Nr. 10 | 2.00 | 84.1 | 91.3 | Fine sand | 53.3 | |
| Nr. 30 | 0.60 | 70.2 | 76.2 | Coarse silt | 3.80 | 5.40 |
| Nr. 40 | 0.43 | 56.1 | 60.9 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 8.6 | 9.3 | | | |
| Nr. 200 | 0.07 | 7.0 | 7.6 | Fine silt | 1.60 | |
| Pan | --- | 0.0 | 0.0 | Clay | 2.20 | 2.20 |

*Percentages relative to entire sample mass



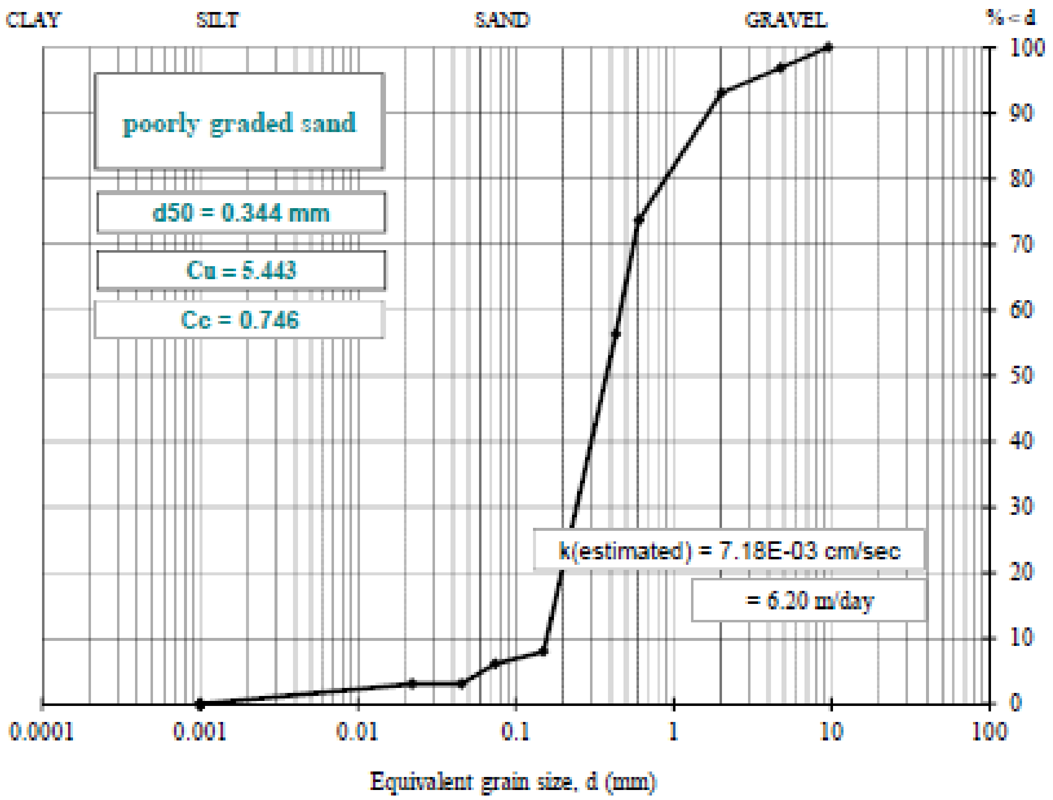
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH4 |
| **Depth** | 6.0 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 3.1 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 3.1 | |
| 3/8" | 9.50 | 112.5 | 100.0 | Coarse sand | 3.8 | 90.8 |
| Nr. 4 | 4.75 | 109.0 | 96.9 | Medium sand | 36.7 | |
| Nr. 10 | 2.00 | 104.7 | 93.1 | Fine sand | 50.2 | |
| Nr. 30 | 0.60 | 82.9 | 73.7 | Coarse silt | 3.07 | 4.36 |
| Nr. 40 | 0.43 | 63.4 | 56.4 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 9.0 | 8.0 | | | |
| Nr. 200 | 0.07 | 6.9 | 6.1 | Fine silt | 1.29 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.78 | 1.78 |

*Percentages relative to entire sample mass



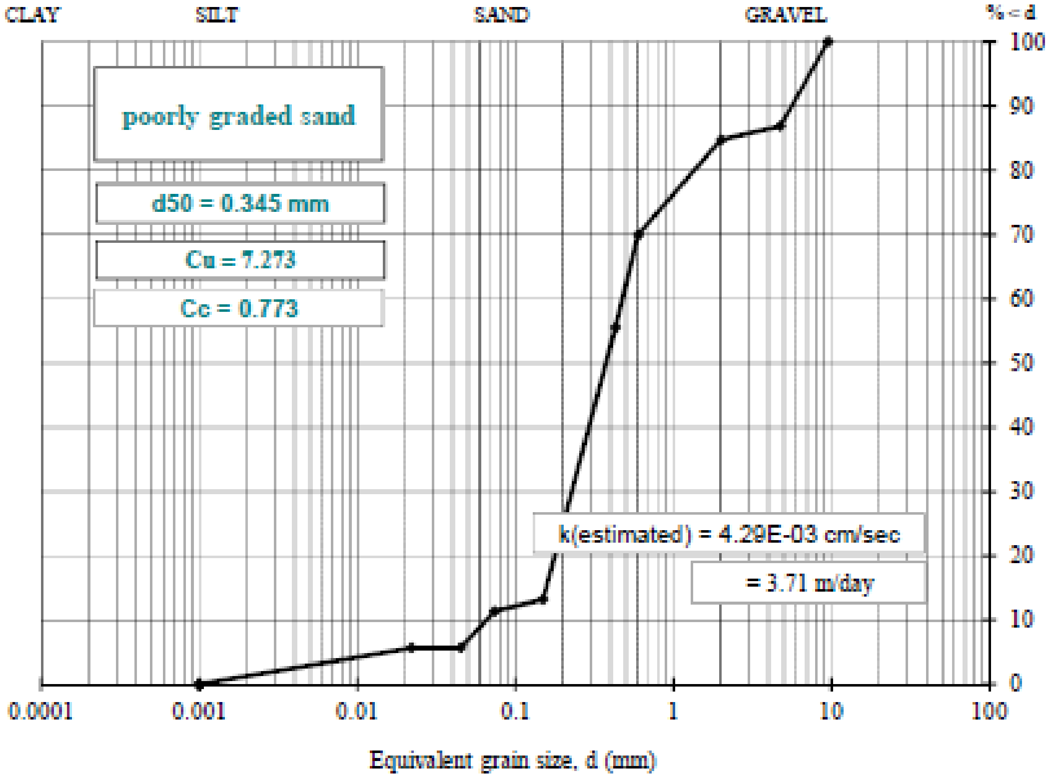
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

**Project:** Master Research-Study- (Eng. Basem Serdah)
**Bore Hole No.** BH4
**Depth** 7.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 13.1 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 13.1 | |
| 3/8" | 9.50 | 98.3 | 100.0 | Coarse sand | 2.1 | 75.5 |
| Nr. 4 | 4.75 | 85.4 | 86.9 | Medium sand | 29.2 | |
| Nr. 10 | 2.00 | 83.3 | 84.7 | Fine sand | 44.2 | |
| Nr. 30 | 0.60 | 68.8 | 70.0 | Coarse silt | 5.70 | 8.09 |
| Nr. 40 | 0.43 | 54.6 | 55.5 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 13.0 | 13.2 | | | |
| Nr. 200 | 0.07 | 11.2 | 11.4 | Fine silt | 2.39 | |
| Pan | --- | 0.0 | 0.0 | Clay | 3.30 | 3.30 |

*Percentages relative to entire sample mass



# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

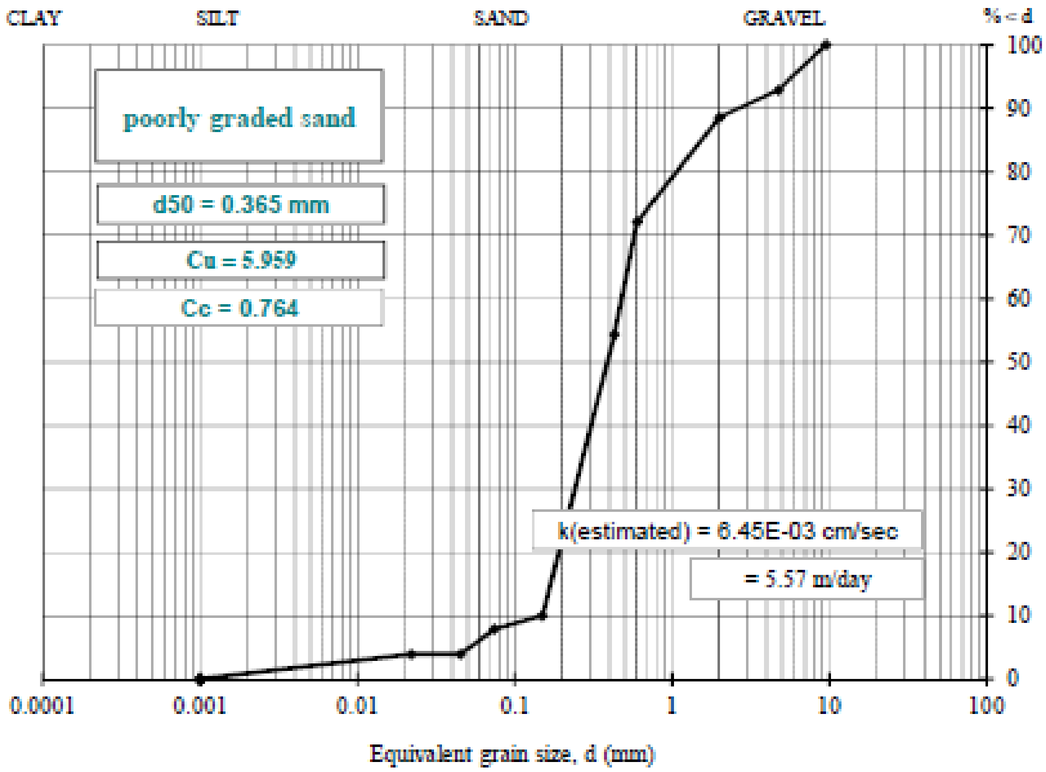
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH4

**Depth** 8.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 7.1 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 7.1 | |
| 3/8" | 9.50 | 94.3 | 100.0 | Coarse sand | 4.3 | 85.0 |
| Nr. 4 | 4.75 | 87.6 | 92.9 | Medium sand | 34.3 | |
| Nr. 10 | 2.00 | 83.5 | 88.5 | Fine sand | 46.4 | |
| Nr. 30 | 0.60 | 68.0 | 72.1 | Coarse silt | 3.92 | 5.57 |
| Nr. 40 | 0.43 | 51.2 | 54.3 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 9.4 | 10.0 | | | |
| Nr. 200 | 0.07 | 7.4 | 7.8 | Fine silt | 1.65 | |
| Pan | --- | 0.0 | 0.0 | Clay | 2.27 | 2.27 |

*Percentages relative to entire sample mass



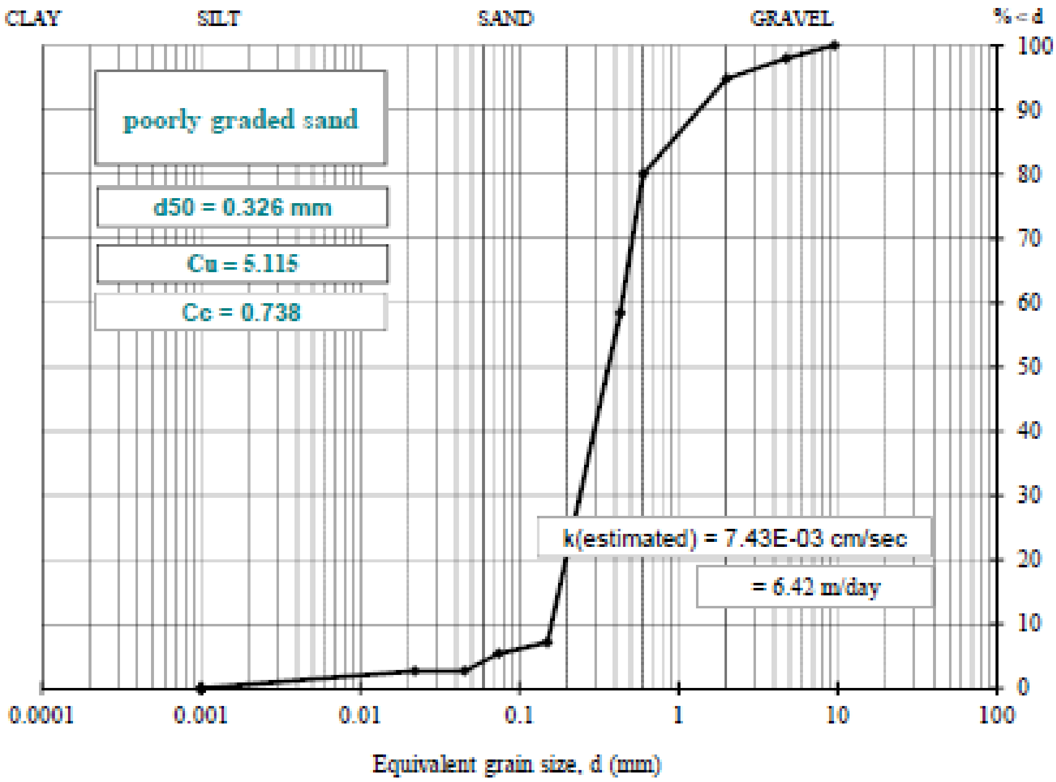
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH4 |
| **Depth** | 9.0 m |

| **Mechanical (sieve) analysis** | | | | **Soil Type** | **%** | **Tot. %** |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 2.0 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 2.0 | |
| 3/8" | 9.50 | 114.6 | 100.0 | Coarse sand | 3.1 | 92.6 |
| Nr. 4 | 4.75 | 112.3 | 98.0 | Medium sand | 36.5 | |
| Nr. 10 | 2.00 | 108.7 | 94.9 | Fine sand | 53.0 | |
| Nr. 30 | 0.60 | 91.7 | 80.0 | Coarse silt | 2.71 | 3.84 |
| Nr. 40 | 0.43 | 66.9 | 58.4 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 8.2 | 7.2 | | | |
| Nr. 200 | 0.07 | 6.2 | 5.4 | Fine silt | 1.14 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.57 | 1.57 |

*Percentages relative to entire sample mass



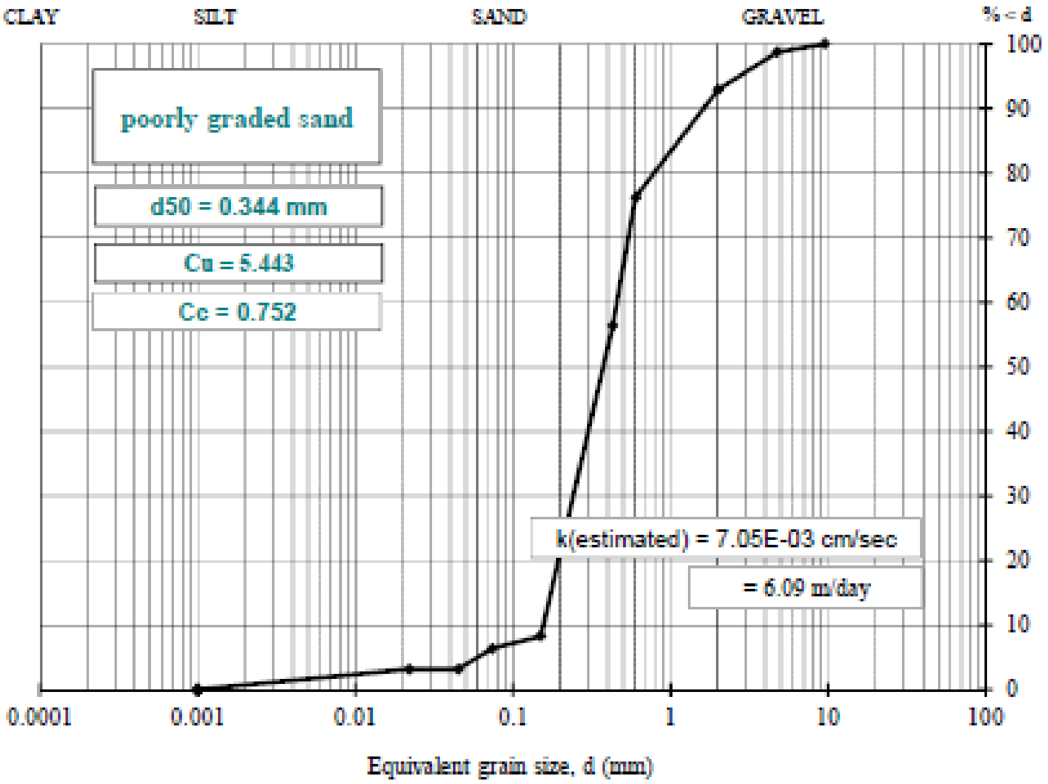
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

**Project:** Master Research-Study- (Eng. Basem Serdah)
**Bore Hole No.** BH4
**Depth** 10.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 1.2 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 1.2 | |
| 3/8" | 9.50 | 88.9 | 100.0 | Coarse sand | 5.8 | 92.4 |
| Nr. 4 | 4.75 | 87.8 | 98.8 | Medium sand | 36.6 | |
| Nr. 10 | 2.00 | 82.6 | 92.9 | Fine sand | 49.9 | |
| Nr. 30 | 0.60 | 67.8 | 76.3 | Coarse silt | 3.21 | 4.55 |
| Nr. 40 | 0.43 | 50.1 | 56.4 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 7.4 | 8.3 | | | |
| Nr. 200 | 0.07 | 5.7 | 6.4 | Fine silt | 1.35 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.86 | 1.86 |

*Percentages relative to entire sample mass



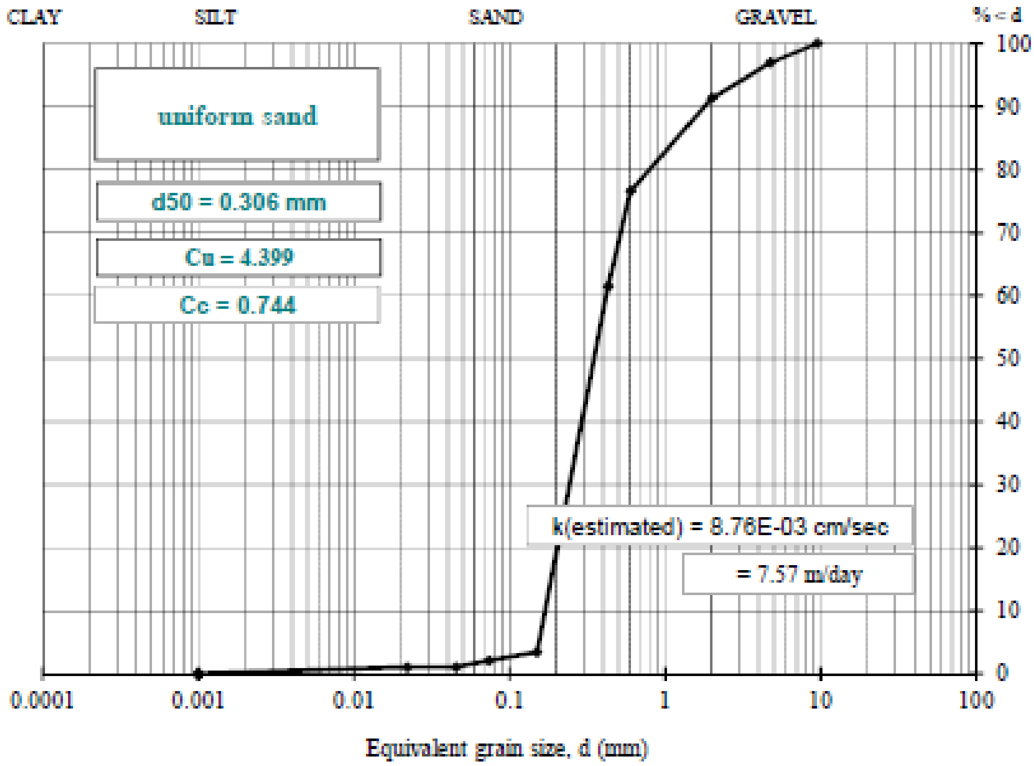
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH4 |
| **Depth** | 11.0 m |

| **Mechanical (sieve) analysis** | | | | **Soil Type** | **%** | **Tot. %** |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 3.0 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 3.0 | |
| 3/8" | 9.50 | 82.0 | 100.0 | Coarse sand | 5.6 | 94.9 |
| Nr. 4 | 4.75 | 79.5 | 97.0 | Medium sand | 29.9 | |
| Nr. 10 | 2.00 | 74.9 | 91.3 | Fine sand | 59.4 | |
| Nr. 30 | 0.60 | 62.8 | 76.6 | Coarse silt | 1.04 | 1.47 |
| Nr. 40 | 0.43 | 50.4 | 61.5 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 2.8 | 3.4 | | | |
| Nr. 200 | 0.07 | 1.7 | 2.1 | Fine silt | 0.44 | |
| Pan | --- | 0.0 | 0.0 | Clay | 0.60 | 0.60 |

*Percentages relative to entire sample mass



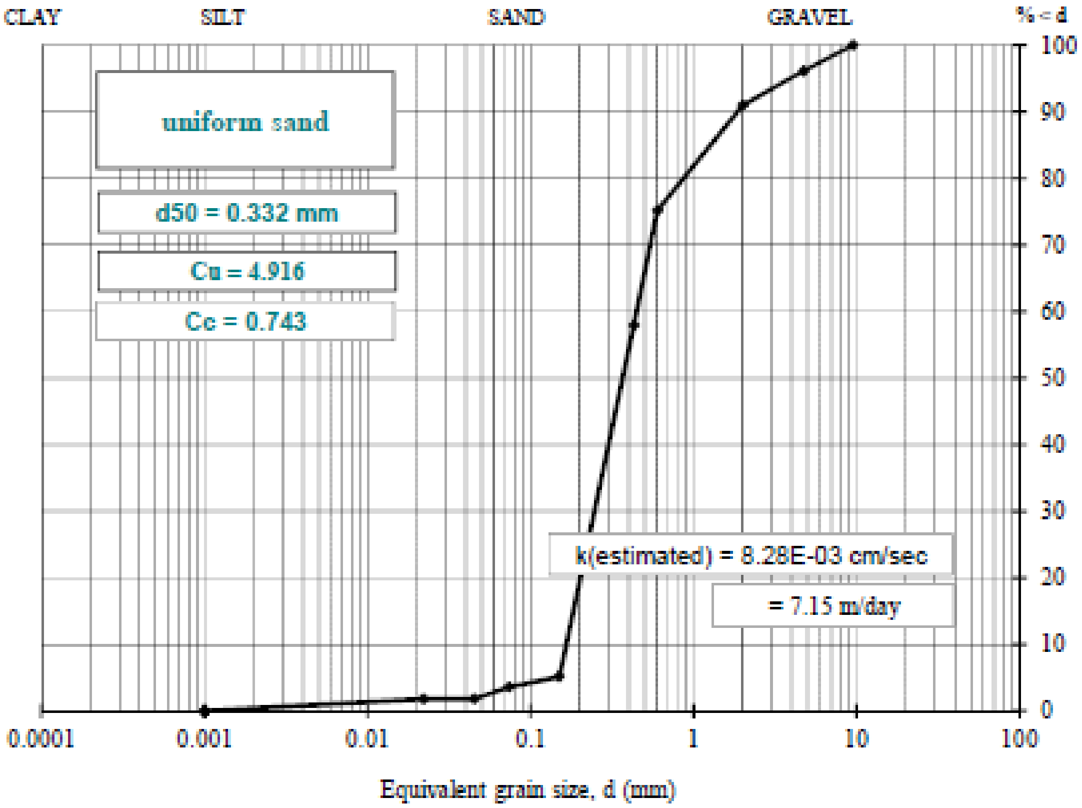
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH4 |
| **Depth** | 12.0 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 3.8 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 3.8 | |
| 3/8" | 9.50 | 96.6 | 100.0 | Coarse sand | 5.2 | 92.5 |
| Nr. 4 | 4.75 | 92.9 | 96.2 | Medium sand | 33.0 | |
| Nr. 10 | 2.00 | 87.9 | 91.0 | Fine sand | 54.3 | |
| Nr. 30 | 0.60 | 72.6 | 75.2 | Coarse silt | 1.81 | 2.57 |
| Nr. 40 | 0.43 | 56.0 | 58.0 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 5.0 | 5.2 | | | |
| Nr. 200 | 0.07 | 3.5 | 3.6 | Fine silt | 0.76 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.05 | 1.05 |

*Percentages relative to entire sample mass



## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

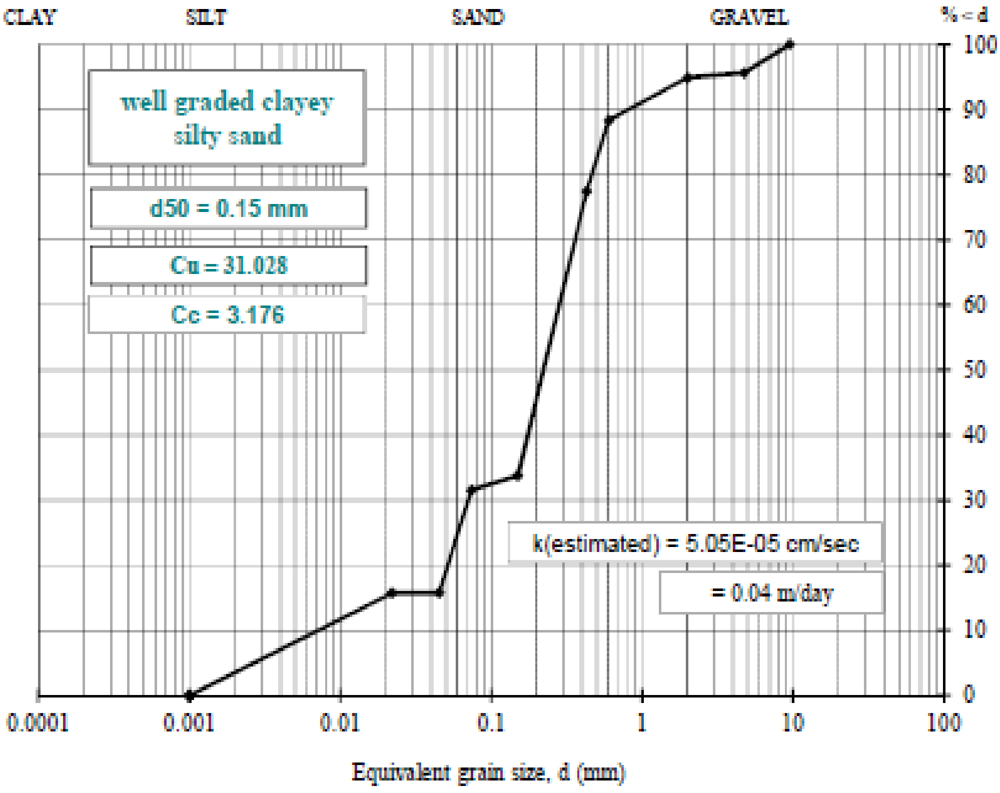
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH5

**Depth** 0.3 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 4.3 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 4.3 | |
| 3/8" | 9.50 | 103.7 | 100.0 | Coarse sand | 0.8 | 64.1 |
| Nr. 4 | 4.75 | 99.2 | 95.7 | Medium sand | 17.5 | |
| Nr. 10 | 2.00 | 98.4 | 94.9 | Fine sand | 45.9 | |
| Nr. 30 | 0.60 | 91.6 | 88.3 | Coarse silt | 15.77 | 22.39 |
| Nr. 40 | 0.43 | 80.3 | 77.4 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 35.0 | 33.8 | | | |
| Nr. 200 | 0.07 | 32.7 | 31.5 | Fine silt | 6.63 | |
| Pan | --- | 0.0 | 0.0 | Clay | 9.14 | 9.14 |

*Percentages relative to entire sample mass



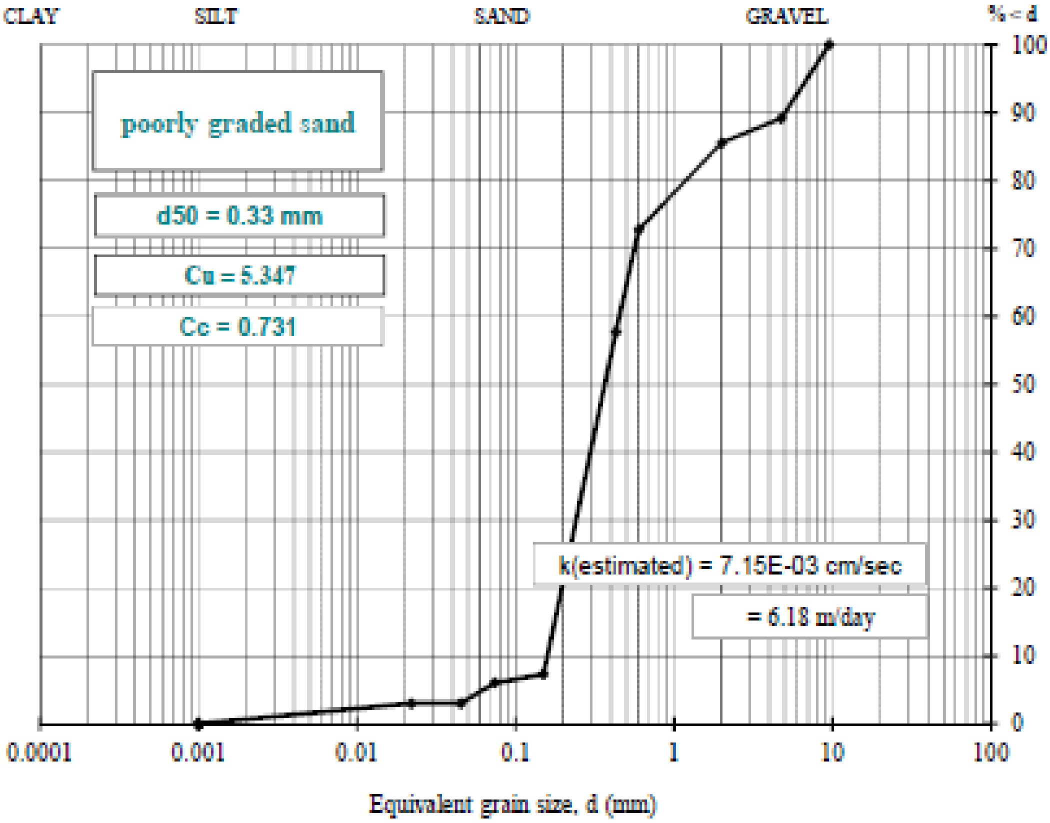
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

**Project:** Master Research-Study- (Eng. Basem Serdah)
**Bore Hole No.** BH5
**Depth** 0.6 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 10.8 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 10.8 | |
| 3/8" | 9.50 | 97.0 | 100.0 | Coarse sand | 3.6 | 83.1 |
| Nr. 4 | 4.75 | 86.5 | 89.2 | Medium sand | 27.8 | |
| Nr. 10 | 2.00 | 83.0 | 85.6 | Fine sand | 51.6 | |
| Nr. 30 | 0.60 | 70.6 | 72.8 | Coarse silt | 3.04 | 4.32 |
| Nr. 40 | 0.43 | 56.0 | 57.7 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 7.1 | 7.3 | | | |
| Nr. 200 | 0.07 | 5.9 | 6.1 | Fine silt | 1.28 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.76 | 1.76 |

*Percentages relative to entire sample mass



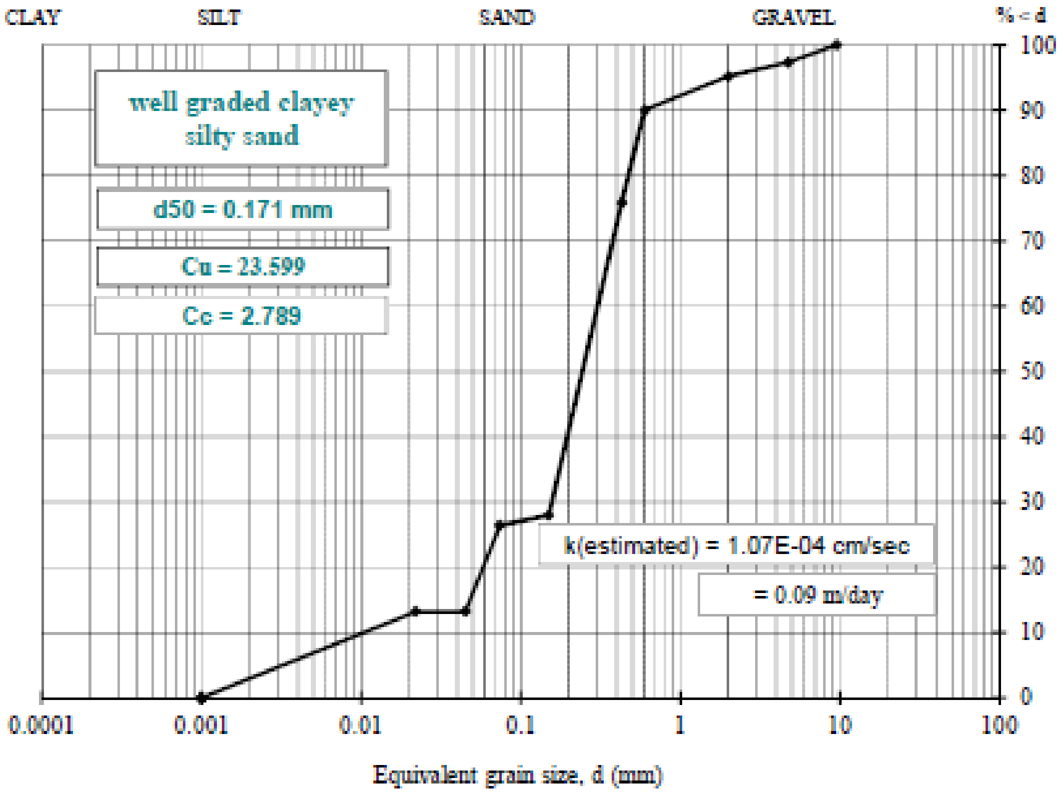
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH5 |
| **Depth** | 0.9 m |

| **Mechanical (sieve) analysis** | | | | **Soil Type** | **%** | **Tot. %** |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 2.6 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 2.6 | |
| 3/8" | 9.50 | 106.6 | 100.0 | Coarse sand | 2.2 | 70.9 |
| Nr. 4 | 4.75 | 103.8 | 97.4 | Medium sand | 19.3 | |
| Nr. 10 | 2.00 | 101.5 | 95.2 | Fine sand | 49.4 | |
| Nr. 30 | 0.60 | 96.0 | 90.1 | Coarse silt | 13.23 | 18.79 |
| Nr. 40 | 0.43 | 80.9 | 75.9 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 29.8 | 28.0 | | | |
| Nr. 200 | 0.07 | 28.2 | 26.5 | Fine silt | 5.56 | |
| Pan | --- | 0.0 | 0.0 | Clay | 7.67 | 7.67 |

*Percentages relative to entire sample mass



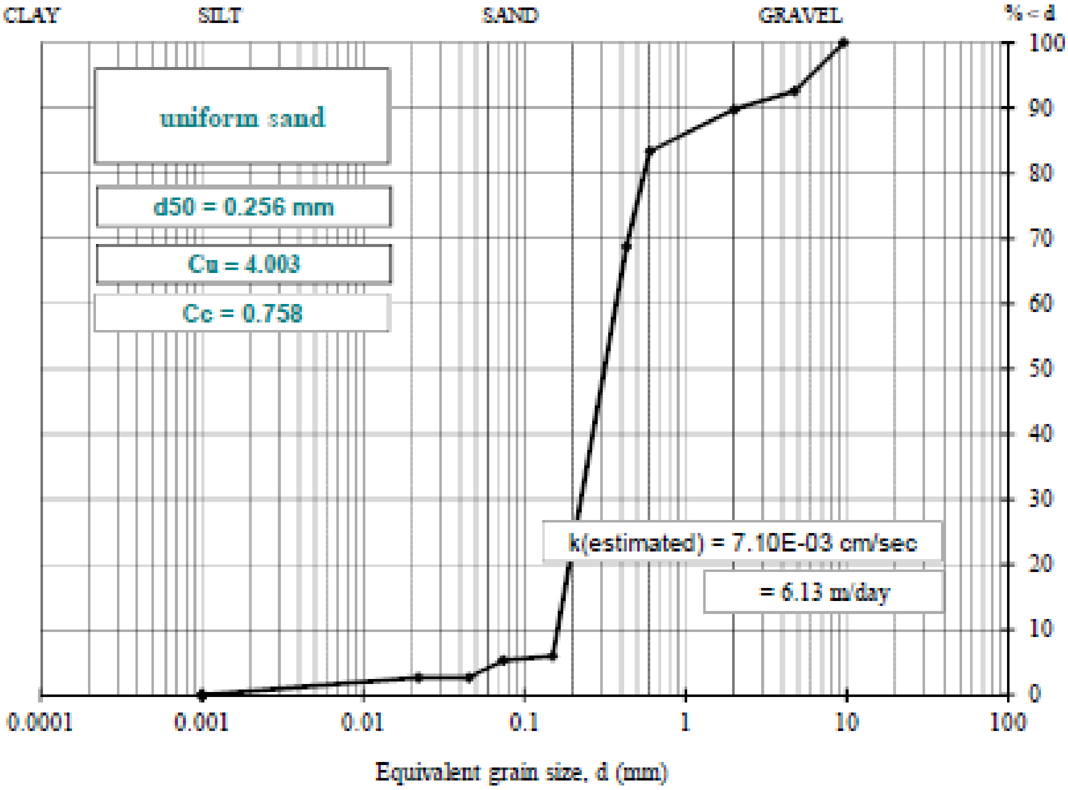
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH5 |
| **Depth** | 1.2 m |

| **Mechanical (sieve) analysis** | | | | **Soil Type** | **%** | **Tot. %** |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 7.5 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 7.5 | |
| 3/8" | 9.50 | 93.8 | 100.0 | Coarse sand | 2.8 | 87.2 |
| Nr. 4 | 4.75 | 86.8 | 92.5 | Medium sand | 21.0 | |
| Nr. 10 | 2.00 | 84.2 | 89.8 | Fine sand | 63.4 | |
| Nr. 30 | 0.60 | 78.2 | 83.4 | Coarse silt | 2.67 | 3.79 |
| Nr. 40 | 0.43 | 64.5 | 68.8 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 5.6 | 6.0 | | | |
| Nr. 200 | 0.07 | 5.0 | 5.3 | Fine silt | 1.12 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.54 | 1.54 |

*Percentages relative to entire sample mass



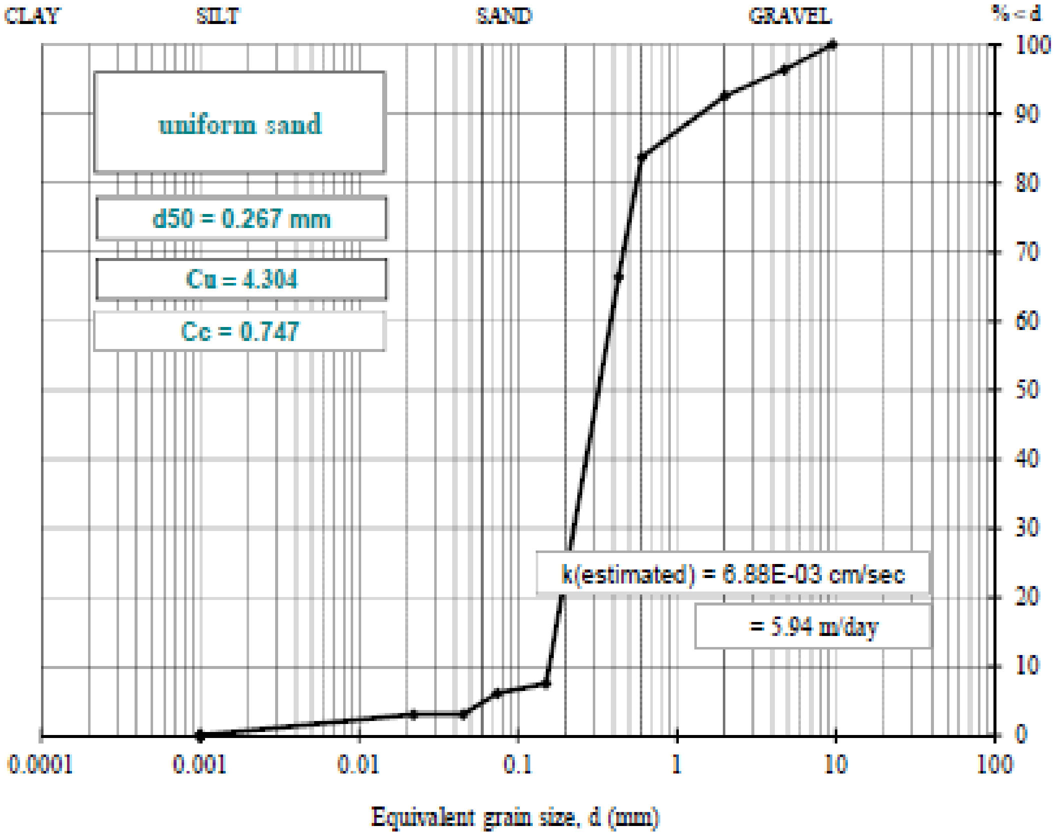
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

**Project:** Master Research-Study- (Eng. Basem Serdah)
**Bore Hole No.** BH5
**Depth** 1.5 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 3.6 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 3.6 | |
| 3/8" | 9.50 | 147.8 | 100.0 | Coarse sand | 3.8 | 90.3 |
| Nr. 4 | 4.75 | 142.5 | 96.4 | Medium sand | 26.3 | |
| Nr. 10 | 2.00 | 136.9 | 92.6 | Fine sand | 60.3 | |
| Nr. 30 | 0.60 | 123.7 | 83.7 | Coarse silt | 3.04 | 4.32 |
| Nr. 40 | 0.43 | 98.1 | 66.4 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 11.1 | 7.5 | | | |
| Nr. 200 | 0.07 | 9.0 | 6.1 | Fine silt | 1.28 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.76 | 1.76 |

*Percentages relative to entire sample mass



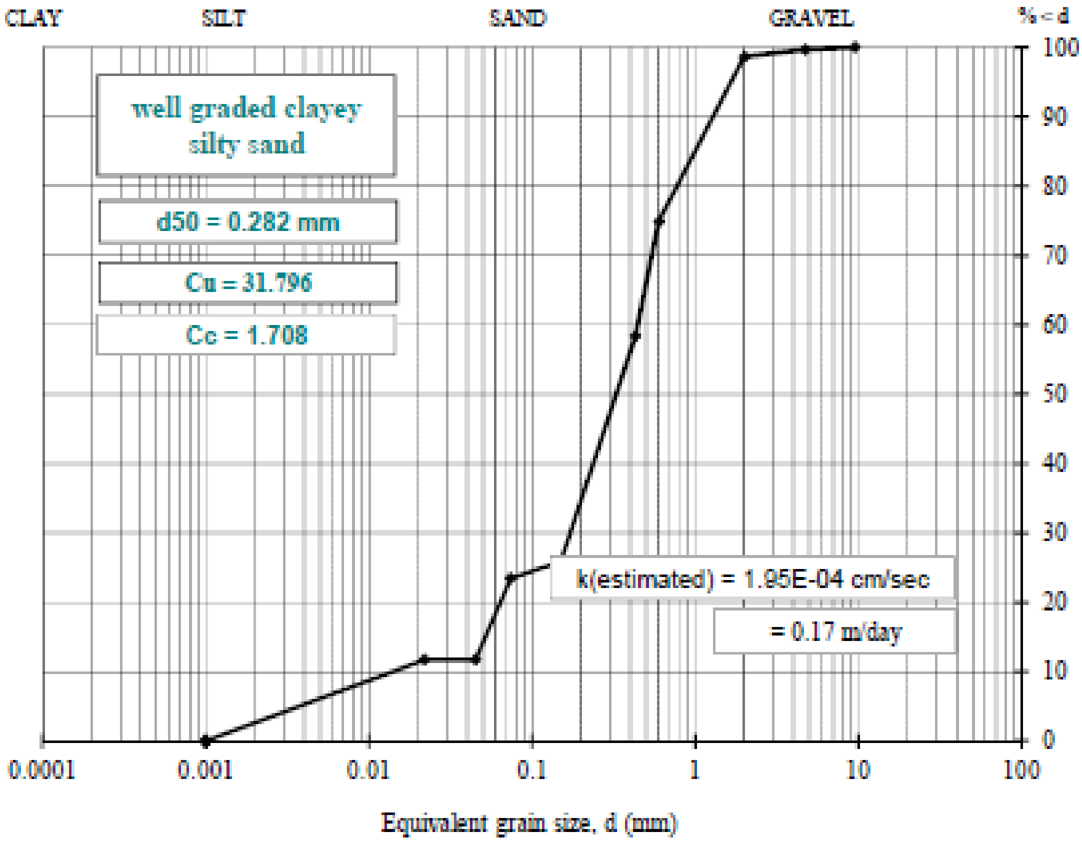
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH5 |
| **Depth** | 1.8 m |

| **Mechanical (sieve) analysis** | | | | **Soil Type** | **%** | **Tot. %** |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 0.3 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 0.3 | |
| 3/8" | 9.50 | 155.7 | 100.0 | Coarse sand | 1.0 | 76.2 |
| Nr. 4 | 4.75 | 155.2 | 99.7 | Medium sand | 40.3 | |
| Nr. 10 | 2.00 | 153.6 | 98.7 | Fine sand | 34.9 | |
| Nr. 30 | 0.60 | 116.6 | 74.9 | Coarse silt | 11.72 | 16.65 |
| Nr. 40 | 0.43 | 90.9 | 58.4 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 40.3 | 25.9 | | | |
| Nr. 200 | 0.07 | 36.5 | 23.4 | Fine silt | 4.93 | |
| Pan | --- | 0.0 | 0.0 | Clay | 6.79 | 6.79 |

*Percentages relative to entire sample mass



# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

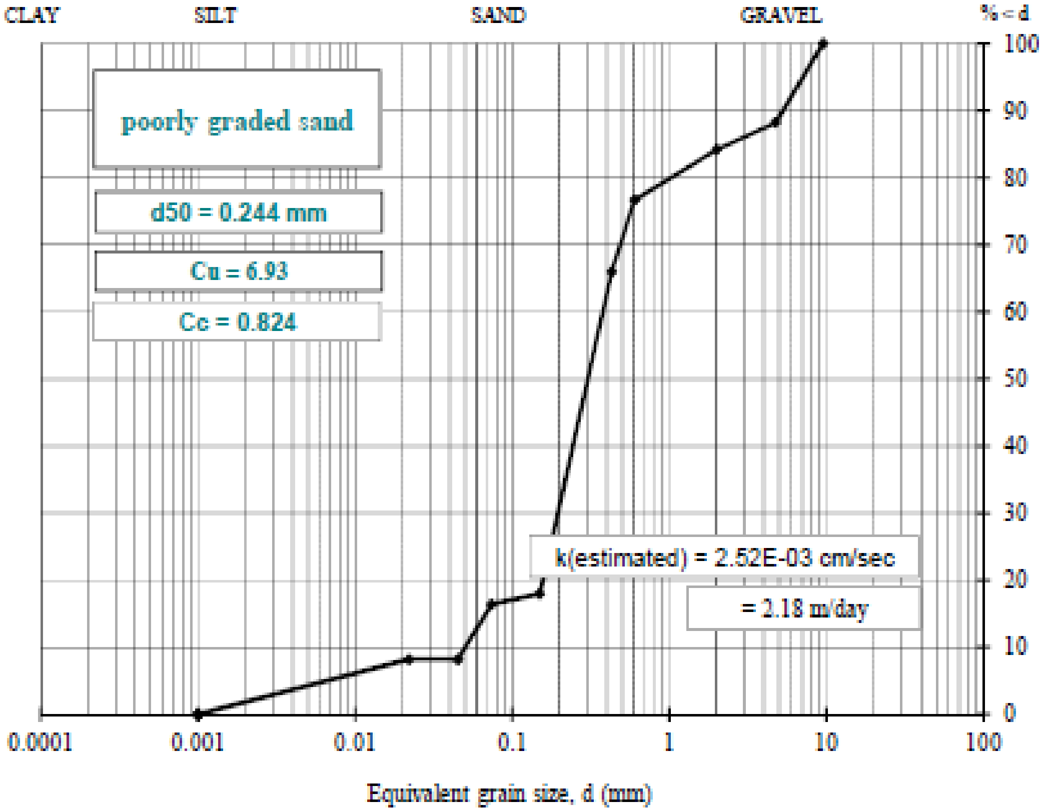
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH5

**Depth** 2.1 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 11.8 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 11.8 | |
| 3/8" | 9.50 | 82.3 | 100.0 | Coarse sand | 4.0 | 71.8 |
| Nr. 4 | 4.75 | 72.6 | 88.2 | Medium sand | 18.2 | |
| Nr. 10 | 2.00 | 69.3 | 84.2 | Fine sand | 49.6 | |
| Nr. 30 | 0.60 | 63.1 | 76.7 | Coarse silt | 8.20 | 11.65 |
| Nr. 40 | 0.43 | 54.3 | 66.0 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 14.8 | 18.0 | | | |
| Nr. 200 | 0.07 | 13.5 | 16.4 | Fine silt | 3.45 | |
| Pan | --- | 0.0 | 0.0 | Clay | 4.75 | 4.75 |

*Percentages relative to entire sample mass



# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

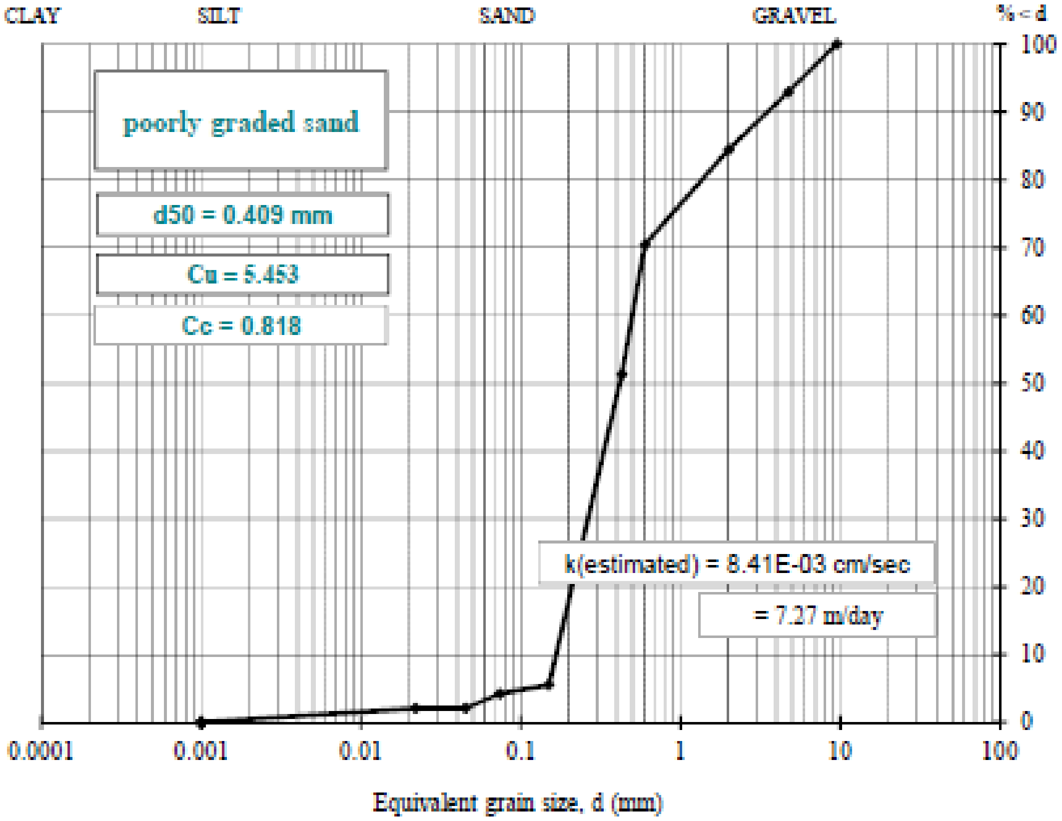
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH5

**Depth** 3.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 7.0 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 7.0 | |
| 3/8" | 9.50 | 101.1 | 100.0 | Coarse sand | 8.5 | 88.7 |
| Nr. 4 | 4.75 | 94.0 | 93.0 | Medium sand | 33.1 | |
| Nr. 10 | 2.00 | 85.4 | 84.5 | Fine sand | 47.1 | |
| Nr. 30 | 0.60 | 71.2 | 70.4 | Coarse silt | 2.13 | 3.02 |
| Nr. 40 | 0.43 | 51.9 | 51.3 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 5.6 | 5.5 | | | |
| Nr. 200 | 0.07 | 4.3 | 4.3 | Fine silt | 0.89 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.23 | 1.23 |

*Percentages relative to entire sample mass



# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

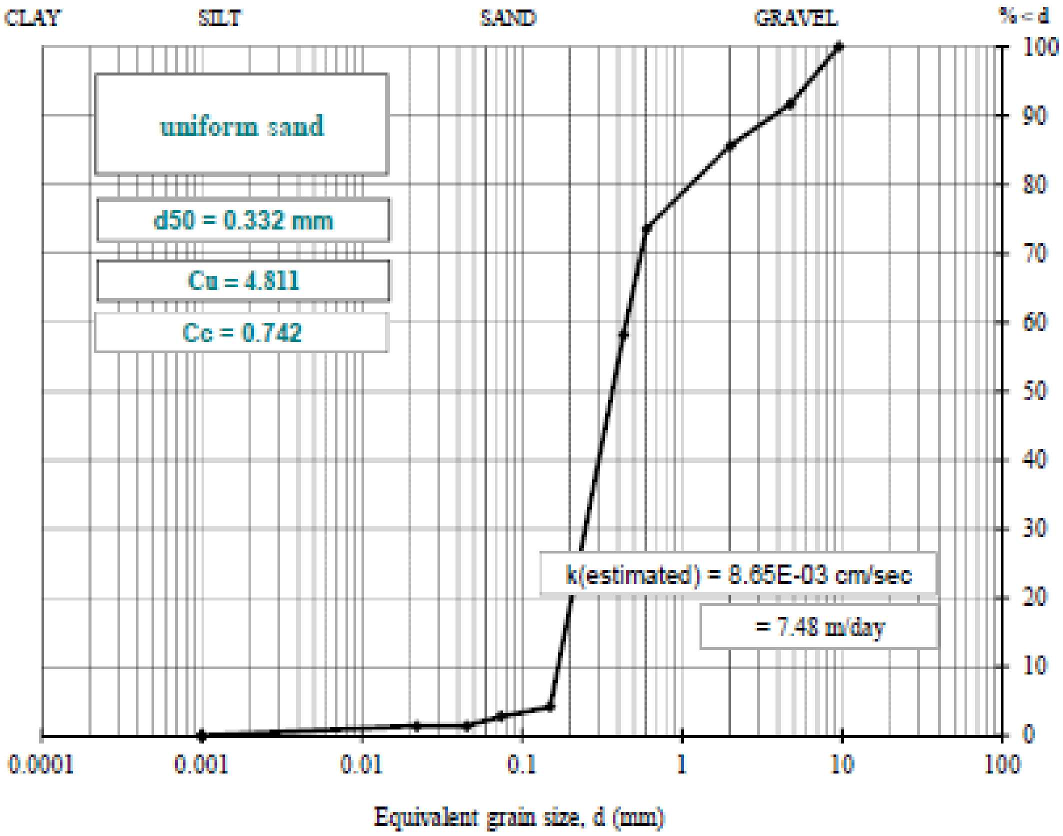
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH5

**Depth** 4.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 8.3 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 8.3 | |
| 3/8" | 9.50 | 114.2 | 100.0 | Coarse sand | 6.0 | 88.9 |
| Nr. 4 | 4.75 | 104.7 | 91.7 | Medium sand | 27.5 | |
| Nr. 10 | 2.00 | 97.8 | 85.6 | Fine sand | 55.3 | |
| Nr. 30 | 0.60 | 84.0 | 73.6 | Coarse silt | 1.40 | 1.99 |
| Nr. 40 | 0.43 | 66.4 | 58.1 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 4.8 | 4.2 | | | |
| Nr. 200 | 0.07 | 3.2 | 2.8 | Fine silt | 0.59 | |
| Pan | --- | 0.0 | 0.0 | Clay | 0.81 | 0.81 |

*Percentages relative to entire sample mass



# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

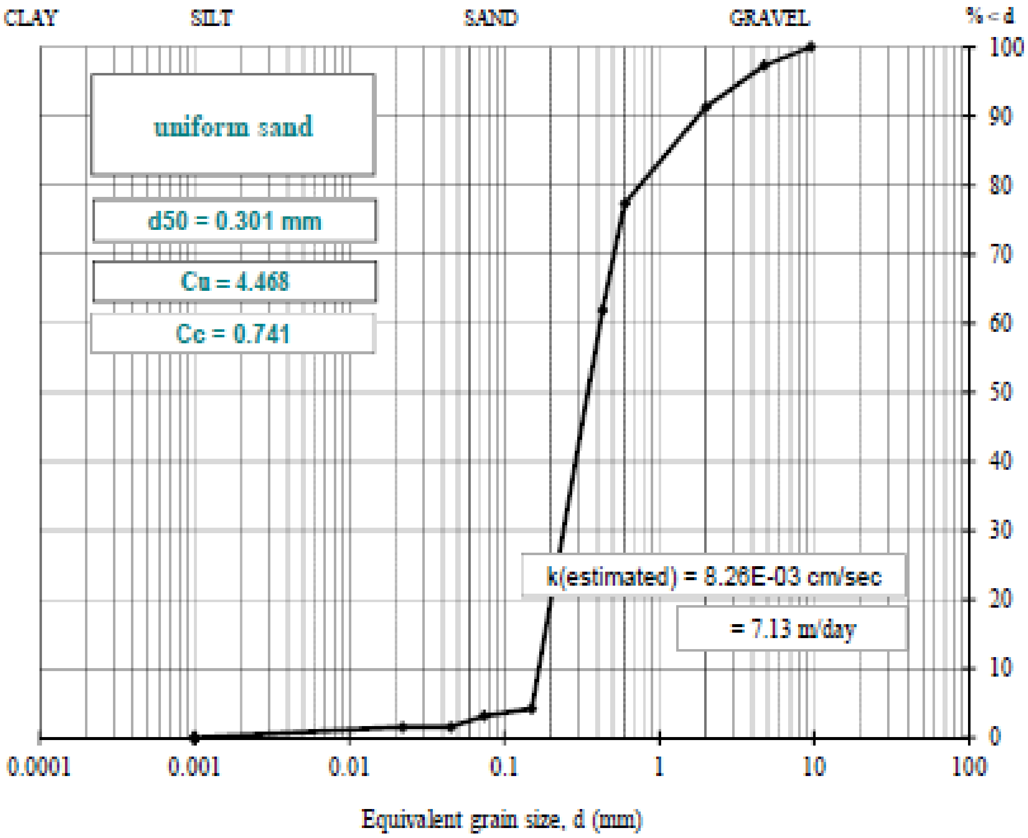
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH5

**Depth** 5.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 2.7 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 2.7 | |
| 3/8" | 9.50 | 108.2 | 100.0 | Coarse sand | 6.0 | 94.2 |
| Nr. 4 | 4.75 | 105.3 | 97.3 | Medium sand | 29.4 | |
| Nr. 10 | 2.00 | 98.8 | 91.3 | Fine sand | 58.8 | |
| Nr. 30 | 0.60 | 83.7 | 77.4 | Coarse silt | 1.57 | 2.23 |
| Nr. 40 | 0.43 | 67.0 | 61.9 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 4.6 | 4.3 | | | |
| Nr. 200 | 0.07 | 3.4 | 3.1 | Fine silt | 0.66 | |
| Pan | --- | 0.0 | 0.0 | Clay | 0.91 | 0.91 |

*Percentages relative to entire sample mass



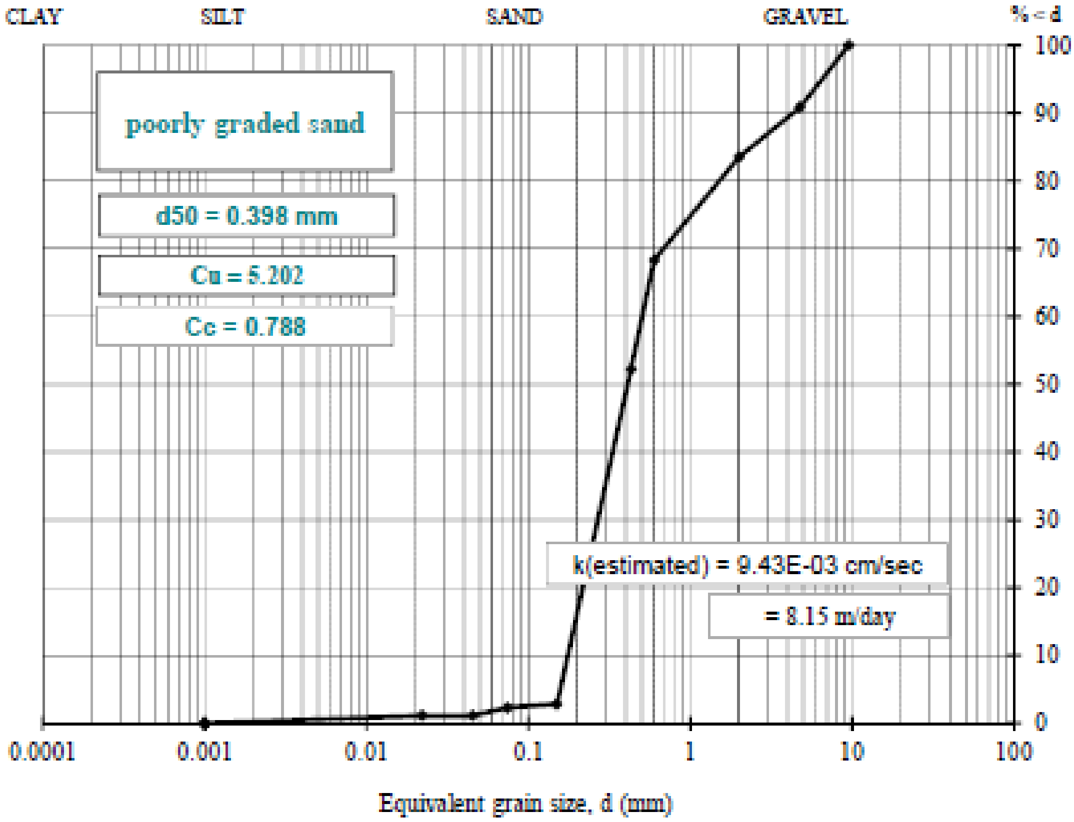
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH5 |
| **Depth** | 6.0 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 9.2 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 9.2 | |
| 3/8" | 9.50 | 91.6 | 100.0 | Coarse sand | 7.3 | 88.5 |
| Nr. 4 | 4.75 | 83.2 | 90.8 | Medium sand | 31.3 | |
| Nr. 10 | 2.00 | 76.5 | 83.5 | Fine sand | 49.9 | |
| Nr. 30 | 0.60 | 62.6 | 68.3 | Coarse silt | 1.15 | 1.63 |
| Nr. 40 | 0.43 | 47.8 | 52.2 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 2.6 | 2.8 | | | |
| Nr. 200 | 0.07 | 2.1 | 2.3 | Fine silt | 0.48 | |
| Pan | --- | 0.0 | 0.0 | Clay | 0.66 | 0.66 |

*Percentages relative to entire sample mass



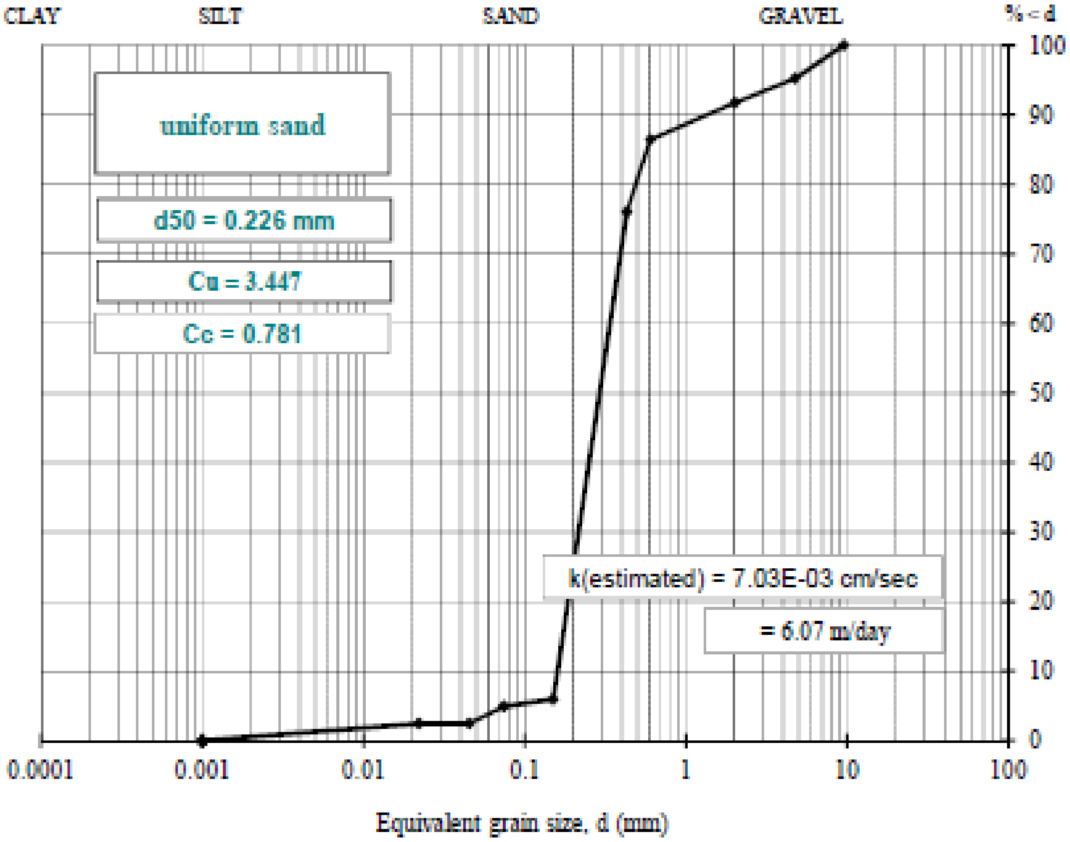
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH5 |
| **Depth** | 7.0 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 4.8 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 4.8 | |
| 3/8" | 9.50 | 109.0 | 100.0 | Coarse sand | 3.5 | 90.3 |
| Nr. 4 | 4.75 | 103.8 | 95.2 | Medium sand | 15.7 | |
| Nr. 10 | 2.00 | 100.0 | 91.7 | Fine sand | 71.1 | |
| Nr. 30 | 0.60 | 94.2 | 86.4 | Coarse silt | 2.48 | 3.52 |
| Nr. 40 | 0.43 | 82.9 | 76.1 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 6.5 | 6.0 | | | |
| Nr. 200 | 0.07 | 5.4 | 5.0 | Fine silt | 1.04 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.44 | 1.44 |

*Percentages relative to entire sample mass



## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

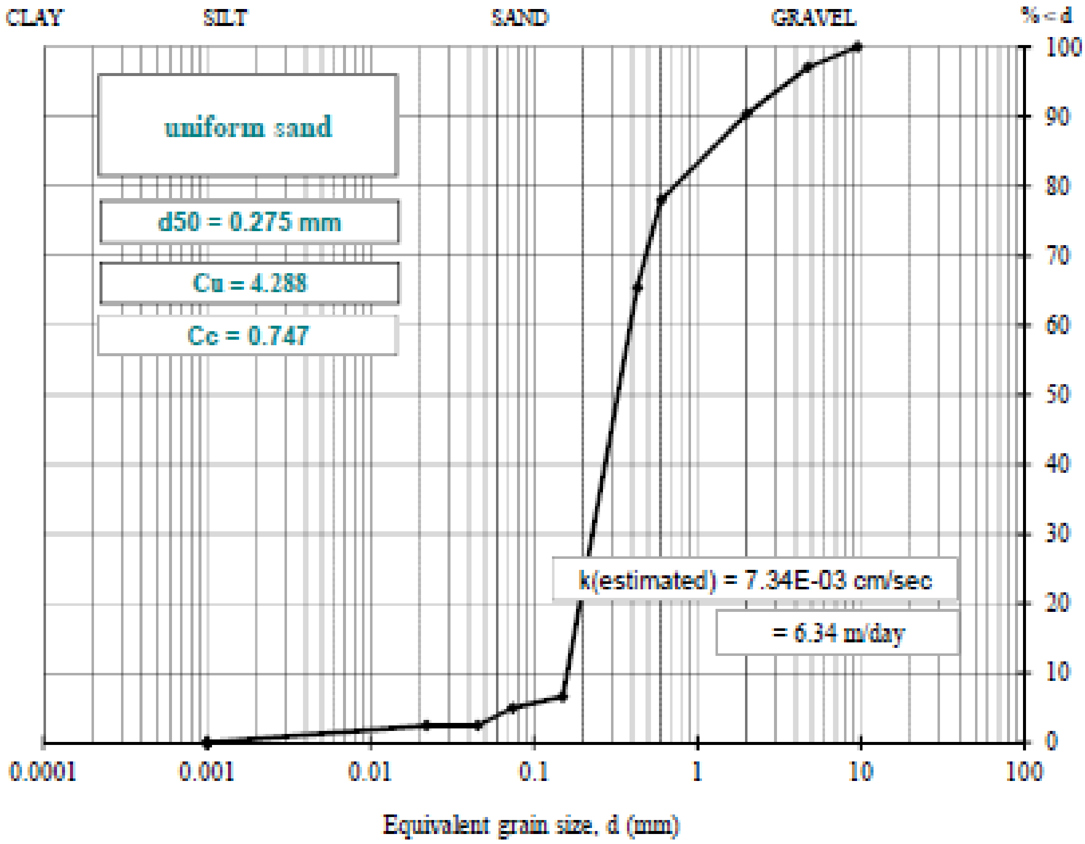
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH5

**Depth** 8.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 2.9 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 2.9 | |
| 3/8" | 9.50 | 114.5 | 100.0 | Coarse sand | 6.7 | 92.1 |
| Nr. 4 | 4.75 | 111.2 | 97.1 | Medium sand | 25.0 | |
| Nr. 10 | 2.00 | 103.5 | 90.4 | Fine sand | 60.4 | |
| Nr. 30 | 0.60 | 89.3 | 78.0 | Coarse silt | 2.49 | 3.54 |
| Nr. 40 | 0.43 | 74.9 | 65.4 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 7.6 | 6.6 | | | |
| Nr. 200 | 0.07 | 5.7 | 5.0 | Fine silt | 1.05 | |
| Pan | --- | 0.0 | 0.0 | Clay | 1.44 | 1.44 |

*Percentages relative to entire sample mass



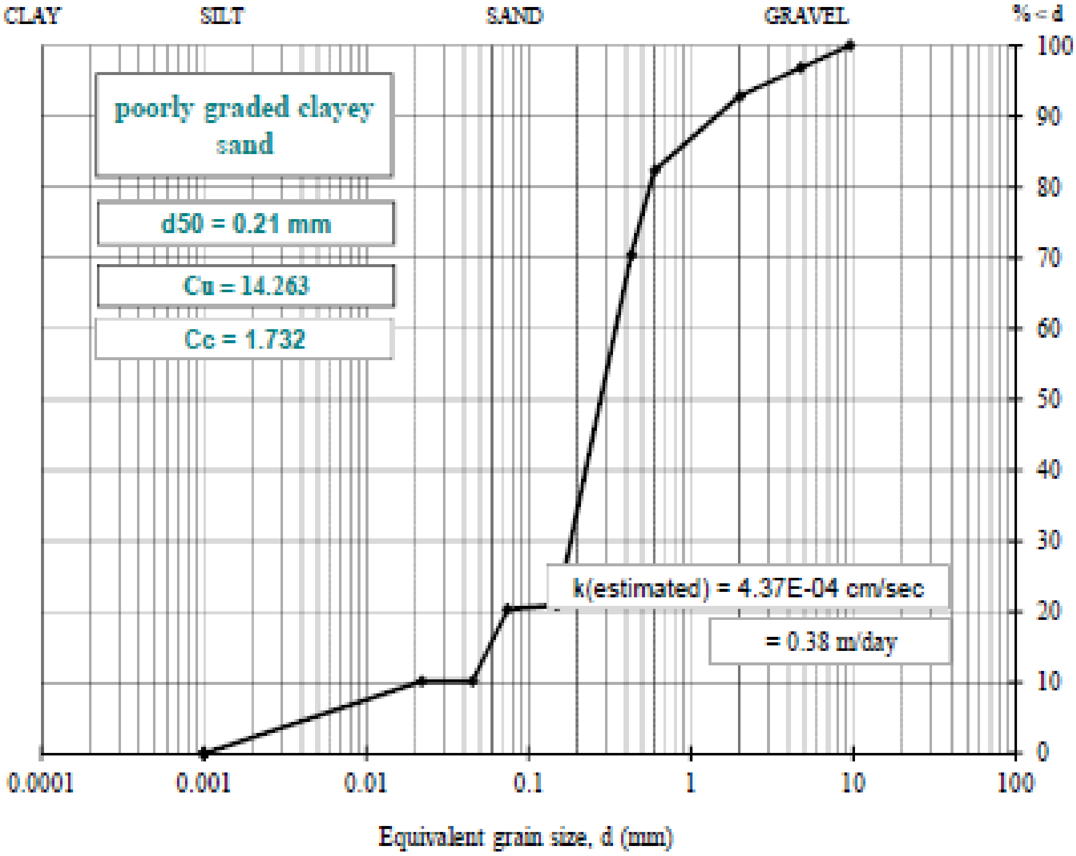
## Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH5 |
| **Depth** | 9.0 m |

| **Mechanical (sieve) analysis** | | | | **Soil Type** | **%** | **Tot. %** |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 3.1 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 3.1 | |
| 3/8" | 9.50 | 125.4 | 100.0 | Coarse sand | 4.0 | 76.6 |
| Nr. 4 | 4.75 | 121.5 | 96.9 | Medium sand | 22.5 | |
| Nr. 10 | 2.00 | 116.5 | 92.9 | Fine sand | 50.1 | |
| Nr. 30 | 0.60 | 103.3 | 82.4 | Coarse silt | 10.17 | 14.44 |
| Nr. 40 | 0.43 | 88.3 | 70.4 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 26.3 | 21.0 | | | |
| Nr. 200 | 0.07 | 25.5 | 20.3 | Fine silt | 4.27 | |
| Pan | --- | 0.0 | 0.0 | Clay | 5.89 | 5.89 |

*Percentages relative to entire sample mass



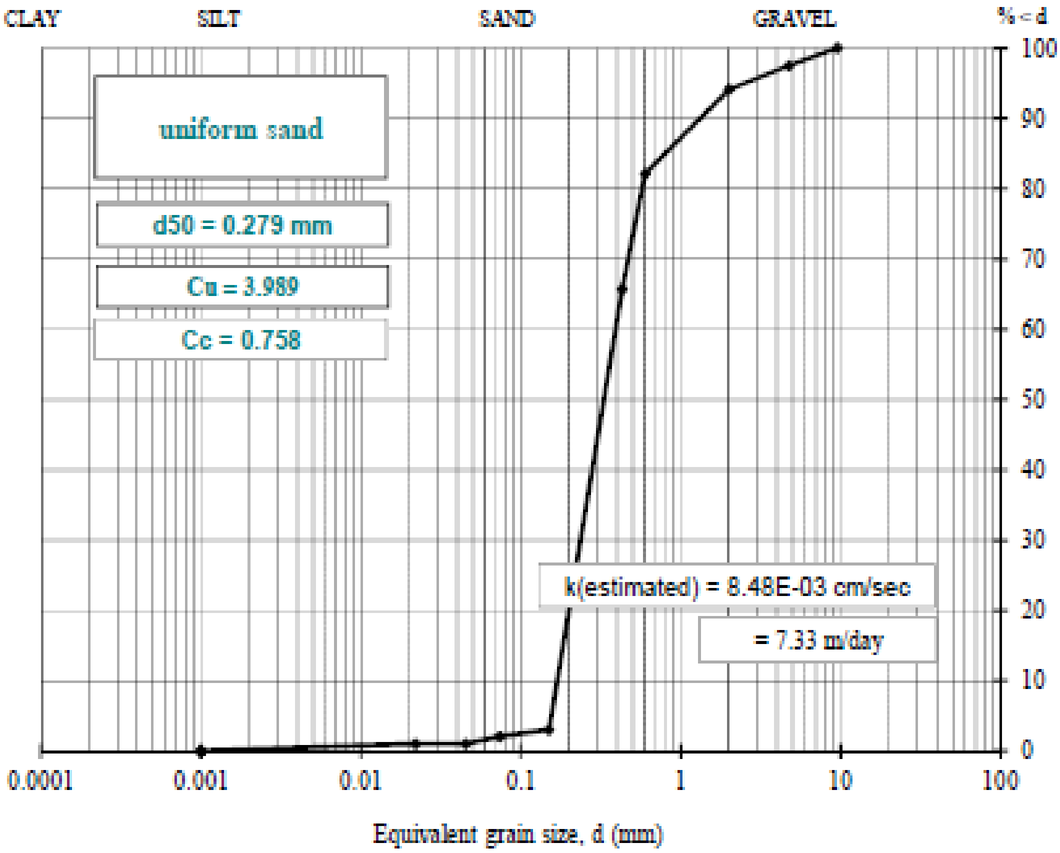
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH5 |
| **Depth** | 10.0 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 2.5 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 2.5 | |
| 3/8" | 9.50 | 105.2 | 100.0 | Coarse sand | 3.4 | 95.4 |
| Nr. 4 | 4.75 | 102.6 | 97.5 | Medium sand | 28.4 | |
| Nr. 10 | 2.00 | 99.0 | 94.1 | Fine sand | 63.6 | |
| Nr. 30 | 0.60 | 86.4 | 82.1 | Coarse silt | 1.05 | 1.49 |
| Nr. 40 | 0.43 | 69.1 | 65.7 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 3.2 | 3.0 | | | |
| Nr. 200 | 0.07 | 2.2 | 2.1 | Fine silt | 0.44 | |
| Pan | --- | 0.0 | 0.0 | Clay | 0.61 | 0.61 |

*Percentages relative to entire sample mass



# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

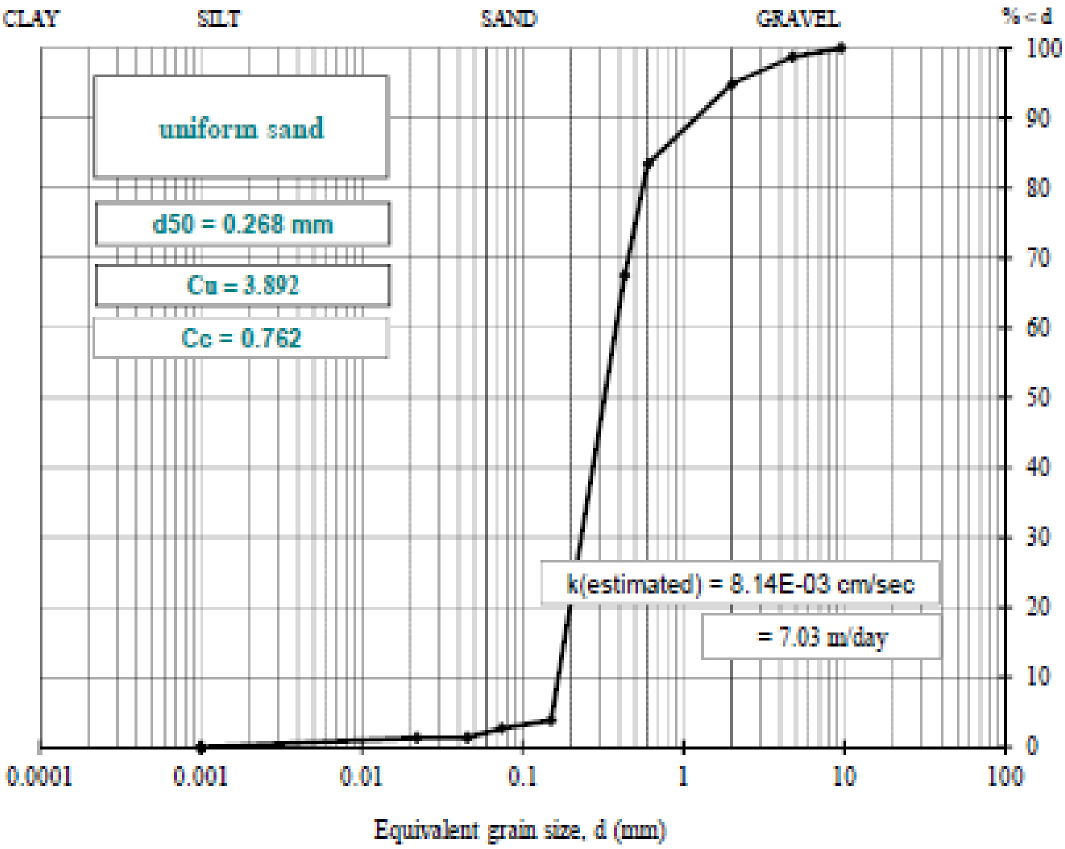
**Project:** Master Research-Study- (Eng. Basem Serdah)

**Bore Hole No.** BH5

**Depth** 11.0 m

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 1.2 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 1.2 | |
| 3/8" | 9.50 | 121.4 | 100.0 | Coarse sand | 3.9 | 96.0 |
| Nr. 4 | 4.75 | 119.9 | 98.8 | Medium sand | 27.4 | |
| Nr. 10 | 2.00 | 115.2 | 94.9 | Fine sand | 64.7 | |
| Nr. 30 | 0.60 | 101.3 | 83.4 | Coarse silt | 1.36 | 1.93 |
| Nr. 40 | 0.43 | 81.9 | 67.5 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 4.7 | 3.9 | | | |
| Nr. 200 | 0.07 | 3.3 | 2.7 | Fine silt | 0.57 | |
| Pan | --- | 0.0 | 0.0 | Clay | 0.79 | 0.79 |

*Percentages relative to entire sample mass



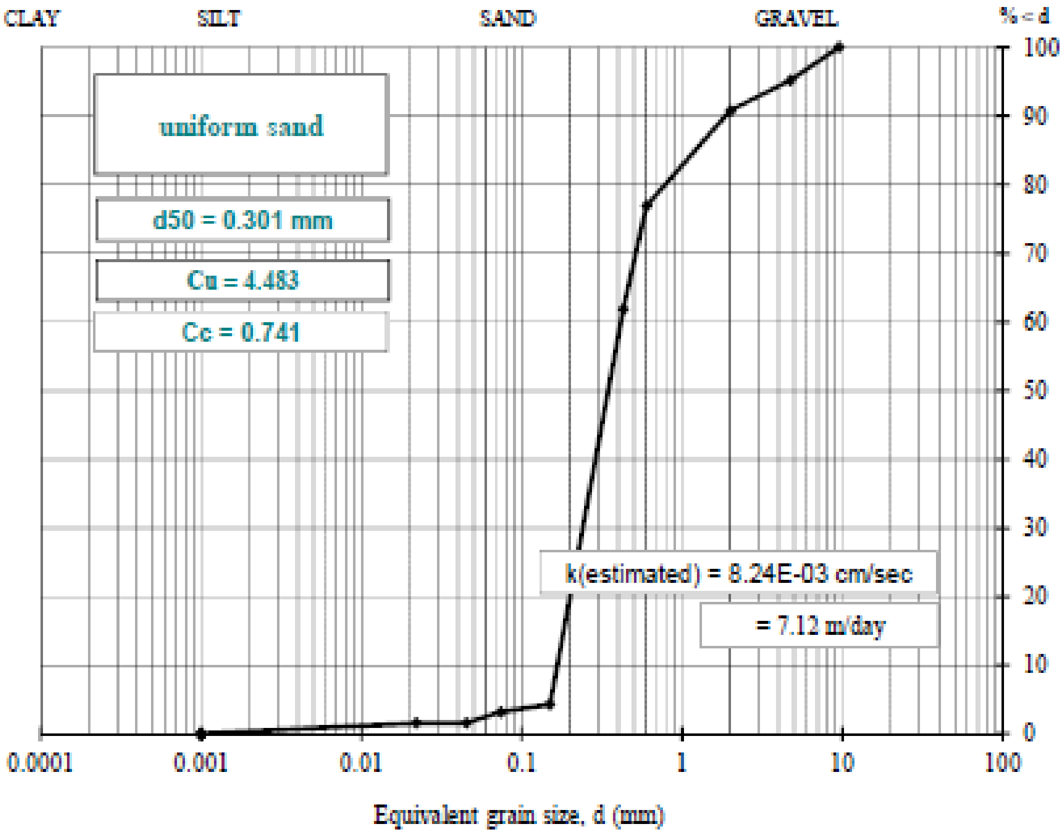
# Grain Size Distribution of Soil

ASTM D 422-63 (1998)

| | |
|---|---|
| **Project:** | Master Research-Study- (Eng. Basem Serdah) |
| **Bore Hole No.** | BH5 |
| **Depth** | 12.0 m |

| Mechanical (sieve) analysis | | | | Soil Type | % | Tot. % |
|---|---|---|---|---|---|---|
| Sieve Number | Sieve mesh opening, mm | Mass passing, g | Percent passing, % | Coarse gravel | 0.0 | 4.8 |
| | | | | Medium gravel | 0.0 | |
| | | | | Fine gravel | 4.8 | |
| 3/8" | 9.50 | 106.4 | 100.0 | Coarse sand | 4.4 | 92.0 |
| Nr. 4 | 4.75 | 101.3 | 95.2 | Medium sand | 28.9 | |
| Nr. 10 | 2.00 | 96.6 | 90.8 | Fine sand | 58.6 | |
| Nr. 30 | 0.60 | 81.8 | 76.9 | Coarse silt | 1.60 | 2.27 |
| Nr. 40 | 0.43 | 65.8 | 61.8 | Medium silt | 0.00 | |
| Nr. 100 | 0.15 | 4.6 | 4.3 | | | |
| Nr. 200 | 0.07 | 3.4 | 3.2 | Fine silt | 0.67 | |
| Pan | --- | 0.0 | 0.0 | Clay | 0.93 | 0.93 |

*Percentages relative to entire sample mass



# APPENDIX (3)

Modeling Calculations

**Model (1), K =37.458cm/hr**

| *K (cm/hr)* | *ψ(cm)* | *t (hr)* | *η* | *θr* | *θe* | Δθ | F (cm) | *f (cm/hr)* | *f (m/d)* | *Kt* | F (t) | Equation | Ln |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 37.458 | 4.950 | 0.0 | 0.430 | 0.042 | 0.388 | 0.349 | 0 | | | 0 | 0 | 0.000 | 0.000 |
| 37.458 | 4.950 | 0.1 | 0.430 | 0.042 | 0.388 | 0.349 | 6.428 | 47.531 | 11.408 | 3.746 | 6.428 | 3.746 | 1.552 |
| 37.458 | 4.950 | 0.2 | 0.430 | 0.042 | 0.388 | 0.349 | 10.934 | 43.380 | 10.411 | 7.492 | 10.934 | 7.492 | 1.991 |
| 37.458 | 4.950 | 0.3 | 0.430 | 0.042 | 0.388 | 0.349 | 15.180 | 41.724 | 10.014 | 11.238 | 15.180 | 11.238 | 2.281 |
| 37.458 | 4.950 | 0.4 | 0.430 | 0.042 | 0.388 | 0.349 | 19.302 | 40.813 | 9.795 | 14.983 | 19.302 | 14.983 | 2.499 |
| 37.458 | 4.950 | 0.5 | 0.430 | 0.042 | 0.388 | 0.349 | 22.869 | 40.290 | 9.670 | 18.729 | 22.869 | 18.279 | 2.655 |
| 37.458 | 4.950 | 1 | 0.430 | 0.042 | 0.388 | 0.349 | 43.085 | 38.961 | 9.351 | 37.458 | 43.085 | 37.458 | 3.255 |
| 37.458 | 4.950 | 1.1 | 0.430 | 0.042 | 0.388 | 0.349 | 46.975 | 38.837 | 9.321 | 41.204 | 46.975 | 41.204 | 3.338 |
| 37.458 | 4.950 | 1.2 | 0.430 | 0.042 | 0.388 | 0.349 | 50.853 | 38.732 | 9.296 | 44.950 | 50.853 | 44.950 | 3.415 |
| 37.458 | 4.950 | 1.3 | 0.430 | 0.042 | 0.388 | 0.349 | 54.722 | 38.642 | 9.274 | 48.696 | 54.722 | 48.696 | 3.486 |
| 37.458 | 4.950 | 1.4 | 0.430 | 0.042 | 0.388 | 0.349 | 58.582 | 38.564 | 9.255 | 52.442 | 58.582 | 52.442 | 3.552 |
| 37.458 | 4.950 | 1.5 | 0.430 | 0.042 | 0.388 | 0.349 | 62.435 | 38.495 | 9.239 | 56.188 | 62.435 | 56.188 | 3.614 |
| 37.458 | 4.950 | 2 | 0.430 | 0.042 | 0.388 | 0.349 | 81.616 | 38.252 | 9.180 | 74.917 | 81.616 | 74.917 | 3.876 |
| 37.458 | 4.950 | 2.5 | 0.430 | 0.042 | 0.388 | 0.349 | 100.702 | 38.101 | 9.144 | 93.646 | 100.702 | 93.646 | 4.082 |
| 37.458 | 4.950 | 3 | 0.430 | 0.042 | 0.388 | 0.349 | 119.725 | 37.999 | 9.120 | 112.375 | 119.725 | 112.375 | 4.252 |
| 37.458 | 4.950 | 3.5 | 0.430 | 0.042 | 0.388 | 0.349 | 138.705 | 37.925 | 9.102 | 131.104 | 138.705 | 131.104 | 4.397 |
| 37.458 | 4.950 | 4 | 0.430 | 0.042 | 0.388 | 0.349 | 157.653 | 37.869 | 9.089 | 149.833 | 157.653 | 149.833 | 4.524 |

| *K (cm/hr)* | *ψ(cm)* | *t (hr)* | *η* | *θr* | *θe* | **Δθ** | **F (cm)** | ***f (cm/hr)*** | ***f (m/d)*** | ***Kt*** | **F (t)** | **Equation** | **Ln** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 37.458 | 4.950 | 4.5 | 0.430 | 0.042 | 0.388 | 0.349 | 176.577 | 37.825 | 9.078 | 168.563 | 176.577 | 168.563 | 4.636 |
| 37.458 | 4.950 | 5 | 0.430 | 0.042 | 0.388 | 0.349 | 195.480 | 37.790 | 9.069 | 187.292 | 195.480 | 187.292 | 4.737 |
| 37.458 | 4.950 | 6 | 0.430 | 0.042 | 0.388 | 0.349 | 233.241 | 37.736 | 9.057 | 224.750 | 233.241 | 224.750 | 4.912 |
| 37.458 | 4.950 | 8 | 0.430 | 0.042 | 0.388 | 0.349 | 308.639 | 37.668 | 9.040 | 299.667 | 308.639 | 299.667 | 5.190 |
| 37.458 | 4.950 | 10 | 0.430 | 0.042 | 0.388 | 0.349 | 383.930 | 37.627 | 9.030 | 374.583 | 383.930 | 374.583 | 5.408 |
| 37.458 | 4.950 | 12 | 0.430 | 0.042 | 0.388 | 0.349 | 459.155 | 37.599 | 9.024 | 449.500 | 459.155 | 449.500 | 5.586 |
| 37.458 | 4.950 | 16 | 0.430 | 0.042 | 0.388 | 0.349 | 609.476 | 37.565 | 9.015 | 599.333 | 609.476 | 599.333 | 5.868 |
| 37.458 | 4.950 | 20 | 0.430 | 0.042 | 0.388 | 0.349 | 759.690 | 37.544 | 9.010 | 749.167 | 759.690 | 749.167 | 6.088 |
| 37.458 | 4.950 | 24 | 0.430 | 0.042 | 0.388 | 0.349 | 909.834 | 37.529 | 9.007 | 899.000 | 909.834 | 899.000 | 6.268 |

**Model (2), K =11.780cm/hr**

| *K (cm/hr)* | *ψ(cm)* | *t (hr)* | *η* | *θi* | **Δθ** | **F (cm)** | ***f* *(cm/hr)*** | ***f (m/d)*** | ***Kt*** | **F (t)** | **Eq.** | **Ln** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11.780 | 4.95 | 0.0 | 0.430 | 0.000 | 0.430 | 0 | | | 0 | 0 | 0.000 | 0.000 |
| 11.780 | 4.950 | 0.1 | 0.430 | 0.000 | 0.430 | 3.085 | 19.909 | 4.778 | 1.178 | 3.085 | 1.178 | 0.896 |
| 11.780 | 4.950 | 0.2 | 0.430 | 0.000 | 0.430 | 4.898 | 16.899 | 4.056 | 2.356 | 4.898 | 2.356 | 1.194 |
| 11.780 | 4.950 | 0.3 | 0.430 | 0.000 | 0.430 | 6.517 | 15.627 | 3.751 | 3.534 | 6.517 | 3.534 | 1.402 |
| 11.780 | 4.950 | 0.4 | 0.430 | 0.000 | 0.430 | 8.041 | 14.898 | 3.576 | 4.712 | 8.041 | 4.712 | 1.564 |
| 11.780 | 4.950 | 0.5 | 0.430 | 0.000 | 0.430 | 9.505 | 14.418 | 3.460 | 5.890 | 9.505 | 5.890 | 1.698 |
| 11.780 | 4.950 | 1 | 0.430 | 0.000 | 0.430 | 16.384 | 13.310 | 3.194 | 11.780 | 16.384 | 11.780 | 2.163 |
| 11.780 | 4.950 | 1.1 | 0.430 | 0.000 | 0.430 | 17.709 | 13.196 | 3.167 | 12.958 | 17.709 | 12.958 | 2.232 |
| 11.780 | 4.950 | 1.2 | 0.430 | 0.000 | 0.430 | 19.024 | 13.098 | 3.144 | 14.136 | 19.024 | 14.136 | 2.296 |
| 11.780 | 4.950 | 1.3 | 0.430 | 0.000 | 0.430 | 20.329 | 13.013 | 3.123 | 15.314 | 20.329 | 15.314 | 2.356 |
| 11.780 | 4.950 | 1.4 | 0.430 | 0.000 | 0.430 | 21.627 | 12.939 | 3.105 | 16.492 | 21.627 | 16.492 | 2.412 |
| 11.780 | 4.950 | 1.5 | 0.430 | 0.000 | 0.430 | 22.917 | 12.874 | 3.090 | 17.670 | 22.917 | 17.670 | 2.465 |
| 11.780 | 4.950 | 2 | 0.430 | 0.000 | 0.430 | 29.290 | 12.636 | 3.033 | 23.560 | 29.290 | 23.560 | 2.692 |
| 11.780 | 4.950 | 2.5 | 0.430 | 0.000 | 0.430 | 35.568 | 12.485 | 2.996 | 29.450 | 35.568 | 29.450 | 2.874 |
| 11.780 | 4.950 | 3 | 0.430 | 0.000 | 0.430 | 41.782 | 12.380 | 2.971 | 35.340 | 41.782 | 35.340 | 3.027 |
| 11.780 | 4.950 | 3.5 | 0.430 | 0.000 | 0.430 | 47.952 | 12.303 | 2.953 | 41.230 | 47.952 | 41.230 | 3.158 |
| 11.780 | 4.950 | 4 | 0.430 | 0.000 | 0.430 | 54.088 | 12.244 | 2.938 | 47.120 | 54.088 | 47.120 | 3.274 |

| *K* (cm/hr) | *ψ(cm)* | *t (hr)* | *η* | *θi* | **Δθ** | **F (cm)** | *f* (cm/hr) | *f (m/d)* | *Kt* | **F (t)** | **Eq.** | **Ln** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11.780 | 4.950 | 4.5 | 0.430 | 0.000 | 0.430 | 60.198 | 12.197 | 2.927 | 53.010 | 60.198 | 53.010 | 3.377 |
| 11.780 | 4.950 | 5 | 0.430 | 0.000 | 0.430 | 66.286 | 12.158 | 2.918 | 58.900 | 66.286 | 58.900 | 3.470 |
| 11.780 | 4.950 | 6 | 0.430 | 0.000 | 0.430 | 78.414 | 12.100 | 2.904 | 70.680 | 78.414 | 70.680 | 3.633 |
| 11.780 | 4.950 | 8 | 0.430 | 0.000 | 0.430 | 102.531 | 12.025 | 2.886 | 94.240 | 102.531 | 94.240 | 3.895 |
| 11.780 | 4.950 | 10 | 0.430 | 0.000 | 0.430 | 126.531 | 11.978 | 2.875 | 117.800 | 126.5306 | 117.800 | 4.102 |
| 11.780 | 4.950 | 12 | 0.430 | 0.000 | 0.430 | 150.454 | 11.947 | 2.867 | 141.360 | 150.4536 | 141.360 | 4.272 |
| 11.780 | 4.950 | 16 | 0.430 | 0.000 | 0.430 | 198.153 | 11.907 | 2.858 | 188.480 | 198.1526 | 188.480 | 4.544 |
| 11.780 | 4.950 | 20 | 0.430 | 0.000 | 0.430 | 245.726 | 11.882 | 2.852 | 235.600 | 245.7262 | 235.600 | 4.757 |
| 11.780 | 4.950 | 24 | 0.430 | 0.000 | 0.430 | 293.219 | 11.866 | 2.848 | 282.720 | 293.2193 | 282.720 | 4.933 |

**Model (3), K = 8.042cm/hr**

| *K (cm/hr)* | *ψ(cm)* | *t (hr)* | *η* | *θr* | *θe* | Δθ | F (cm) | *f (cm/hr)* | *f (m/d)* | *Kt* | F (t) | Eq. | Ln |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8.042 | 20.880 | 0.0 | 0.460 | 0.156 | 0.304 | 0.195 | 0 | | | 0 | 0 | 0.000 | 0.000 |
| 8.042 | 20.880 | 0.1 | 0.460 | 0.156 | 0.304 | 0.195 | 3.118 | 18.520 | 4.445 | 0.804 | 3.118 | 0.804 | 0.570 |
| 8.042 | 20.880 | 0.2 | 0.460 | 0.156 | 0.304 | 0.195 | 4.757 | 14.909 | 3.578 | 1.608 | 4.757 | 1.608 | 0.775 |
| 8.042 | 20.880 | 0.3 | 0.460 | 0.156 | 0.304 | 0.195 | 6.163 | 13.342 | 3.202 | 2.413 | 6.163 | 2.413 | 0.923 |
| 8.042 | 20.880 | 0.4 | 0.460 | 0.156 | 0.304 | 0.195 | 7.448 | 12.428 | 2.983 | 3.217 | 7.448 | 3.217 | 1.041 |
| 8.042 | 20.880 | 0.5 | 0.460 | 0.156 | 0.304 | 0.195 | 8.658 | 11.815 | 2.836 | 4.021 | 8.658 | 4.021 | 1.141 |
| 8.042 | 20.880 | 1 | 0.460 | 0.156 | 0.304 | 0.195 | 14.133 | 10.353 | 2.485 | 8.042 | 14.133 | 8.042 | 1.499 |
| 8.042 | 20.880 | 1.1 | 0.460 | 0.156 | 0.304 | 0.195 | 15.160 | 10.197 | 2.447 | 8.846 | 15.160 | 8.846 | 1.554 |
| 8.042 | 20.880 | 1.2 | 0.460 | 0.156 | 0.304 | 0.195 | 16.173 | 10.062 | 2.415 | 9.650 | 16.173 | 9.650 | 1.606 |
| 8.042 | 20.880 | 1.3 | 0.460 | 0.156 | 0.304 | 0.195 | 17.173 | 9.944 | 2.387 | 10.454 | 17.173 | 10.454 | 1.654 |
| 8.042 | 20.880 | 1.4 | 0.460 | 0.156 | 0.304 | 0.195 | 18.162 | 9.840 | 2.362 | 11.258 | 18.162 | 11.258 | 1.699 |
| 8.042 | 20.880 | 1.5 | 0.460 | 0.156 | 0.304 | 0.195 | 19.142 | 9.748 | 2.340 | 12.063 | 19.142 | 12.063 | 1.743 |
| 8.042 | 20.880 | 2 | 0.460 | 0.156 | 0.304 | 0.195 | 23.923 | 9.407 | 2.258 | 16.083 | 23.923 | 16.083 | 1.930 |
| 8.042 | 20.880 | 2.5 | 0.460 | 0.156 | 0.304 | 0.195 | 28.568 | 9.185 | 2.204 | 20.104 | 28.568 | 20.104 | 2.083 |
| 8.042 | 20.880 | 3 | 0.460 | 0.156 | 0.304 | 0.195 | 33.119 | 9.028 | 2.167 | 24.125 | 33.119 | 24.125 | 2.214 |
| 8.042 | 20.880 | 3.5 | 0.460 | 0.156 | 0.304 | 0.195 | 37.603 | 8.910 | 2.139 | 28.146 | 37.603 | 28.146 | 2.328 |
| 8.042 | 20.880 | 4 | 0.460 | 0.156 | 0.304 | 0.195 | 42.034 | 8.819 | 2.117 | 32.167 | 42.034 | 32.167 | 2.429 |

| *K (cm/hr)* | *ψ(cm)* | *t (hr)* | *η* | *θr* | *θe* | **Δθ** | **F (cm)** | *f (cm/hr)* | *f (m/d)* | *Kt* | **F (t)** | **Eq.** | **Ln** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8.042 | 20.880 | 4.5 | 0.460 | 0.156 | 0.304 | 0.195 | 46.425 | 8.745 | 2.099 | 36.188 | 46.425 | 36.188 | 2.520 |
| 8.042 | 20.880 | 5 | 0.460 | 0.156 | 0.304 | 0.195 | 50.781 | 8.685 | 2.084 | 40.208 | 50.781 | 40.208 | 2.603 |
| 8.042 | 20.880 | 6 | 0.460 | 0.156 | 0.304 | 0.195 | 59.417 | 8.591 | 2.062 | 48.250 | 59.417 | 48.250 | 2.749 |
| 8.042 | 20.880 | 8 | 0.460 | 0.156 | 0.304 | 0.195 | 76.467 | 8.469 | 2.033 | 64.333 | 76.467 | 64.333 | 2.987 |
| 8.042 | 20.880 | 10 | 0.460 | 0.156 | 0.304 | 0.195 | 93.323 | 8.392 | 2.014 | 80.417 | 93.323 | 80.417 | 3.177 |
| 8.042 | 20.880 | 12 | 0.460 | 0.156 | 0.304 | 0.195 | 110.050 | 8.339 | 2.001 | 96.500 | 110.050 | 96.500 | 3.335 |
| 8.042 | 20.880 | 16 | 0.460 | 0.156 | 0.304 | 0.195 | 143.254 | 8.270 | 1.985 | 128.667 | 143.254 | 128.667 | 3.591 |
| 8.042 | 20.880 | 20 | 0.460 | 0.156 | 0.304 | 0.195 | 176.241 | 8.227 | 1.974 | 160.833 | 176.241 | 160.833 | 3.793 |
| 8.042 | 20.880 | 24 | 0.460 | 0.156 | 0.304 | 0.195 | 209.088 | 8.198 | 1.967 | 193.000 | 209.088 | 193.000 | 3.960 |

**Model (4), K = 1.083cm/hr**

| *K (cm/hr)* | *ψ(cm)* | *t (hr)* | *η* | *θr* | *θe* | Δθ | F (cm) | *f (cm/hr)* | *f (m/d)* | *Kt* | F (t) | Eq. | Ln |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.083 | 20.880 | 0.0 | 0.460 | 0.127 | 0.333 | 0.250 | 0 | | | 0 | 0 | 0.000 | 0.000 |
| 1.083 | 20.880 | 0.1 | 0.460 | 0.127 | 0.333 | 0.250 | 1.135 | 6.063 | 1.455 | 0.108 | 1.135 | 0.108 | 0.197 |
| 1.083 | 20.880 | 0.2 | 0.460 | 0.127 | 0.333 | 0.250 | 1.652 | 4.502 | 1.081 | 0.217 | 1.652 | 0.217 | 0.275 |
| 1.083 | 20.880 | 0.3 | 0.460 | 0.127 | 0.333 | 0.250 | 2.064 | 3.821 | 0.917 | 0.325 | 2.064 | 0.325 | 0.333 |
| 1.083 | 20.880 | 0.4 | 0.460 | 0.127 | 0.333 | 0.250 | 2.423 | 3.415 | 0.820 | 0.433 | 2.423 | 0.433 | 0.382 |
| 1.083 | 20.880 | 0.5 | 0.460 | 0.127 | 0.333 | 0.250 | 2.752 | 3.136 | 0.753 | 0.542 | 2.752 | 0.542 | 0.424 |
| 1.083 | 20.880 | 1 | 0.460 | 0.127 | 0.333 | 0.250 | 4.118 | 2.455 | 0.589 | 1.083 | 4.118 | 1.083 | 0.582 |
| 1.083 | 20.880 | 1.1 | 0.460 | 0.127 | 0.333 | 0.250 | 4.362 | 2.379 | 0.571 | 1.192 | 4.362 | 1.192 | 0.608 |
| 1.083 | 20.880 | 1.2 | 0.460 | 0.127 | 0.333 | 0.250 | 4.595 | 2.313 | 0.555 | 1.300 | 4.595 | 1.300 | 0.632 |
| 1.083 | 20.880 | 1.3 | 0.460 | 0.127 | 0.333 | 0.250 | 4.823 | 2.255 | 0.541 | 1.408 | 4.823 | 1.408 | 0.655 |
| 1.083 | 20.880 | 1.4 | 0.460 | 0.127 | 0.333 | 0.250 | 5.047 | 2.203 | 0.529 | 1.517 | 5.047 | 1.517 | 0.677 |
| 1.083 | 20.880 | 1.5 | 0.460 | 0.127 | 0.333 | 0.250 | 5.264 | 2.156 | 0.518 | 1.625 | 5.264 | 1.625 | 0.698 |
| 1.083 | 20.880 | 2 | 0.460 | 0.127 | 0.333 | 0.250 | 6.296 | 1.981 | 0.475 | 2.167 | 6.296 | 2.167 | 0.792 |
| 1.083 | 20.880 | 2.5 | 0.460 | 0.127 | 0.333 | 0.250 | 7.254 | 1.862 | 0.447 | 2.708 | 7.254 | 2.708 | 0.872 |
| 1.083 | 20.880 | 3 | 0.460 | 0.127 | 0.333 | 0.250 | 8.163 | 1.775 | 0.426 | 3.250 | 8.163 | 3.250 | 0.942 |
| 1.083 | 20.880 | 3.5 | 0.460 | 0.127 | 0.333 | 0.250 | 9.034 | 1.709 | 0.410 | 3.792 | 9.034 | 3.792 | 1.005 |
| 1.083 | 20.880 | 4 | 0.460 | 0.127 | 0.333 | 0.250 | 9.873 | 1.656 | 0.397 | 4.333 | 9.873 | 4.333 | 1.062 |

| *K (cm/hr)* | *ψ(cm)* | *t (hr)* | *η* | *θr* | *θe* | **Δθ** | **F (cm)** | *f (cm/hr)* | *f (m/d)* | *Kt* | **F (t)** | **Eq.** | **Ln** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.083 | 20.880 | 4.5 | 0.460 | 0.127 | 0.333 | 0.250 | 10.690 | 1.612 | 0.387 | 4.875 | 10.690 | 4.875 | 1.115 |
| 1.083 | 20.880 | 5 | 0.460 | 0.127 | 0.333 | 0.250 | 11.487 | 1.575 | 0.378 | 5.417 | 11.487 | 5.417 | 1.164 |
| 1.083 | 20.880 | 6 | 0.460 | 0.127 | 0.333 | 0.250 | 13.031 | 1.517 | 0.364 | 6.500 | 13.031 | 6.500 | 1.252 |
| 1.083 | 20.880 | 8 | 0.460 | 0.127 | 0.333 | 0.250 | 15.979 | 1.437 | 0.345 | 8.667 | 15.979 | 8.667 | 1.402 |
| 1.083 | 20.880 | 10 | 0.460 | 0.127 | 0.333 | 0.250 | 18.796 | 1.384 | 0.332 | 10.833 | 18.796 | 10.833 | 1.527 |
| 1.083 | 20.880 | 12 | 0.460 | 0.127 | 0.333 | 0.250 | 21.524 | 1.346 | 0.323 | 13.000 | 21.524 | 13.000 | 1.635 |
| 1.083 | 20.880 | 16 | 0.460 | 0.127 | 0.333 | 0.250 | 26.796 | 1.294 | 0.311 | 17.333 | 26.796 | 17.333 | 1.815 |
| 1.083 | 20.880 | 20 | 0.460 | 0.127 | 0.333 | 0.250 | 31.901 | 1.260 | 0.303 | 21.667 | 31.901 | 21.667 | 1.963 |
| 1.083 | 20.880 | 24 | 0.460 | 0.127 | 0.333 | 0.250 | 36.892 | 1.236 | 0.297 | 26.000 | 36.892 | 26.000 | 2.089 |

**Model (5), K = 0.833cm/hr**

| *K (cm/hr)* | *ψ(cm)* | *t (hr)* | *η* | *θr* | *θe* | Δθ | F (cm) | *f (cm/hr)* | *f (m/d)* | *Kt* | F (t) | Eq. | Ln |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.833 | 20.880 | 0.0 | 0.460 | 0.121 | 0.339 | 0.254 | 0 | | | 0 | 0 | 0.000 | 0.000 |
| 0.833 | 20.880 | 0.1 | 0.460 | 0.121 | 0.339 | 0.254 | 0.995 | 5.280 | 1.2672 | 0.083 | 0.995 | 0.083 | 0.172 |
| 0.833 | 20.880 | 0.2 | 0.460 | 0.121 | 0.339 | 0.254 | 1.445 | 3.895 | 0.9347 | 0.167 | 1.445 | 0.167 | 0.241 |
| 0.833 | 20.880 | 0.3 | 0.460 | 0.121 | 0.339 | 0.254 | 1.800 | 3.291 | 0.7899 | 0.250 | 1.800 | 0.250 | 0.292 |
| 0.833 | 20.880 | 0.4 | 0.460 | 0.121 | 0.339 | 0.254 | 2.109 | 2.931 | 0.7035 | 0.333 | 2.109 | 0.333 | 0.334 |
| 0.833 | 20.880 | 0.5 | 0.460 | 0.121 | 0.339 | 0.254 | 2.391 | 2.684 | 0.6441 | 0.417 | 2.391 | 0.417 | 0.372 |
| 0.833 | 20.880 | 1 | 0.460 | 0.121 | 0.339 | 0.254 | 3.553 | 2.078 | 0.4988 | 0.833 | 3.553 | 0.833 | 0.512 |
| 0.833 | 20.880 | 1.1 | 0.460 | 0.121 | 0.339 | 0.254 | 3.759 | 2.010 | 0.4824 | 0.917 | 3.759 | 0.917 | 0.535 |
| 0.833 | 20.880 | 1.2 | 0.460 | 0.121 | 0.339 | 0.254 | 3.957 | 1.951 | 0.4684 | 1.000 | 3.957 | 1.000 | 0.557 |
| 0.833 | 20.880 | 1.3 | 0.460 | 0.121 | 0.339 | 0.254 | 4.148 | 1.900 | 0.4559 | 1.083 | 4.148 | 1.083 | 0.577 |
| 0.833 | 20.880 | 1.4 | 0.460 | 0.121 | 0.339 | 0.254 | 4.337 | 1.853 | 0.4448 | 1.167 | 4.337 | 1.167 | 0.597 |
| 0.833 | 20.880 | 1.5 | 0.460 | 0.121 | 0.339 | 0.254 | 4.520 | 1.812 | 0.4349 | 1.250 | 4.520 | 1.250 | 0.616 |
| 0.833 | 20.880 | 2 | 0.460 | 0.121 | 0.339 | 0.254 | 5.384 | 1.655 | 0.3972 | 1.667 | 5.384 | 1.667 | 0.700 |
| 0.833 | 20.880 | 2.5 | 0.460 | 0.121 | 0.339 | 0.254 | 6.183 | 1.549 | 0.3717 | 2.083 | 6.183 | 2.083 | 0.772 |
| 0.833 | 20.880 | 3 | 0.460 | 0.121 | 0.339 | 0.254 | 6.937 | 1.471 | 0.3530 | 2.500 | 6.937 | 2.500 | 0.836 |
| 0.833 | 20.880 | 3.5 | 0.460 | 0.121 | 0.339 | 0.254 | 7.658 | 1.411 | 0.3386 | 2.917 | 7.658 | 2.917 | 0.893 |
| 0.833 | 20.880 | 4 | 0.460 | 0.121 | 0.339 | 0.254 | 8.350 | 1.363 | 0.3272 | 3.333 | 8.350 | 3.333 | 0.945 |

| *K (cm/hr)* | *ψ(cm)* | *t (hr)* | *η* | *θr* | *θe* | **Δθ** | **F (cm)** | *f (cm/hr)* | *f (m/d)* | *Kt* | **F (t)** | **Eq.** | **Ln** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.833 | 20.880 | 4.5 | 0.460 | 0.121 | 0.339 | 0.254 | 9.022 | 1.324 | 0.3177 | 3.750 | 9.022 | 3.750 | 0.993 |
| 0.833 | 20.880 | 5 | 0.460 | 0.121 | 0.339 | 0.254 | 9.676 | 1.291 | 0.3097 | 4.167 | 9.676 | 4.167 | 1.038 |
| 0.833 | 20.880 | 6 | 0.460 | 0.121 | 0.339 | 0.254 | 10.938 | 1.238 | 0.2971 | 5.000 | 10.938 | 5.000 | 1.119 |
| 0.833 | 20.880 | 8 | 0.460 | 0.121 | 0.339 | 0.254 | 13.336 | 1.165 | 0.2796 | 6.667 | 13.336 | 6.667 | 1.256 |
| 0.833 | 20.880 | 10 | 0.460 | 0.121 | 0.339 | 0.254 | 15.614 | 1.117 | 0.2680 | 8.333 | 15.614 | 8.333 | 1.371 |
| 0.833 | 20.880 | 12 | 0.460 | 0.121 | 0.339 | 0.254 | 17.811 | 1.082 | 0.2596 | 10.000 | 17.811 | 10.000 | 1.471 |
| 0.833 | 20.880 | 16 | 0.460 | 0.121 | 0.339 | 0.254 | 22.035 | 1.034 | 0.2482 | 13.333 | 22.035 | 13.333 | 1.639 |
| 0.833 | 20.880 | 20 | 0.460 | 0.121 | 0.339 | 0.254 | 26.105 | 1.003 | 0.2407 | 16.667 | 26.105 | 16.667 | 1.778 |
| 0.833 | 20.880 | 24 | 0.460 | 0.121 | 0.339 | 0.254 | 30.069 | 0.980 | 0.2353 | 20.000 | 30.069 | 20.000 | 1.897 |

**Model (6), K = 0.042cm/hr**

| *K (cm/hr)* | *ψ(cm)* | *t (hr)* | *η* | *θr* | *θe* | Δθ | F (cm) | *f (cm/hr)* | *f (m/d)* | *Kt* | F (t) | Eq. | Ln |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.042 | 23.900 | 0.0 | 0.480 | 0.179 | 0.301 | 0.211 | 0 | | | 0 | 0 | 0.000 | 0.000 |
| 0.042 | 23.900 | 0.1 | 0.480 | 0.179 | 0.301 | 0.211 | 0.203 | 1.073 | 0.258 | 0.004 | 0.203 | 0.004 | 0.040 |
| 0.042 | 23.900 | 0.2 | 0.480 | 0.179 | 0.301 | 0.211 | 0.289 | 0.767 | 0.184 | 0.008 | 0.289 | 0.008 | 0.056 |
| 0.042 | 23.900 | 0.3 | 0.480 | 0.179 | 0.301 | 0.211 | 0.371 | 0.608 | 0.146 | 0.013 | 0.371 | 0.013 | 0.071 |
| 0.042 | 23.900 | 0.4 | 0.480 | 0.179 | 0.301 | 0.211 | 0.425 | 0.535 | 0.128 | 0.017 | 0.425 | 0.017 | 0.081 |
| 0.042 | 23.900 | 0.5 | 0.480 | 0.179 | 0.301 | 0.211 | 0.474 | 0.484 | 0.116 | 0.021 | 0.474 | 0.021 | 0.090 |
| 0.042 | 23.900 | 1 | 0.480 | 0.179 | 0.301 | 0.211 | 0.679 | 0.351 | 0.084 | 0.042 | 0.679 | 0.042 | 0.126 |
| 0.042 | 23.900 | 1.1 | 0.480 | 0.179 | 0.301 | 0.211 | 0.712 | 0.337 | 0.081 | 0.046 | 0.712 | 0.046 | 0.132 |
| 0.042 | 23.900 | 1.2 | 0.480 | 0.179 | 0.301 | 0.211 | 0.743 | 0.324 | 0.078 | 0.050 | 0.743 | 0.050 | 0.138 |
| 0.042 | 23.900 | 1.3 | 0.480 | 0.179 | 0.301 | 0.211 | 0.774 | 0.313 | 0.075 | 0.054 | 0.774 | 0.054 | 0.143 |
| 0.042 | 23.900 | 1.4 | 0.480 | 0.179 | 0.301 | 0.211 | 0.803 | 0.303 | 0.073 | 0.058 | 0.803 | 0.058 | 0.148 |
| 0.042 | 23.900 | 1.5 | 0.480 | 0.179 | 0.301 | 0.211 | 0.839 | 0.292 | 0.070 | 0.063 | 0.839 | 0.063 | 0.154 |
| 0.042 | 23.900 | 2 | 0.480 | 0.179 | 0.301 | 0.211 | 0.970 | 0.258 | 0.062 | 0.083 | 0.970 | 0.083 | 0.176 |
| 0.042 | 23.900 | 2.5 | 0.480 | 0.179 | 0.301 | 0.211 | 1.094 | 0.233 | 0.056 | 0.104 | 1.094 | 0.104 | 0.197 |
| 0.042 | 23.900 | 3 | 0.480 | 0.179 | 0.301 | 0.211 | 1.207 | 0.216 | 0.052 | 0.125 | 1.207 | 0.125 | 0.215 |
| 0.042 | 23.900 | 3.5 | 0.480 | 0.179 | 0.301 | 0.211 | 1.312 | 0.202 | 0.048 | 0.146 | 1.312 | 0.146 | 0.232 |
| 0.042 | 23.900 | 4 | 0.480 | 0.179 | 0.301 | 0.211 | 1.411 | 0.190 | 0.046 | 0.167 | 1.411 | 0.167 | 0.247 |

| *K (cm/hr)* | *ψ(cm)* | *t (hr)* | *η* | *θr* | *θe* | **Δθ** | **F (cm)** | ***f (cm/hr)*** | ***f (m/d)*** | ***Kt*** | **F (t)** | **Eq.** | **Ln** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.042 | 23.900 | 4.5 | 0.480 | 0.179 | 0.301 | 0.211 | 1.504 | 0.181 | 0.043 | 0.188 | 1.504 | 0.188 | 0.261 |
| 0.042 | 23.900 | 5 | 0.480 | 0.179 | 0.301 | 0.211 | 1.589 | 0.174 | 0.042 | 0.208 | 1.589 | 0.208 | 0.274 |
| 0.042 | 23.900 | 6 | 0.480 | 0.179 | 0.301 | 0.211 | 1.758 | 0.161 | 0.039 | 0.250 | 1.758 | 0.250 | 0.299 |
| 0.042 | 23.900 | 8 | 0.480 | 0.179 | 0.301 | 0.211 | 2.060 | 0.144 | 0.034 | 0.333 | 2.060 | 0.333 | 0.343 |
| 0.042 | 23.900 | 10 | 0.480 | 0.179 | 0.301 | 0.211 | 2.336 | 0.131 | 0.032 | 0.417 | 2.336 | 0.417 | 0.381 |
| 0.042 | 23.900 | 12 | 0.480 | 0.179 | 0.301 | 0.211 | 2.589 | 0.123 | 0.029 | 0.500 | 2.589 | 0.500 | 0.415 |
| 0.042 | 23.900 | 16 | 0.480 | 0.179 | 0.301 | 0.211 | 3.054 | 0.110 | 0.026 | 0.667 | 3.054 | 0.667 | 0.474 |
| 0.042 | 23.900 | 20 | 0.480 | 0.179 | 0.301 | 0.211 | 3.476 | 0.102 | 0.024 | 0.833 | 3.476 | 0.833 | 0.525 |
| 0.042 | 23.900 | 24 | 0.480 | 0.179 | 0.301 | 0.211 | 3.872 | 0.096 | 0.023 | 1.000 | 3.872 | 1.000 | 0.570 |

# APPENDIX (4)

Palestinian Standards for Treated Wastewater

| Descrption mg/l | Discharge to see (500)m | Recahrg to Ground Water by Infiltration |
|---|---|---|
| $BOD_5$ | 60 | 40 |
| COD | 200 | 150 |
| DO | > 1 | > 1 |
| TDS | - | 1500 |
| TSS | 60 | 50 |
| pH | 6-9 | 6-9 |
| Color (PCU) | - | - |
| Fat Oil & Grease | 10 | 0 |
| Phenol | 1 | 0.002 |
| DETERGENTS | 25 | 5 |
| $No_3$ (N) | 25 | 15 |
| $NH_4$ (N) | 5 | 10 |
| Organic N | 10 | 10 |
| $PO_4$ (P) | 5 | 15 |
| CL | - | 600 |
| $SO_4$ | 1000 | 1000 |
| Na | - | 230 |
| Mg | - | 150 |
| Ca | - | 400 |
| Al | 5 | 1 |
| Ar | 0.05 | 0.05 |
| Cu | 0.2 | 0.2 |
| Fe | 2 | 2 |
| Mn | 0.2 | 0.2 |
| Ni | 0.2 | 0.2 |
| Pb | 0.1 | 0.1 |

| Descrption mg/l | Discharge to see (500)m | Recahrg to Ground Water by Infiltration |
|---|---|---|
| Se | 0.02 | 0.02 |
| Cd | 0.01 | 0.01 |
| Zn | 5 | 5 |
| CN | 0.1 | 0.1 |
| Cr | 0.5 | 0.05 |
| Hg | 0.001 | 0.001 |
| Co | 1 | 0.05 |
| B | 2 | 1 |
| FC /100ml | 50000 | 1000 |
| Pathoens | - | - |
| Amoebo & Gardia | - | - |
| Nematodes (Eggs/L) | < 1 | < 1 |