ENGINEERING GEOLOGICAL ASSESSMENT OF CLAYEY SOILS IN ANKARA FOR BEING UTILIZED AS COMPACTED CLAY LINERS

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ABSTRACT

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Clayey soils are considered as a source for compacted clay liners due to their low hydraulic conductivities and widespread distributions throughout the Ankara region. This study makes an attempt to determine the engineering geological properties and the compaction permeability characteristics of clayey soil samples obtained from three sites in the Ankara region. The index properties of the soil samples were determined. All of the soil samples were permeability tested at 2 to 4% on the wet sides of their optimum moisture contents through using falling head compaction permeameter apparatus.

The mineralogy of the soil samples were examined by X-ray diffraction (XRD) and scanning electron microscope (SEM) analyses. Cation exchange capacities (CEC) of the soil samples were determined by the Methylene Blue Adsorption Test in order to determine the presence of swelling clay minerals in the soil samples.

Several landfill profiles containing geomembrane/clay composite lining systems were simulated by using the HELP model. Expected leakage rates through the bottommost compacted clay liners and the average heads acting on the bottom compacted clay liner were determined for each profile. Analyses indicate that sanitary landfill should contain leachate collection layers as well as geomembrane/clay composite lining systems. Moreover, usage of compacted clay liner in the cap cover system is essential to improve the long term performance.

All of the soil samples tested herein have hydraulic conductivities lower than suggested limits of Turkish regulatory ($1x10^{-8}$ m/s) and therefore they can be utilized as compacted clay liners in potential sanitary landfill sites.

Key words: Compacted Clay Liner, Hydraulic Conductivity, Falling Head Permeability Testing, Expected Leakage Rate.

ÖZ

ANKARA VE ÇEVRESİNDEKİ KİLLİ ZEMİNLERİN SIKIŞTIRILMIŞ KİL TABAKASI OLARAK KULLANILABİLİRLİKLERİNİN MÜHENDİSLİK JEOLOJİSİ AÇISINDAN DEĞERLENDİRİLMESİ

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Ankara ve çevresinde yaygın bir dağılım gösteren killi zeminler, düşük geçirimlilik katsayılarından dolayı sıkıştırılmış kil tabakaları için kaynak teşkil edebilir. Bu çalışma Ankara'nın üç değişik yerinden toplanan killi toprak numunelerinin mühendislik jeolojisi özelliklerinin, sıkıştırma ve geçirimsizlik katsayılarının tayinine yöneliktir. Bütün numunelerin geçirimsizlik değerleri, optimum su muhtevalarının yüzde 2 ile 4 üzerindeki su muhtevalarında düşen seviyeli kompaksiyon permeametre cihazı kullanılarak bulunmuştur.

Numunelerde olası şişen kil minerallerinin varlığını belirlemek amacı ile katyon değiştirme kapasitelerinin tayininde Metilen Mavisi deneyi kullanılmıştır. Daha sonra bütün numunelerin mineralojik özellikleri X-ışını toz difraktometresi ve taramalı elektron mikroskobu kullanılarak incelenmiştir.

Çeşitli katı atık saha profillerinin randımanları HELP modeli kullanılarak incelenmiştir. Bütün numunelerde jeomembran/kil karma yalıtım sistemi kullanılmıştır. Bu simulasyon sonucunda profillerin beklenen sızıntı oranları ve ortalama su seviyeleri sıkıştırılmış kil tabakaları için tayin edilmiştir.

Bu çalışmada incelenen bütün killi toprak numunelerinin hidrolik iletkenlik değerleri, Türkiye'de geçerli olan yönetmeliklerin ön gördüğü seviyenin altındadır. Dolayısıyla bütün numuneler Ankara'daki potansiyel katı atık sahalarında sıkıştırılmış kil tabakası olarak kullanılabilinir.

Anahtar kelimeler: Sıkıştırılmış Kil Tabakası, Hidrolik İletkenlik, Düşen Seviyeli Geçirimlilik Deneyi, Beklenen Sızıntı Oranı.

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CHAPTER 1

INTRODUCTION

1.1. Purpose and Scope

The safe and reliable long-term disposal of solid waste residues is an important component of integrated waste management. Solid waste residues are waste components that are not recycled, that remain after processing at a materials recovery facility, or that remain after the recovery of conservation products and/or energy. In the past, solid waste was dumped in soil or deposited in the oceans. Ocean dumping of municipal solid waste was officially abandoned in the United States in 1933. Since then, landfills have been the most economical and environmentally acceptable method for the disposal of solid wastes throughout the world. Even with the implementation of waste reduction, recycling, and transformation technologies, disposal of residual solid waste in landfills still remains as an important component of integrated solid waste management strategies.

Storage of waste material in a landfill also poses several potential problems. One problem is the possible contamination of soil, groundwater and surface water. Contamination may occur as the leachate produced by liquid wastes moving into, through and out of the landfill migrates into adjacent areas through rain water or snow melt. The first key step in controlling leachate migration is to limit leachate production by preventing the entry of external water into the waste layers to a certain extent. The second step is to collect any leachate for subsequent treatment and disposal. Thus, a modern landfill should comprise suitable lining, leakage detection and leakage collection systems.

The lining system is generally composed of compacted natural soil liners, such as clay liners, or synthetic materials, such as geomembrane liners, including high density polyethylene (HDPE), very low density polyethylene (VLDPE), chlorinated polyethylene (CPE), clorosulfonated polyethylene (CSPE), ethylene interpolymer alloy (EIA) and polyvinyl chloride (PVC). Since geosynthetic-lining materials are quite expensive, soil barriers, containing enough clay minerals to provide low hydraulic conductivity (permeability) are used extensively to prevent rapid advective migration of various leachates from waste disposal sites. The soil barriers can take the form of thin bentonite liners (1-3 cm thick), compacted clay liners (up to 1 m thick), natural undisturbed clayey barriers with a thickness of up to 30 or 40 m (Rowe *et al.*, 1995). Although undisturbed clayey barriers have a long record of performance with respect to the containment of chemical wastes, it is not always possible to find a sufficiently thick natural undisturbed clayey barrier, and therefore compacted clay liners have become an integral component of lining systems used in municipal and hazardous waste landfills. They are widely used to line landfills and waste impoundments, to cap new waste disposal units, and to close old waste disposal sites. Because the primary purpose of a compacted clay liner is to impede the flow of fluids, its most significant property is hydraulic conductivity (Daniel, 1987; 1990). A compacted clay liner should have a low hydraulic conductivity in order to be effective. Nearly all environmental regulatory agencies require that compacted clay liners be designed to have a hydraulic conductivity less than or equal to a specified maximum value (for example, 1 x 10^{-8} m/s in Turkey (Resmi Gazete, 1991) and 1 x 10^{-9} m/s in the United States according to (USEPA , 1993)).

Ankara is the second largest city in Turkey with a population of 2,985,000 according to the 1997 census. There has been a distinct increase in the population between 1950 and 1975, and the population is estimated to be about 3,2 million by the year 2000 as a result of the mass migration from rural areas to the city. The daily total amount of waste generated in Ankara ranges approximately between 0.56 to 0.62 kg/person, with an average of about 0.59 kg/person (Kırca, 1990). For the last ten years, solid waste, including hospital waste collected from all of the municipalities of Ankara, has been brought to Mamak open dumpsite, which poses serious environmental threats due to the lack of a containment system. Moreover, since the site is located adjacent to a proposed large residential satellite called "Doğukent"; alternative new landfill sites in and around Ankara need to be selected. In order to fulfil the landfilling needs of Ankara, Ankara Metropolitan Municipal Authority developed a sanitary landfill project at Sincan-Çadırtepe with an estimated total waste capacity of 57,523,125 m^3 and a life span of approximately 20 years, to bring a solution to the Mamak problem (Sezer, 1998). However, since the new landfill site has a limited capacity, the Ankara Metropolitan Municipal Authority is planning to construct new alternative landfill sites in the future which requires the comprehensive investigation of the availability and the determination of the engineering properties of natural clayey soils in and around Ankara.

The main objective of this study; therefore, is to evaluate the suitability of clayey soils in Ankara as a compacted clay liner in order to be utilized in future landfills. Ankara can be considered as a major source for natural clay liners, since clay bearing Upper Miocene - Pliocene deposits show a widespread distribution in the city limits. Some of these deposits, referred to as "Ankara Clay" by Birand (1963) are rich in clay minerals (such as smectite, illite, chlorite and kaolinite) making these deposits valuable material for landfill liners.

This study is aimed at determining the feasibility of sealing waste by clay liners to a level where it can be reasonably assured that the sealed waste will not become preferential contaminant paths to groundwater resources. In order to determine such feasibility, clayey soils outcropping in three different sites in Ankara were identified and quantified in terms of their basic engineering properties and hydraulic conductivity values. An extensive laboratory investigation of the suitability of these clayey soils as a compacted clay liner has been performed since the hydraulic conductivity of compacted clays can vary tremendously depending on the soil composition and the conditions under which they are compacted (Lambe, 1954; Mitchell *et al.*, 1965; Garcia-Bengochea *et al.*, 1979; Acar and Oliveri, 1990; Benson *et al.*, 1994).

1.2. Study Area

To determine the effectiveness of clayey soils in Ankara as a compacted clay liner, three sites have been chosen (Figure 1.1). The first site is located in Karakusunlar and one soil sample (soil sample A) has been collected from the basement excavation of Karamustafaoğlu Construction Cooperation (Figure 1.2). The second site is located at Gölbaşı. At this site two soil samples have been collected: one (soil sample B1) from the slope near the central heating unit of TEDAŞ (Figure 1.3) and other (soil sample B2) from the slope near the Gazi University Recreation Center. Sincan neighbourhood is the third site. At this site three soil samples have been collected: two (soil samples C1 and C2) from the side walls of the municipal waste disposal cells and the other (soil sample C3) from the side walls of the hazardous waste disposal cells at Sincan Çadırtepe Sanitary Landfill site (Figure 1.4).

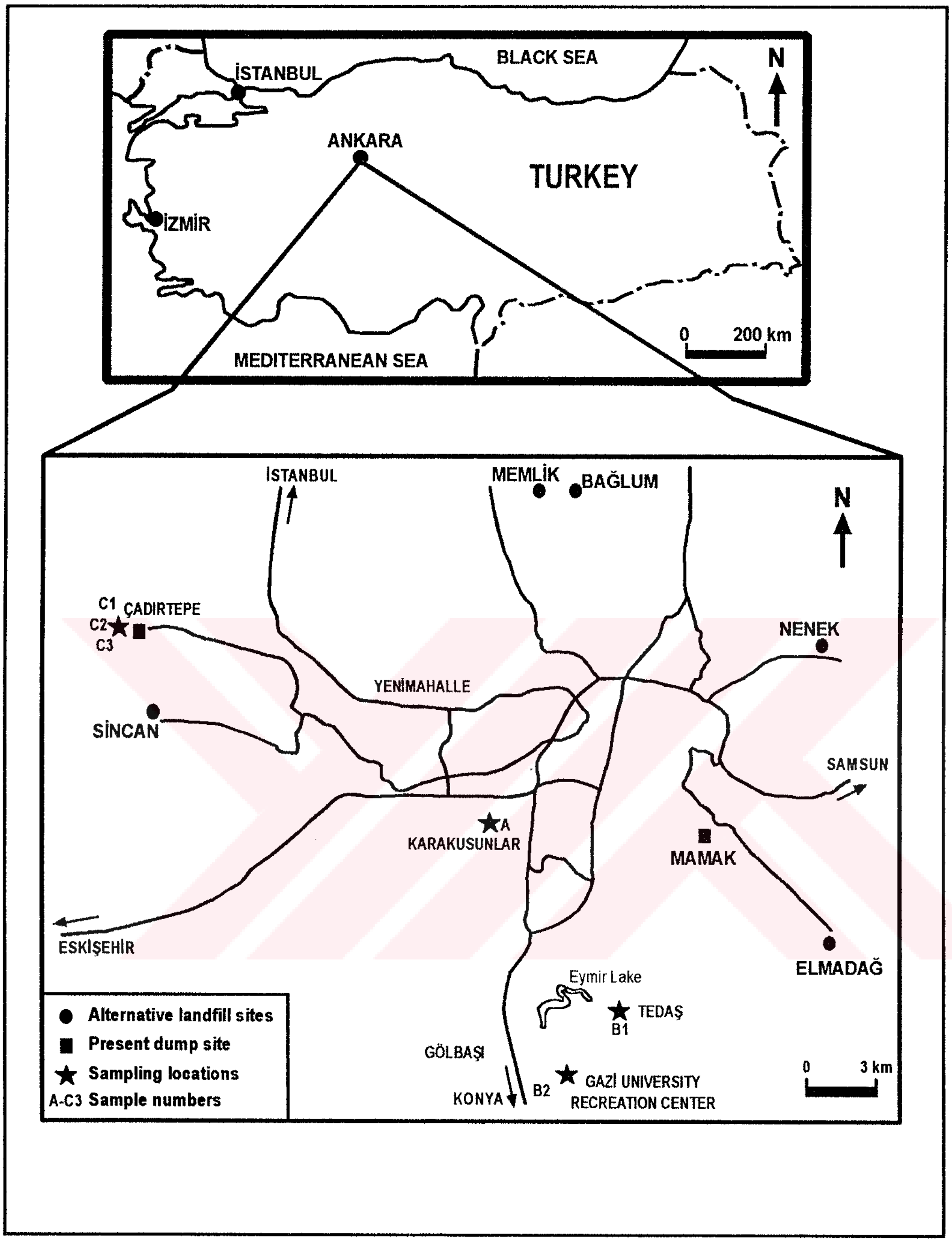

Figure 1.1. Location map of the study area (Sampling codes are presented in Table 1.1).

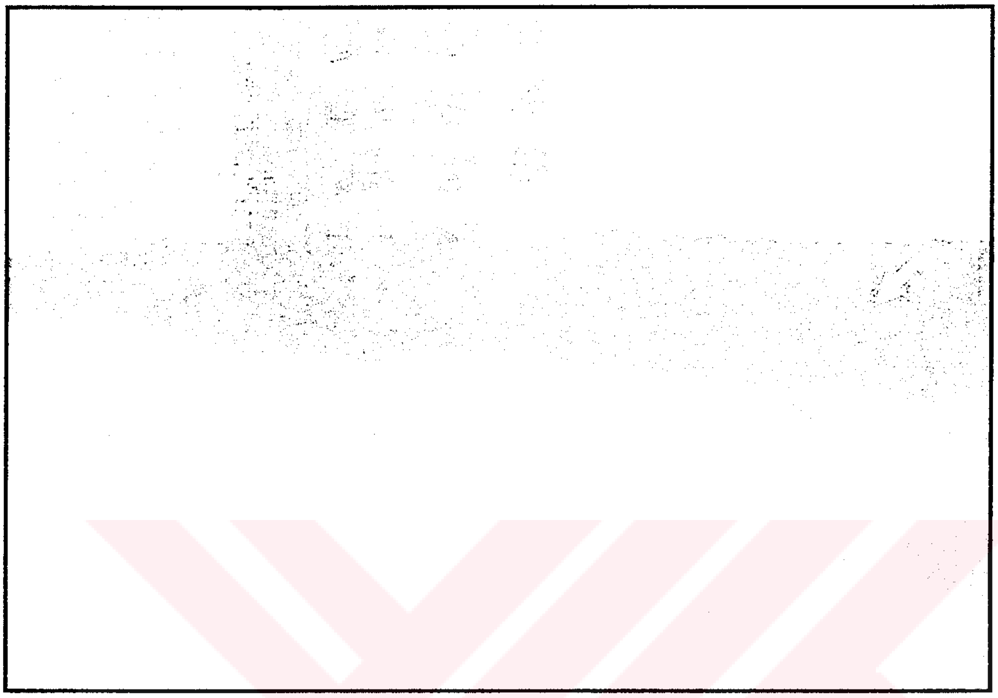

Figure 1.2. A view from soil sample A location in Karakusunlar. The arrow shows the construction site of Karamustafaoğlu Construction Cooperation.

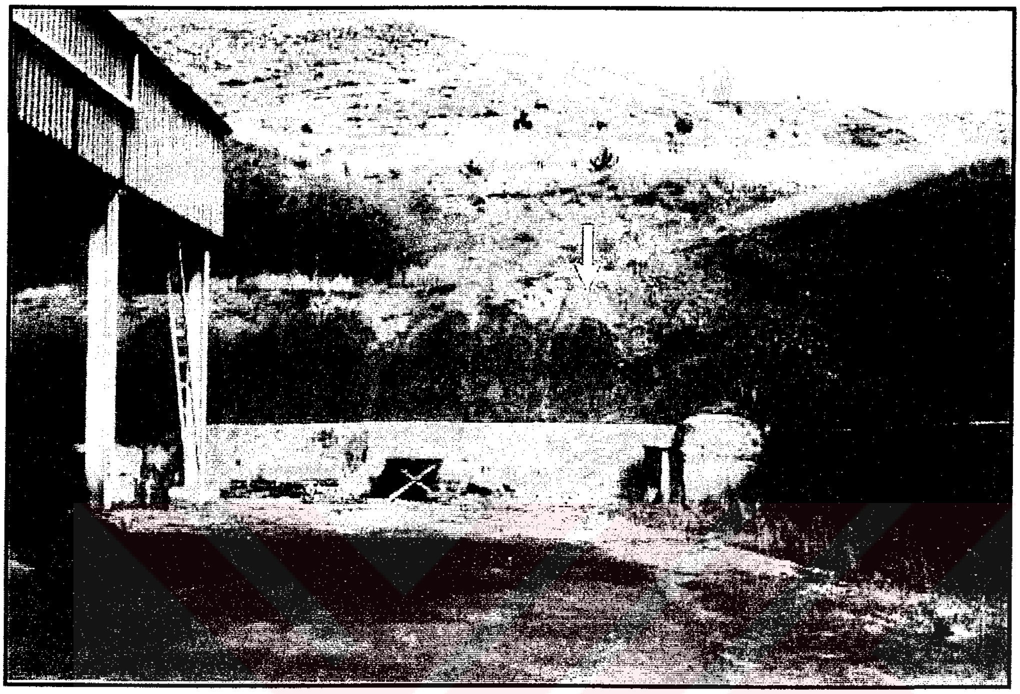

Figure 1.3. A view from soil sample B1 location in Gölbaşı. The arrow shows sampling point. The building to the left is the TEDAŞ Central Heating Unit.

Figure 1.4. A view from soil sample C3 location in Sincan-Çadırtepe Landfill Site. The arrow shows the sampling point. Geomembrane liner is laid to contain hazardous wastes.

The soil samples have been collected from Karakusunlar and Gölbaşı to investigate the suitability of Ankara Clay as a lining material for the Gölbaşı landfill sites and future landfill sites of Ankara. Ankara Clay, which is red, stiff, fissured, highly plastic and over consolidated material, shows a widespread distribution in Karakusunlar and Gölbaşı areas with a uniformity in the above mentioned lithological characteristics. On the other hand, the soil samples of Sincan may provide in-situ lining material for the Sincan-Çadırtepe landfill site and they are different than so called Ankara Clay with respect to color as observed in the field. The color varies from white (for soil sample C3) to light brown (soil sample C1).

1.3. Method of Study

This study involves field, experimental and mineralogical investigations, and computer analyses. Six disturbed clayey soil specimens were collected from three sites between July 1997 and September 1997. The sampling codes of the soils used throughout the study are presented in Table 1.1.

Table 1.1. Soil sample numbers and locations.

Soil sample no	Location
A	Karakusunlar
B1	Gölbaşı
B2	Gölbaşı
C1	Sincan
C2	Sincan
C3	Sincan

Mineralogy of the soils was analyzed by using X-ray diffraction (XRD) and scanning electron microscope (SEM). Semi quantitative analyses were performed to determine the clay mineral percentages of the soil samples. Cation exchange capacities (CEC) were measured by the methylene blue adsorption test.

All the soil specimens were kept in plastic bags under ambient room conditions (22 ± 2 ^{0}C, 30 ± 1 % relative humidity) in the Engineering Geology Laboratories of Department of Geological Engineering at the Middle East Technical University, Ankara. Approximately 200 kg of soil was used for the laboratory experiments.

Experimental studies included the determination of the hydraulic conductivity of the soil samples and investigation of effects of index properties, namely particle size distribution and Atterberg Limits [liquid limit (LL), plastic limit (PL), and plasticity index (PI)]. A total of 62 standard compaction tests were performed to evaluate the optimum moisture contents and maximum dry densities of the soil samples. The hydraulic conductivity of compacted clay was measured through falling head permeability testing apparatus. Hydraulic conductivities of the soil samples were measured within 2 to 4% wet side of the line of optimum moisture content.

As a part of computer analysis, the HELP model was used to determine the expected unitized leakage rate through the bottommost compacted clay liner (CCL) and average leachate head acting on bottom CCL for several landfill profiles.

1.4. Previous Studies

1.4.1. Compacted clay liners (CCLs) and CCL regulations

Sanitary landfills are defined as disposal facilities which are normally, but not necessarily, located in areas serving populations of 5,000 or more people and which may accept all types of municipal solid wastes. Sanitary landfills are normally required to comply with all the criteria for landfill siting, design, operation and closure. International regulations and practices agree on the following basic principles for siting and operating landfill facilities (Daniel, 1993):

1. siting the facility preferable upon a clay formation,
2. ensuring or improving this formation's imperviousness,
3. minimizing rainwater percolation,
4. collecting and processing the possible leachates, and biogas.

Today, at landfill facilities, natural clayey soil barriers, containing enough clay minerals to provide low hydraulic conductivity, are used extensively to prevent the rapid advective migration of various leachates from the waste disposal sites. The clayey barriers vary from thin bentonite liners (1-3 cm thick) to compacted clay liners (1 m thick), or even undisturbed clay deposits in excess of 30 or 40 meters thick (Rowe *et al.*, 1995).

Undisturbed clayey barriers have a long record of performance with respect to the containment of chemical wastes often found in a waste disposal site (Quigley *et al.*, 1983; Quigley and Rowe, 1986; and Rowe and Sawicki, 1992).

Because of difficulty in finding natural undisturbed clay deposits of sufficient thickness, compacted clay liners (CCLs) have been used as liners for landfills and impoundments to serve as barriers to the flow of water. Developments in the equipment for measuring field permeability and increased regulatory interest have led to a greater awareness that careful design and construction are needed to achieve a low permeability in a clay liner (Daniel, 1984; Daniel and Trautwein, 1986).

Current regulations in the United States require that sanitary landfills consist of a minimum of 0.90 m of compacted soil with a hydraulic conductivity (permeability) of $1x10^{-9}$ m/s, or less. The side slopes should generally not exceed a gradient of 1 vertical to 3 horizontal in order to allow suitable compaction of the barrier and to facilitate subsequent testing. However, there is a growing belief that these minimum standards may not satisfy the goal of preventing the migration of any waste constituents through the barrier during the operational life of the containment facility (such as a total of 40 to 50 years) (USEPA, 1993).

However, the performance of a specific clay as a barrier to municipal, industrial or hazardous wastes cannot be assumed or inferred from permeability estimates alone, especially if measured in a controlled laboratory environment. Hydraulic performance will depend on a number of important factors, including the method of placement and compaction of the clay, and the clay mineralogy, or more specifically the interaction between the clay minerals and leachate and the resulting effect on hydraulic conductivity.

The followings are several specifications that should be taken into consideration for selecting a suitable material for a compacted clay liner (Rowe *et al.*, 1995):

1. As the dominant chemical flux mechanism is diffusion in landfill sites, a hydraulic conductivity of $1x10^{-10}$ m/s should be probably

preferable to 1×10^{-9} m/s. This leads to better attenuation of contaminants through sorption.

2. Low hydraulic conductivity is usually associated with the presence of clay minerals. Hence a minimum percentage by weight of soil with particle size less than 2 μm should be specified, along with a plasticity index (PI). Alternatively, a minimum cation exchange capacity (CEC) may be specified.

3. The CCL should be compatible with the leachate to be retained (i.e. hydraulic conductivity should not increase over time when exposed to leachate).

Many natural soils contain two or more clay minerals, often mixed with quartz, feldspars and carbonates. Mixed layers such as smectite-illite mixed layer is also common, adding to the complexity of soil characterization procedures.

Not all clayey soils are suitable as CCLs hence many researchers provided different requirements. Oweis and Khera (1990) only suggested that clayey soils should have a plasticity index less than 20 percent. Gordon *et al.* (1990) further suggested the following guidelines:

1. Plasticity index should be greater than 15 percent,

2. Liquid limit should not be less than 30 percent,

3. The percent of fines (percent by dry unit weight passing No. 200 sieve) should be greater than 50 and the clay percent should be greater than 25.

Daniel (1990) on the other hand provided the following requirements:

1. Plasticity index should be greater than 10 percent,

2. Percent of gravel (percent by dry unit weight retained on No.4 sieve) should be less than 10,

3. Percent by dry unit weight passing sieve number 200 should be greater than 30.

Finally Rowe *et al.* (1995) further suggested the following general requirements for soil liner materials:

1. Inert clay materials, having low activity with modest CEC, such as chlorite and illite, produce the most reliable CCLs.

2. Kaolinites are very inert but suffer from very low CEC and relatively high permeability ($1x10^{-7}$ m/s).

3. Smectites (e.g. montmorillonite) are susceptible to volume instability due to c-axis contraction and expansion. At this point, it will be better to remember that volume instability is not usually encountered in geosynthetic clay liners due to the relatively small thickness of the product (<1 cm), and confinement by surcharges and the needle-punching between upper and lower geotextile layers.

4. Quantitative mineral analyses and even leachate compatibility testing will be necessary for soils for which no data exists or whose clay mineralogy indicates reactive mineral constituents.

Rowe *et al.* (1995) summarized the compaction requirements for CCLs:

1. In order to construct a CCL that is able to withstand any significant differential settlement or strain, field compaction should be performed on the wet side of the optimum moisture content (w_{opt}) and probably close to the plastic limit.

2. Compaction at around 2% to 4% wet of the optimum produces the minimum hydraulic conductivity value for most clayey soils.

3. Compaction requires excessive passes with a pad-foot or sheepsfoot roller to break down any clods of soil and eliminate voids. The interface between successive lifts should be scoured to prevent delamination and macro-cracks.

4. CCLs must be covered immediately and kept moist to prevent volume instability and desiccation. Desiccated sections should be removed, broken up, re-wetted and recompacted.

In Turkey, usage a CCL is a new concept and current regulations require only a hydraulic conductivity value of $1x10^{-8}$ m/s with a thickness of at least 60 cm for a CCL (Resmi Gazete, 1991).

1.4.2. Factors affecting hydraulic conductivity of CCLs

As mentioned in the previous section, CCLs are used in waste containment units as base and side slope liners or hydraulic barriers. Micropores, arrangement of clay mineral particles in single aggregates, and macropores, arrangement of aggregates are the two features of the structure of compacted clays.

The particle arrangement is referred to as particle orientation theory, suggested by Lambe (1954). He suggested that the flocculated structure produced at dry of optimum moisture content (OMC) has larger voids than those of a dispersed structure that is obtained at wet of OMC. Thus, hydraulic conductivity value (k) for a flocculated structure is higher than hydraulic conductivity for a dispersed structure. According to this theory, the orientation or arrangement of individual particles, which is affected by the molding water content controls the hydraulic conductivity.

The arrangement of aggregates, referred as clod theory, is proposed by Olsen (1962), and suggests that most of the flow of water in compacted clay occurs through pores between clods of clay (macropores). When clays are compacted at moisture contents wet of OMC, the soft and wet clods of soil are remoulded, resulting in smaller interfold voids and lower hydraulic conductivity (Benson and Daniel, 1990).

Mitchell *et al.* (1965) studied the effect of moisture water content and compaction methods on permeability. They showed that higher moisture contents result in dispersed structure, resulting in lower hydraulic conductivity. They also concluded that for compacted clay, hydraulic conductivity decreases with increasing compactive effort. Mitchell *et al.* (1965) also identified the critical variables affecting hydraulic conductivity of CCLs such as molding water content, method of compaction, compactive effort, and degree of saturation. They showed that as the water content is increased beyond the optimum moisture content or the compactive effort is raised, the hydraulic conductivity decreases. Daniel and Benson (1990) also confirmed the observations of Mitchell *et al.* (1965) that for a given method of compaction, increasing the compactive effort decreases the hydraulic conductivity value of a soil.

Benson and Daniel (1990) suggested that during soil processing and compaction, clods and interclod pores control the hydraulic conductivity value of compacted soil. They concluded that to achieve low hydraulic conductivity, it was necessary to destroy the clods, either by wetting the soil at high moisture content or using large compactive effort. Garcia-Bengochea *et al.* (1979) proposed that hydraulic conductivity is controlled by changes in macropore distribution rather than overall porosity and suggested that clays molded at wet of OMC generally yielded dispersed structure and smaller interclod pores, resulting in lower hydraulic conductivity.

Clay particle orientation and pore size distribution are also influenced by clay mineralogy and pore fluid chemistry. Yong and Warkentin (1975) showed that Na-saturated soil, having a lower valance yields a thicker diffused double layer resulting in a dispersed structure and lower hydraulic conductivity.

Lambe (1954) showed that hydraulic conductivity is also sensitive to plasticity by presenting the hydraulic conductivity values of different clayey soils. The hydraulic conductivity measurements were conducted in consolidometers on normally consolidated specimens. The data showed that for a given void ratio monovalent montmorillonite (e.g., sodium) had the lowest hydraulic conductivity, followed by divalent montmorillonite (e.g., calcium), and kaolinite. Although Atterberg limits of the clayey soils were not presented by Lambe (1954), their plasticity decreases in the following order: monovalent montmorillonite > divalent montmorillonite > kaolinite (Mitchell, 1976).

Mesri and Olson (1971) also presented a distinct trend of decreasing hydraulic conductivity with increasing plasticity. They also investigated the relation between hydraulic conductivity versus clay type, void ratio, and permeant chemistry.

Benson *et al.* (1994) also reported that hydraulic conductivity is sensitive to the particle size distribution as well as to the Atterberg limits. Typically soils that are more plastic (have higher liquid limit or higher plasticity index) or contain a greater quantity of fines, including clay-sized particles have lower hydraulic conductivity.

Daniel (1987) presented a plot of hydraulic conductivity versus percent bentonite for a sand-bentonite mixture. He found that hydraulic conductivity decreased significantly (i.e. from 10^{-4} to 10^{-8} cm/s) as the percentage of bentonite was increased from 0% to 8%. At higher bentonite contents, however, little further reduction in hydraulic conductivity occurred. Similar results have been observed by Kenney *et al.* (1992), who compacted and permeated sand-bentonite mixtures at various molding water contents.

D'Appolonia (1980) evaluated how the percentage of fines (particles smaller than the No. 200 sieve size) affected the hydraulic conductivity of soil-bentonite slurries. He found that hydraulic conductivity decreased as the percentage of fines increased even when the percentage of fines was substantial (>30%). He also found that slurries containing plastic fines typically had hydraulic conductivities one order of magnitude lower than slurries containing primarily nonplastic fines. Ryan (1987) has presented similar results on the effect of plasticity on hydraulic conductivity.

Shakoor and Cook (1990) mixed various percentage of gravel with a low plasticity glacial till and compacted it slightly above dry of the optimum water content. They found little change in hydraulic conductivity for the gravel contents less than 50%, but a rapid increase in hydraulic conductivity occurred when the gravel content was increased beyond 50%. Similar results have been presented by Shelley and Daniel (1993) who mixed varying quantities of subrounded concrete gravel with kaolinite or clayey mine spoil and compacted the specimens at several water contents.

Several investigations of the in-situ hydraulic conductivity of compacted soils have been performed (Daniel, 1984; Day and Daniel, 1985). An important finding is that laboratory measurements of hydraulic conductivity sometimes underestimate the in-situ hydraulic conductivity by one order of magnitude or more. This is not suprising, since hydraulic conductivity is generally recognized as one of the most variable engineering properties associated with construction materials. The range is over 10 billion times from gravel to clay and 1,000 times in clay alone (Cedergren, 1965).

There are numerous studies on compaction behaviour of CCLs in the field. In most of the fieldwork, a clay liner can be compacted within a range of moisture contents (w) and dry densities (γ_d) and still achieve the required hydraulic conductivity. Dry densities and molding water content values achieving hydraulic conductivity less than or equal to the maximum allowable value may create an acceptable zone of w-γ_d. Although this approach provides a flexibility to the construction contractor during liner placement, it requires an elaborate laboratory testing program before preparing specimens (Daniel and Benson, 1990).

Daniel and Wu (1993) presented the “acceptable zone” approach for compacted clay liners and covers for arid site in west Texas, USA. This liner had to meet (1) $k<1x10^{-7}$ cm/s, (2) low potential for shrinkage and cracking when dried (i.e., maximum volumetric shrinkage upon drying of 4 percent), and (3) adequate shear strength (a minimum unconfined compressive strength of 207 kPa). Daniel and Wu (1993) concluded that the three requirements listed above could be met by compacting the soil at a water content of ±2 percent from OMC and γ_d of at least 96 to 98 percent of the maximum dry density.

As it can be concluded from the previous studies explained above, hydraulic conductivity measurements alone are not sufficient for the investigation of materials used for a CCL. An elaborate laboratory-testing program should be performed including particle size distribution, Atterberg limits, compaction tests, and hydraulic conductivity measurements.

CHAPTER 2

GEOLOGY

2.1. Geology and Origin of Late Pliocene Sediments in the Ankara Region

Both fluvial red clastics of Late Pliocene age and Quaternary alluvial deposits fill the Ankara basin, which is an approximately ENE-WSW trending, 18-20 km long and 6-8 km wide depression (Koçyiğit and Türkmenoğlu, 1991). Abundance of clay content of these fine-grained red clastics leads to serious foundation problems, which has lead to a considerable amount of research towards determining the engineering properties of these red-colored clay rich clastics.

Although pioneer researchers studied with the geology of the Ankara region, they simply put some emphasis on the Upper Pliocene Deposits of Ankara. (Erol, 1954; Akyürek *et al.*, 1984). Birand (1963) and Ordemir *et al.* (1965) used the term "Ankara Clay" for the Late Pliocene sediments intensely found in the Ankara region. Both Birand (1963) and Ordemir *et al.* (1965) mainly focused on the geotechnical properties of these sediments. Birand (1965) summarized the swelling properties of so called Ankara Clay and studied the active state of the preloading processes in the region. Kiper (1983) later proposed that both overburden and desiccation cracks in Ankara Clay can be explained as a result of possible active state of preloading processes suggested by Birand (1965). A detailed study of the origin, geology and clay mineralogy of Ankara Clay is presented by Aras (1991), Aras *et al.* (1991) and Koçyiğit and Türkmenoğlu (1991).

Aras *et al.* (1991) studied the clayey levels of Upper Pliocene deposits in the Ankara Plain and Mogan Depression in order to determine the mineralogy, and depositional environment of Ankara Clay. In their study, they used five sections of Upper Pliocene deposits of the Ankara Plain and Mogan Depression. Investigation on these sections showed that in the southern margin of the Ankara Plain, most of the clastics were of local origin. Moreover, they pointed out that these deposits, interfingering with flood plain deposits of a meandering river, formed a transition zone in the southern margin of the Ankara Plain. They concluded that the three distinctive properties of these sequences were:

1. The color change from reddish brown to brown,

2. Presence of volcanic component in coarser beds, and

3. Internal structural features.

Aras *et al.* (1991) also observed three facies in the Mogan Depression, when compared with the Ankara Plain. They concluded that most of the clastics were derived from a local source area as a result of the lithological similarity between the fragments of the lowermost units of the Mogan Depression. Aras *et al.* (1991) further pointed out that the characteristic clay mineral content of Ankara Clay was smectite, illite, chlorite and kaolinite, which were suggested to be originated from the source rocks such as graywacke, schist and limestone. However, the absence of chlorite in pinkish or purplish clastic deposits towards the northern parts of the Ankara Basin was the most important observation in the study of Aras *et al.* (1991). This observation indicates that red mudstones are the alluvial deposits of the rivers eroding Mesozoic source rocks in the Ankara region.

Koçyiğit and Türkmenoğlu (1991) attempted to present both the geological and mineralogical characteristics of the clay bearing soils, referred to "Ankara Clay", at a type locality sited near Yalıncak village (Figure 2.1).

At this site, Ankara basin is underlain by Triassic rocks to the south, Jurassic-Cretaceous carbonates to the west, Upper Miocene Lower Pliocene volcanics and fluvial lacustrine clastics to the north. Koçyiğit and Türkmenoğlu (1991) studied Yalıncak Formation, which is composed of fluvial clastics including clays and is underlain unconformably by the Triassic Kısıküstü Formation (Figure 2.2). They suggested that the Kısıküstü Formation is formed by dark brown graywacke, black shale and diverse sized carbonate blocks.

Koçyiğit and Türkmenoğlu (1991), previously named the basin fill of Ankara as Yalıncak Formation, which has its type locality in the ruins of Yalıncak village in the Middle East Technical University. According to them, the Yalıncak Formation mainly consists of three different lithofacies. These are, from bottom to top, the debris flow conglomerate, braided plain conglomerate to sandstone and clay-bearing finer clastics of flood plain origin (Figure 2.2).

They also observed that at the type locality, the Yalıncak Formation rests unconformably on the irregular erosional surface of the underlying Upper Carboniferous-Permian carbonate blocks and Trassic graywackes. The basal conglomerate on the top of this pre-Triassic basement is the first unit, this unit is overlain by a caliche-like carbonate occurrance, debris flow conglomerate, wedge to trough cross-bedded conglomerate to sandstone and very thick and finer flood plain clastics which are dominated by growth faulted channel conglomerates and carbonate concentrations (Figures 2.2). In their study, Koçyiğit and Türkmenoğlu (1991) suggested that the lower parts of the Yalıncak Formation were deposited in an alluvial fan and braided plain type of

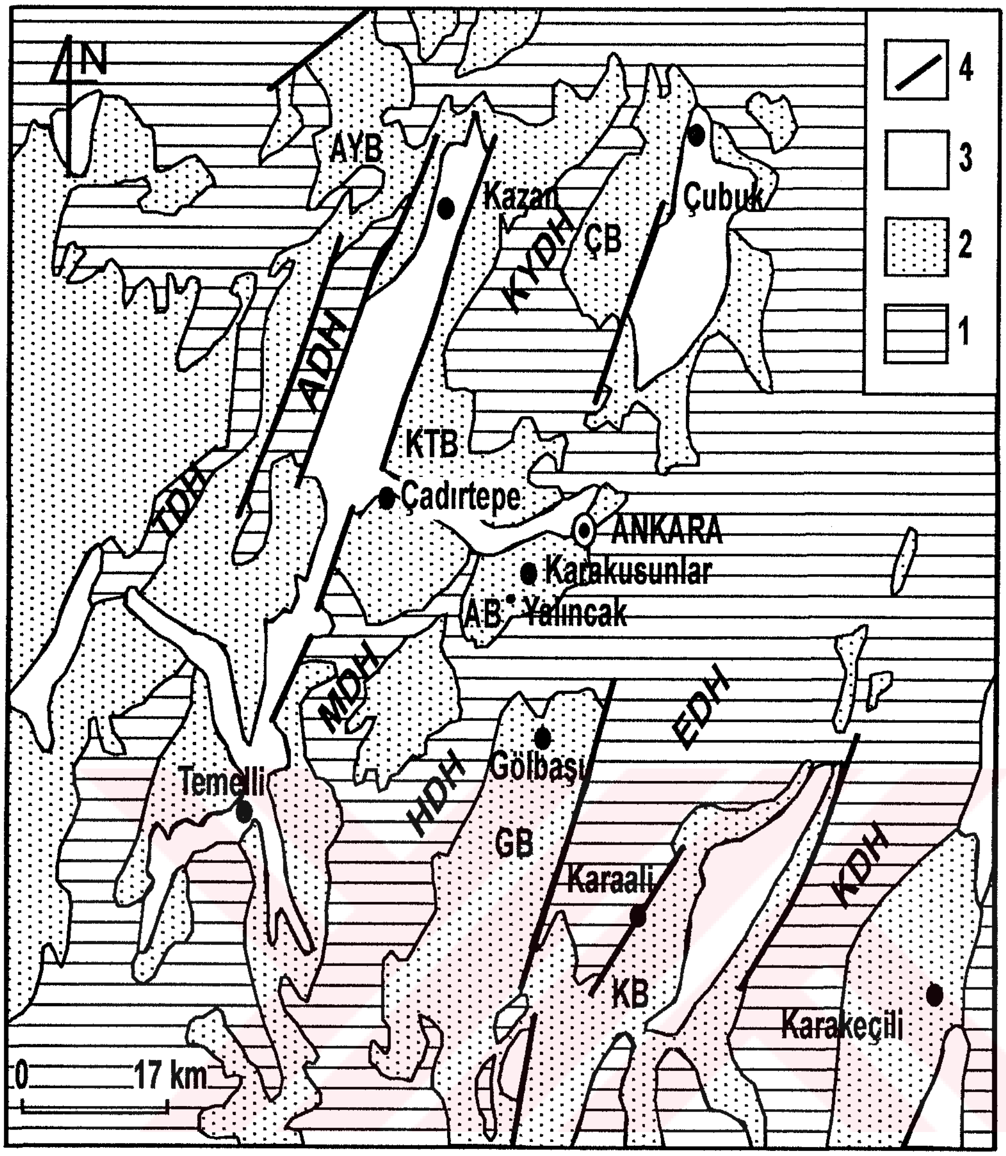

Figure 2.1. Simplified geologic map of Ankara Region (1. Quaternary alluvial sediments, 2. Late Miocene - Pliocene continental basin deposits and volcanics, 3. Pre-Late Miocene basement rocks, and 4. basin margin fault. Key to abbrevations: AB-Ankara Basin, AYB-Ayaş Basin, BB-Beypazarı Basin, ÇB-Çubuk Basin, GB-Gölbaşı Basin, KB-Karaali Basin, KKB-Karakeçili Basin, KTB-Kazan-Temelli Basin, ADH-Abdülselamdağ Highland, EDH-Elmadağ Highland, HDH-Hacılardağ Highland, KDH-Küredağ Highland, KYDH-Karyağdıdağ Highland, MDH-Meşedağ Highland, and TDH-Torludağ Highland.) (Koçyiğit and Türkmenoğlu, 1991).

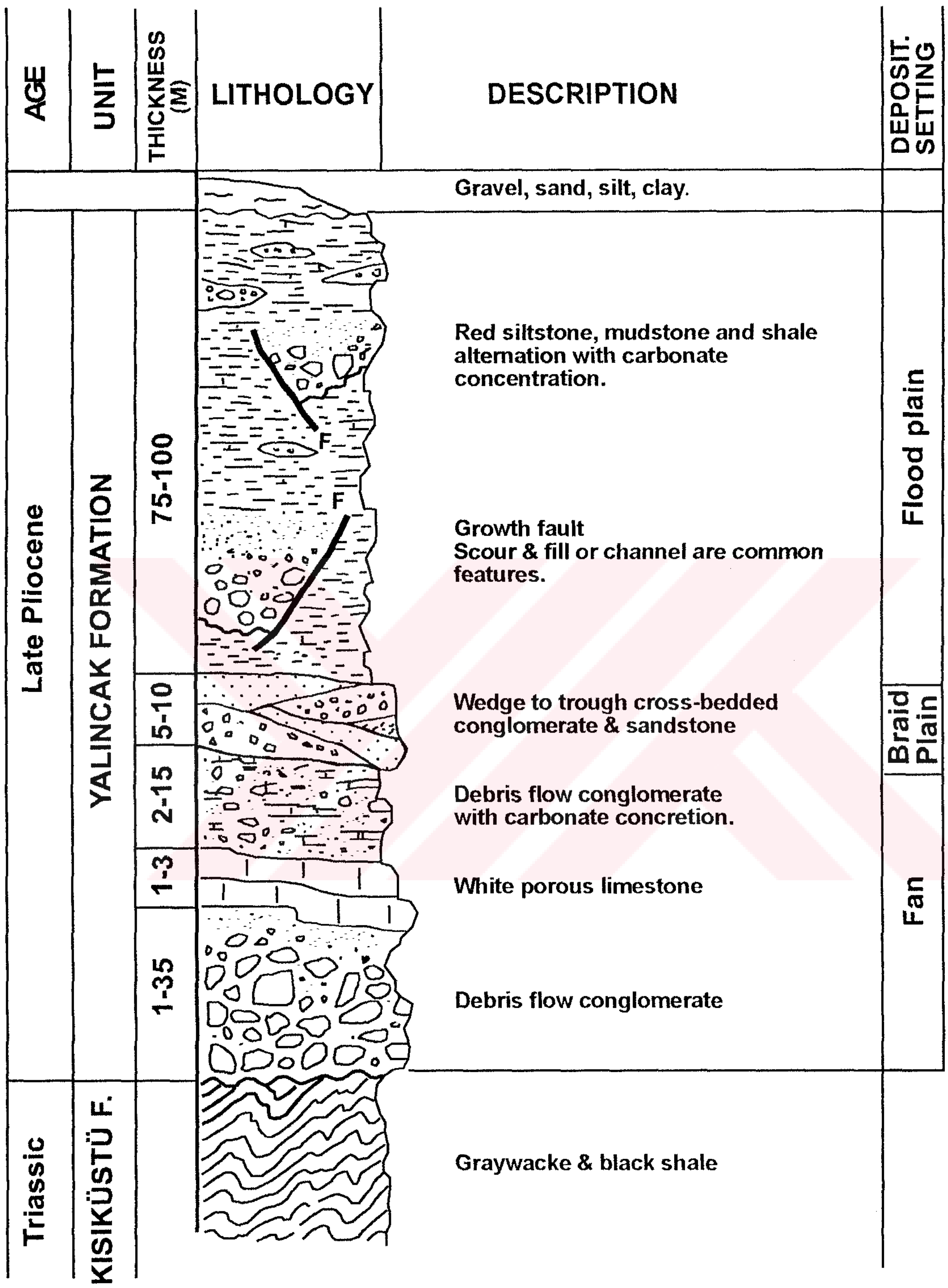

Figure 2.2. Stratigraphic columnar section of the Yalıncak Formation. (Koçyiğit and Türkmenoğlu, 1991).

depositional setting. However, the thicker upper half of the Yalıncak Formation consisting of clay bearing finer red clastics with abundant carbonate concentrations indicate that the sedimantation of the upper half of the Yalıncak Formation continued in a flood plain under tectonically unstable conditions.

Koçyiğit and Türkmenoğlu (1991) also observed that, although red clastics filling the Ankara basin are only fluvial in nature, and they are mostly horizontal or gently tilted at maximum 12°, some other basins in the Ankara region, such as Gölbaşı, Kazan-Temelli, Çubuk and Gölbaşı depressions are occupied both by lacustrine and fluvial clastics, and contain volcanic intercalations.

Koçyiğit and Türkmenoğlu (1991) concluded that the term "Ankara Clay" was used to refer only to the finer red clastics contained on the upper half of the Yalıncak Formation. The clay mineral assemblage contained in these red mudstones and siltstones is dominated mainly by smectite and by lesser quantities of illite, chlorite and kaolinite. The composition of their sand and gravel size particles reflects a similar composition to the underlying graywacke and limestone bedrocks. According to these observations, Koçyiğit and Türkmenoğlu (1991) concluded that graywackes and limestones are the sources of inherited clay and non-clay mineral assemblages of these red clastics.

CHAPTER 3

MINERALOGY

3.1. Cation Exchange Capacity (CEC) Measurements

Cation exchange capacity (CEC) is the measure of the number of positive cations in miliequivalents to neutralize 100 g of clay. In this study, the amounts of exchangeable cations adsorbed to the soil samples were determined by the Methylene Blue Adsorption test. Adsorption of a significant amount of methylene blue by soil or rock material usually indicates the presence of swelling clay minerals (Stapel and Verhoef, 1989; Rytwo *et al.*, 1991; Verhoef, 1992).

Turbidimetric and spot tests are the two methods for methylene blue adsorption test. In this study, the spot method was used according to the procedures of AFNOR (1980). The use of the spot test is very common in engineering practice, since this method is relatively simple and allows determination of CEC values of soil quickly. This method requires addition of certain concentrations of methylene blue solution in definite volumes to a suspension of fine grained soil or rock particles. The total amount of methylene blue solution adsorbed is used for the calculation of methylene blue and cation exchange capacity of the soil or rock (Stapel and Verhoef, 1989; Çokça, 1991; Verhoef; 1992; Topal, 1995).

The results of CEC values are tabulated in Table 3.1. The CEC values of the soil samples range from 12 to 27 meq/100 g.

Table 3.1. Cation exchange capacity (CEC) values of soil samples.

Sample number	CEC (meq/100 g soil)
A (Karakusunlar)	25
B1 (Gölbaşı)	16
B2 (Gölbaşı)	12
C1 (Sincan)	23
C2 (Sincan)	24
C3 (Sincan)	27

High CEC value may indicate the presence of swelling clay minerals. If the clayey soils contain significant amounts of swelling clay, c-axis contraction or expansion may lead to an increase or decrease in the hydraulic conductivity. The levels of Na^+, K^+, and NH_4^+ in municipal solid waste leachate are sufficiently high that they effectively exchange some of the Ca^{+2} and Mg^{+2} present in natural clays during advection and diffusion. Since it takes two Na^+ to exchange one Ca^{+2}, this reaction should expand the double layers and decrease hydraulic conductivity. The role of the similarly sized cations, K^+ and NH_4^+, is quite different and undesirable. These two species tend to fix smectites and vermiculites. If they do fix into the interlayer position between 2:1 layers they may reduce the CEC. This may contract the double layers, owing to charge reduction, causing large increases in free pore space at constant void ratio. In other words, hydraulic conductivity of the clayey soil may increase (Rowe *et al.*, 1995). Therefore the presence of the swelling clay mineral, if so the amount of it in the soil samples should be carefully studied by X-ray diffraction (XRD) analyses.

3.2. X-Ray Diffraction (XRD) Analyses

X-ray diffraction (XRD) is the most widely used method for identification of fine-grained soil minerals and the study of their crystal structure. XRD is particularly well suited for identification of the clay minerals because the basal spacing (d_{001}) is characteristic for each mineral group. The basal planes generally give the most intense reflections of any plane in the crystals because of the close packing of atoms in these planes. The common nonclay minerals occurring in soils are also detectable by XRD (Moore and Reynolds, 1997).

The complete XRD pattern (Figures 3.1 through 3.6 in this section) consists of a series of reflections of different intensities and values of diffraction angle (θ). Each reflection must be accounted for in terms of some mineral component of the sample. The test pattern may be compared directly with patterns for known minerals. The American Society for Testing Materials maintains a card file of patterns indexed on the basis of the strongest lines in the pattern. Grim (1968), Brown (1961), Carroll (1970), and Chen (1977) present extensive XRD data for identification of clay minerals.

3.2.1. Equipment and sampling preparation

In this study, "Phillips PW3710 X-Ray diffractometer" was used for determination of the mineral content of the soil samples in the General Directorate of Mineral Research and Exploration Department (MTA). Non-clay mineral content of the soil samples were analysed by unoriented (whole rock samples) mounts. These mounts have been prepared by placing soils passing through No. 200 Sieve into glass holders.

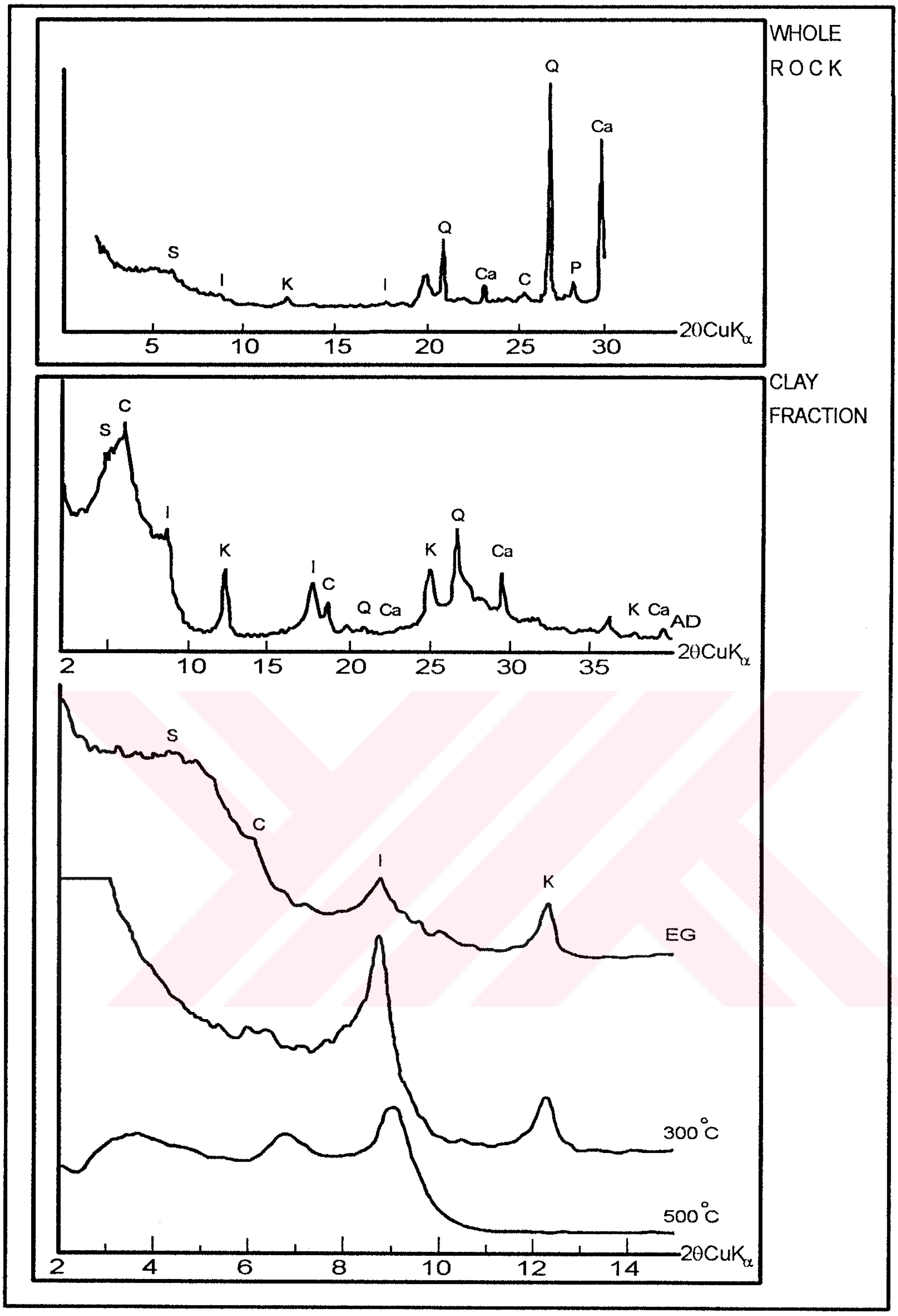

Figure 3.1. X-ray diffraction pattern of soil sample A (AD: air dried, EG: ethylene glycolated, 300 °C: heated to 300 °C for one hour, 500 °C: heated to 500 °C for one hour, S: smectite, I: illite, C: chlorite, Q: quartz, Ca: calcium, P: plagioclase, K: kaolinite).

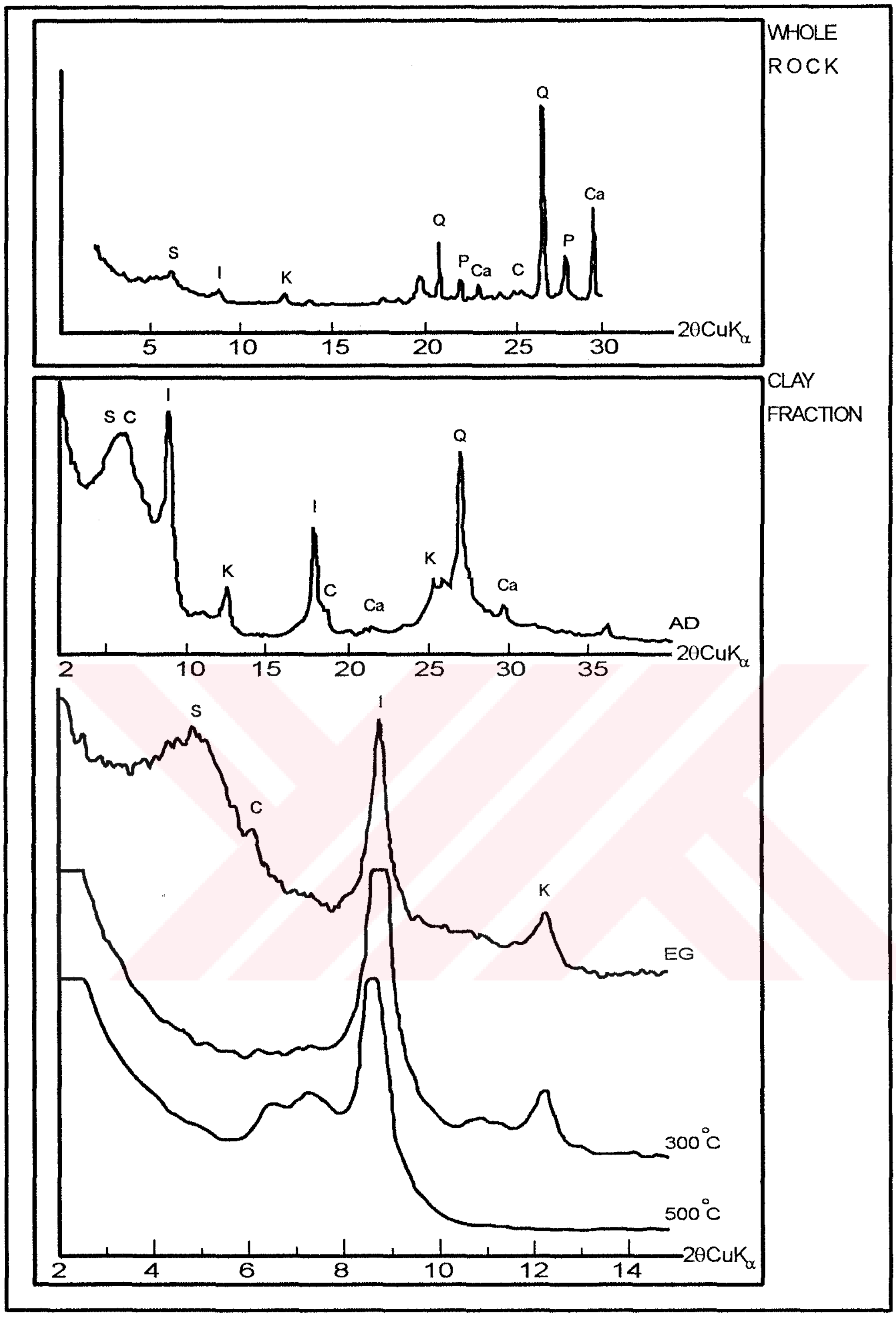

Figure 3.2. X-ray diffraction pattern of soil sample B1 (same abbreviations are used as in Figure 3.1).

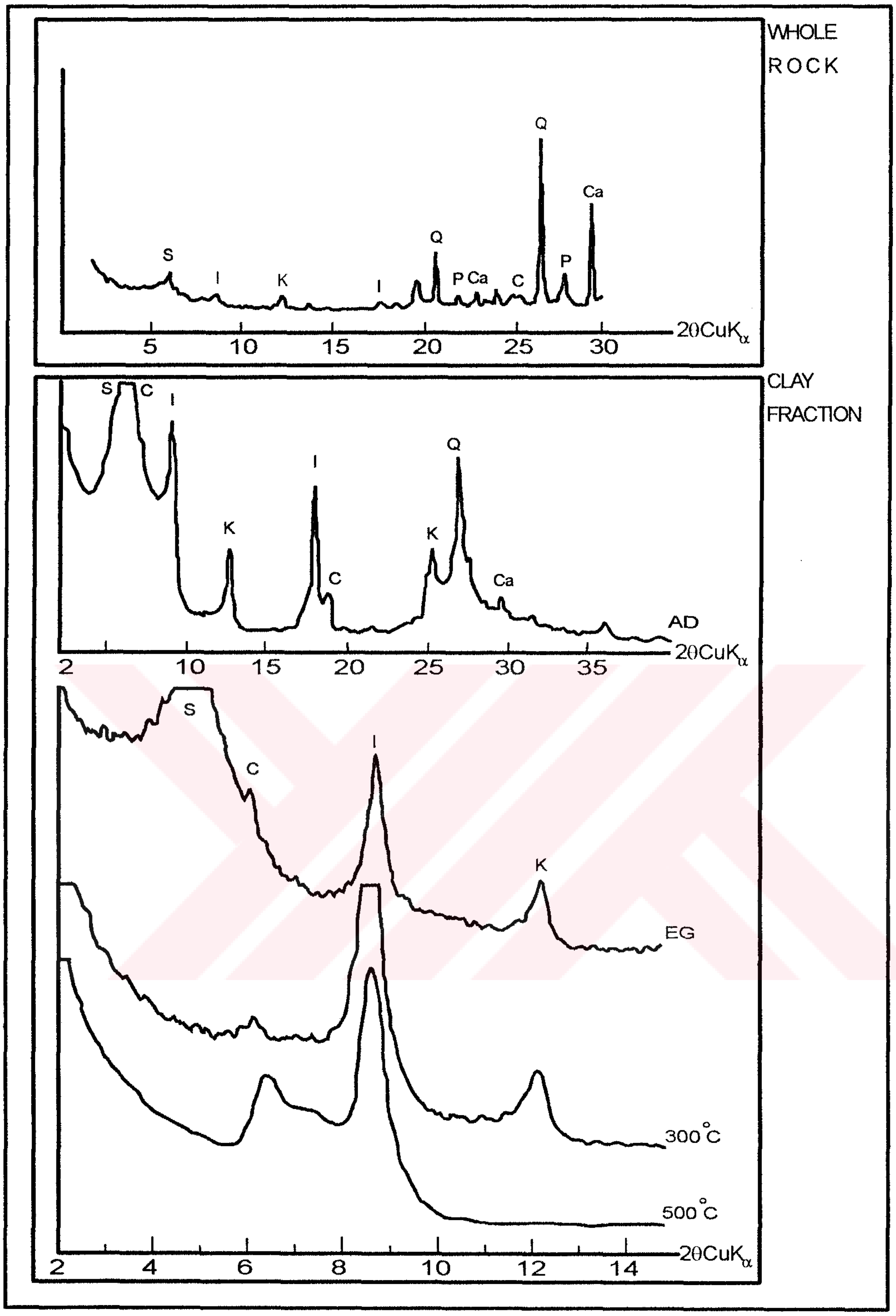

Figure 3.3. X-ray diffraction pattern of soil sample B2 (same abbreviations are used as in Figure 3.1).

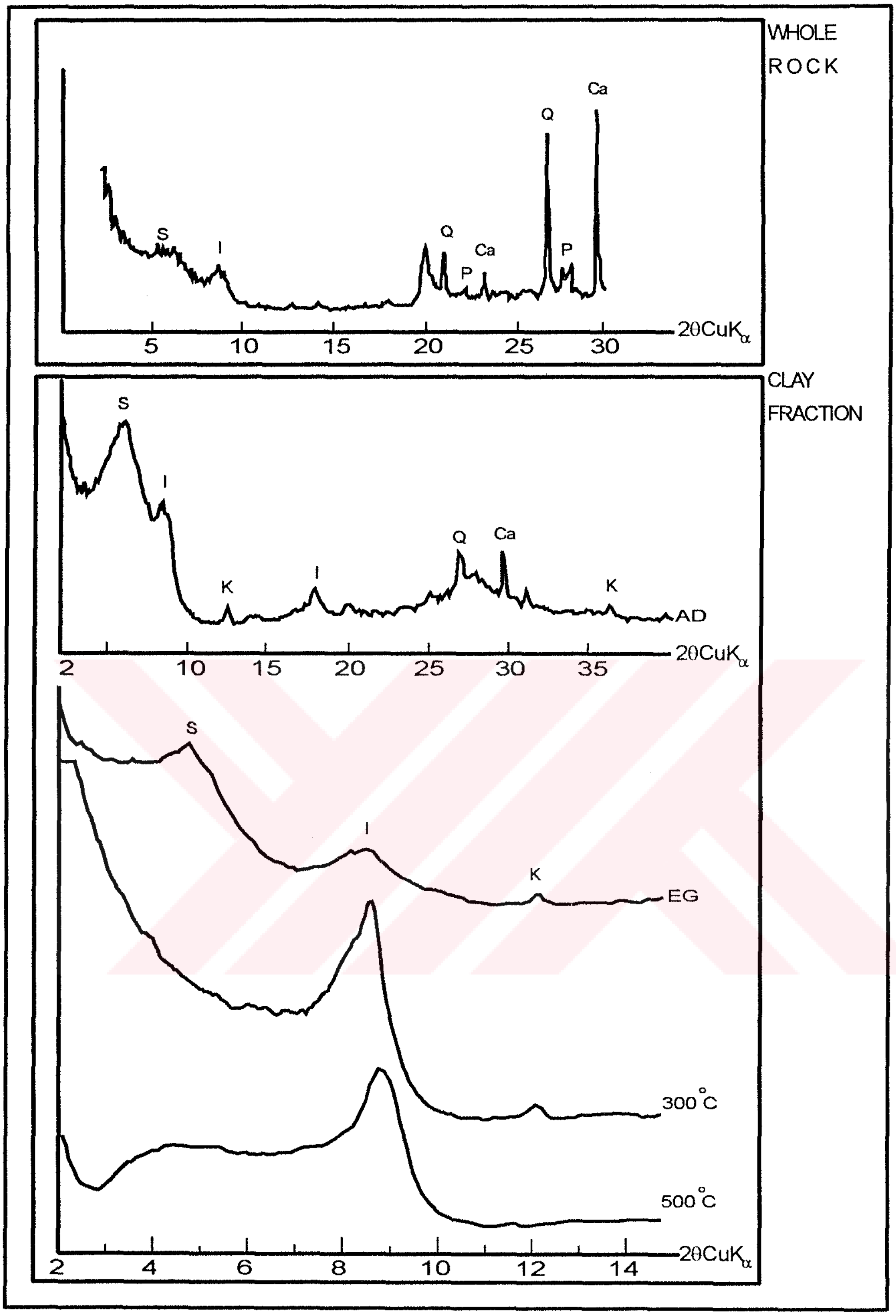

Figure 3.4. X-ray diffraction pattern of soil sample C1 (same abbreviations are used as in Figure 3.1).

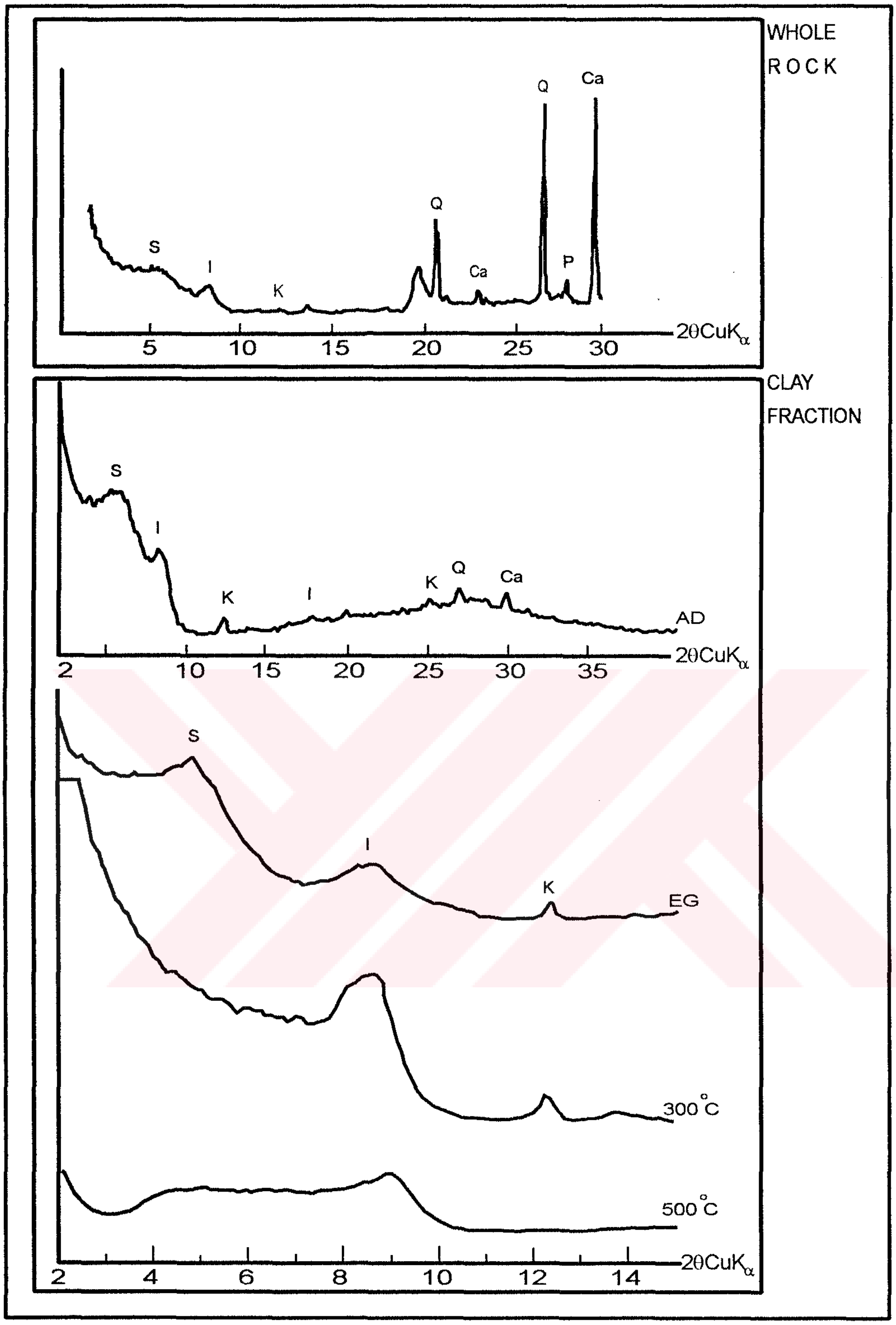

Figure 3.5. X-ray diffraction pattern of soil sample C2 (same abbreviations are used as in Figure 3.1).

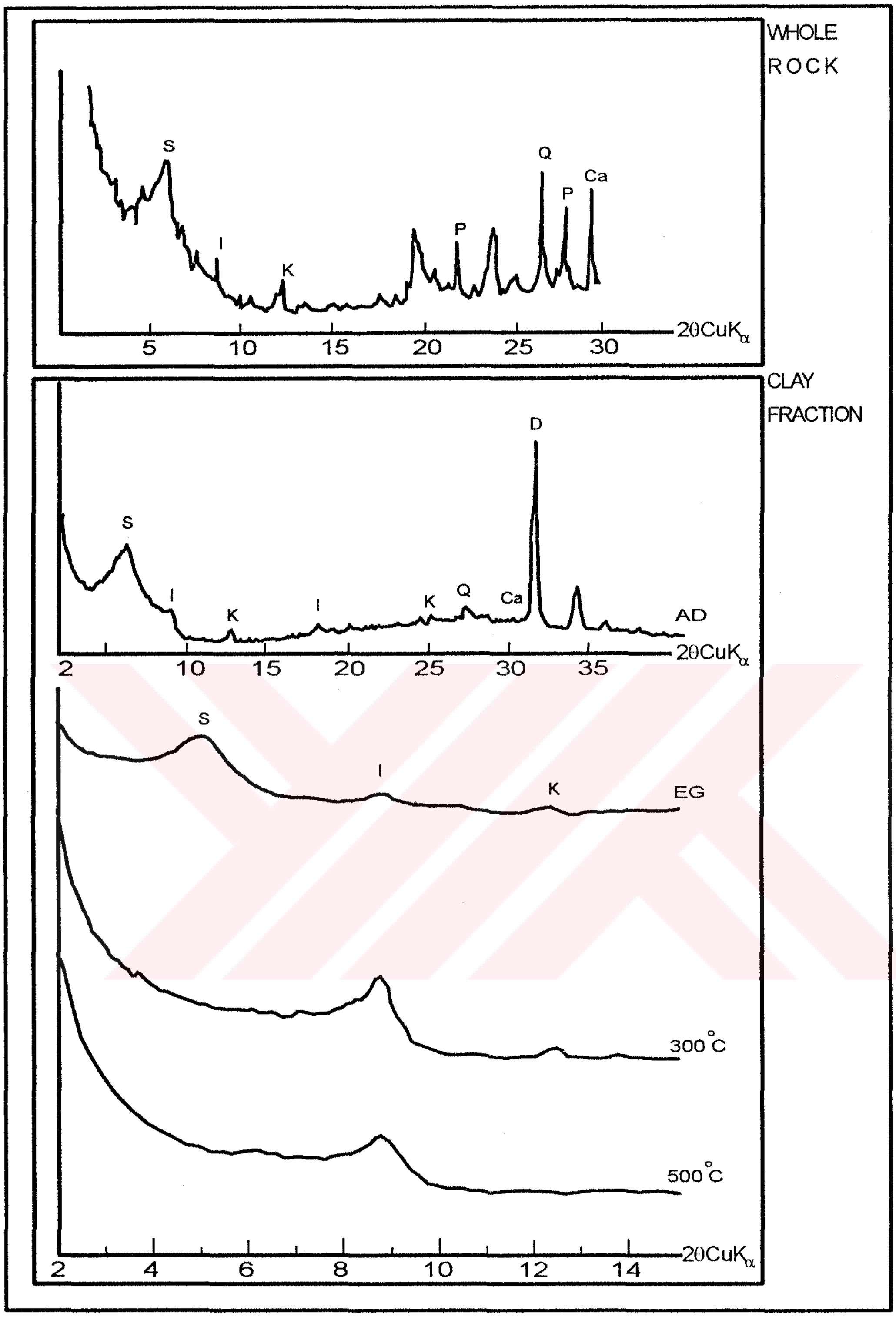

Figure 3.6. X-ray diffraction pattern of soil sample C3 (same abbreviations are used as in Figure 3.1 and D: dolomite).

Basal reflections of clay minerals were obtained by oriented samples. The clay fraction was extracted through the sedimentation method suggested by Tanner and Jackson (1947). Initially, the clay fraction of the samples were concentrated by allowing soils to settle down in a water column for approximately 4 hours and 15 minutes at 20 °C. Then the first 5 cm of the concentrations were taken out by a pipette, to obtain the suspended particles less than 2 μm size. Flocculation during the settlement period was prevented by the addition of a small amount of Sodium Pyrophosphate into the solution. Finally, the clay fraction was settled down by centrifugation at 6000 rpm for 15 minutes and smeared on glass slides. Four slides were prepared for each soil sample. The first one was allowed to dry at room temperature, the second slide was ethylene glycolated in a desiccator filled with ethylene glycol and placed in an oven at about 60 °C overnight, the third and the last slides were placed in the furnace for one hour at 350 °C and 500 °C, respectively.

Finally, X-ray diffraction patterns of the four slides were obtained and studied to determine the mineralogical composition of the samples. CuK_{α} radiation with a Ni filter, at 40 kV, 30 mA, with a slit aperture of 0.2, at a speed of 0.05° per second was used for determination of diffraction patterns of both un-oriented (whole rock samples) and oriented samples. The diffraction range for un-oriented samples were selected between 2° to 30°, between 2° to 40° for air-dried slides and between 2° to 15° for the ethylene glycolated and heated slides.

3.2.2. Results of the X-ray diffraction analyses

The X-ray diffraction analyses of the whole rock samples (from soil samples A through C3) indicate the presence of quartz, calcite and plagioclase as non-clay minerals. However, soil sample C3 differs from others, due to the presence of dolomite as a non-clay mineral (Figures

3.1 through 3.6). The identification criteria of non-clay minerals are tabulated in Table 3.2 for whole rock samples.

In XRD patterns, different clay minerals are characterised by the first order basal reflections at 7 Å, 10 Å, or 14 Å. Illite is characterised by a $d_{(001)}$ of about 10 Å, which remains fixed both in the presence of ethylene glycol and after heating. Kaolinite, on the other hand, has a basal spacing of about 7.2 Å on air-dried samples, which does not change at moderately heated samples, whereas collapses when heated to 500 °C. Smectite is identified by its expansive character. Smectite has a basal spacing of 12 Å to 15 Å on air-dried samples. After treatment with ethylene glycol, the smectite expands to a $d_{(001)}$ value of 17 Å to 18 Å, while oven dried, $d_{(001)}$ drops to about 10 Å as a result of the removal of interlayer water. Chlorite is identified by its fixed basal spacing at 14 Å. Heating chlorite to 500 °C for 1-hour cause dehydroxylation of the hydroxide sheet with attendant changes in the diffraction pattern. The intensity of 001 reflection increases greatly and shifts about 6.3 to 6.4 °2θ.

All the clay minerals peaks observed in XRD patterns of the samples were studied according to their characteristic basal reflections. The identification criteria of clay minerals in soil samples A through C3 are summarised in Table 3.3.

Table 3.2. X-ray data for identification of common non-clay minerals in the soil samples (the most intense peaks are underlined, nObs: not observed, d(Å): spacing in Angstrom).

Sample No and Location	Quartz d (Å)	Calcite d (Å)	Dolomite d (Å)	Plagioclase d (Å)
A	<u>3.35</u>	<u>3.04</u>	nObs	<u>3.19</u>
(Karakusunlar)	4.26	3.85		
B1	<u>3.34</u>	<u>3.03</u>	nObs	<u>3.19</u>
(Gölbaşı)	4.26	3.85		4.03
B2	<u>3.35</u>	<u>3.04</u>	nObs	<u>3.19</u>
(Gölbaşı)	4.26	3.85		4.03
C1	<u>3.34</u>	<u>3.03</u>	nObs	<u>3.19</u>
(Sincan)	4.25	3.84		4.03
C2	<u>3.34</u>	<u>3.03</u>	nObs	<u>3.19</u>
(Sincan)	4.25	3.85		
C3	<u>3.34</u>	<u>3.04</u>	<u>2.89</u>	<u>3.19</u>
(Sincan)				4.04

The oriented diffraction pattern of the all soil samples reveals that the dominant clay minerals are illite, kaolinite and smectite. Illite and smectite may also form an illite-smectite mixed layer structure, according to XRD patterns although its presence can not be proved certainly. Soil samples A, B1, and B2 are rich in chlorite peaks (Figures 3.1, 3.2, and 3.3) whereas, no chlorite peaks was observed at oriented diffraction patterns of soil samples C1, C2, and C3 (Figures 3.4, 3.5, and 3.6).

Table 3.3. X-ray data for identification of common clay minerals in the soil samples (the most intense air dried peaks are underlined unless mentioned, nObs:not observed, d(°A): spacing in Angstrom, EG: ethylene glycolated).

Sample No and Location	Kaolinite d (Å)	Smectite d (Å)	Illite d (Å)	Chlorite d (Å)
A	<u>7.16</u>	<u>17.86</u> (EG)	10.10	<u>14.3</u>
(Karakusunlar)	3.58	15.00	5.00	4.7
	2.38			
B1	<u>7.18</u>	<u>17.52</u> (EG)	<u>10.08</u>	<u>14.3</u>
(Gölbaşı)	3.55	15.23	5.00	4.77
B2	<u>7.18</u>	<u>18.02</u> (EG)	<u>10.16</u>	<u>14.29</u>
(Gölbaşı)	3.58	15.49	5.02	4.78
C1	<u>7.20</u>	<u>17.87</u> (EG)	10.02	nObs
(Sincan)		15.44	5.00	
C2	<u>7.19</u>	<u>17.59</u> (EG)	10.54	nObs
(Sincan)	3.59	15.71	5.00	
C3	<u>7.18</u>	<u>17.45</u> (EG)	<u>10.04</u>	nObs
(Sincan)	3.58	16.17	5.00	

3.2.3. Semi-quantitative estimation of clay minerals

After identifying the major clay minerals present in the samples, the percentages of these minerals were determined semi-quantitatively according to the method developed by Brindley and Kurtossy (1961) and Biscaye (1965). This method is based on summation of the weighted peak areas, which represent approximations of the abundance of each mineral and provide an accuracy of ± 5-10%. It is important to note that semi-quantitative analyses do not give the accurate results and they should be considered good if the accuracy ranges between ± 10% and 20% (Moore and Reynolds, 1997).

In this study weighted peak areas were determined on XRD patterns of air-dried and ethylene glycolated soil samples. The details of the calculations have been clearly presented in the studies of Brindley and Kurtossy (1961) and Biscaye (1965). For calculations, the XRD patterns were obtained by using "Siemens X-Ray diffractometer" in the Department of Geology, at the University of Cincinnati, Cincinnati.

The results of semi-quantitative XRD estimation of clay minerals in the samples are listed in Table 3.4. It can be observed that, soil samples A and C3 are rich in smectite content with percentages of 54% and 64%, respectively. Soil samples B1, B2, C1, and C2, on the other hand, are rich in illite with percentages of 77%, 54%, 66% and 69%, respectively. Chlorite is a minor clay mineral in soil samples A, B1, and B2 and the compositional percentage ranges from 1% to 4%. Another important result is that all of the soil samples contain more or less the same amount of kaolinite ranging from 3% to 4%. So major compositional percentage variation occurs in smectite to illite ratio.

Table 3.4. Percentage of clay minerals in the soil samples.

Sample No and Location	Kaolinite (%)	Smectite (%)	Illite (%)	Chlorite (%)
A (Karakusunlar)	3	54	39	4
B1 (Gölbaşı)	3	18	77	2
B2 (Gölbaşı)	4	41	54	1
C1 (Sincan)	4	30	66	0
C2 (Sincan)	4	27	69	0
C3 (Sincan)	3	64	33	0

3.3. Scanning Electron Microscope (SEM) Analyses

The scanning electron microscope (SEM) represents a recent development. The SEM has a magnification range of x20 to x150,000 and a depth of field some 300 times greater than that of the light microscope. These characteristics, coupled with the fact that clay particles themselves and fracture surfaces through soil masses may be viewed directly, have led to an exclusive use of the SEM for investigation of clay morphology of the samples detaily (Reed, 1996).

3.3.1. Equipment and sampling preparation

Cambridge Stereoscan microscope, model S 4 – 10 with a Link Analysis system was used for the SEM analyses in the Metallurgical Engineering Department at the Middle East Technical University, Ankara.

Small chips were broken from fresh and representative parts of the specimens and these were coated by a thin film of gold-palladium in order to provide conduction of excess electrical charge that results from the electron beam of scanning electron microscope (McCrone and Delly, 1973).

3.3.2. Results of the SEM analyses

Interpretation of the SEM images (Figures 3.7 and 3.8) leads to the following results:

Typical fine grained, thick morphology of clay is observed in soil sample A (Figure 3.7a). Chlorite and calcite are the other minerals observed in soil sample A (Figures 3.7b and 3.7c).

In soil sample B1, quartz, feldspar and chlorite are detected by SEM analyses (Figures 3.7d and 3.7e). The quartz grains in soil sample B1, are rounded and this might be an indication of transportation (Figure 3.7e).

Calcite, feldspar, quartz and smectite minerals detected by XRD analyses are also observed by SEM studies in soil sample B2. Different than the XRD analyses, SEM studies indicate the presence of titanite and dolomite in soil sample B2 (Figure 3.8a). Energy dispersion X-ray analysis (EDX) on soil sample B2 also proves the presence of titanite (Figure 3.9).

SEM investigations on soil sample C1 exhibit typical corn-flake morphology of smectitic clays (Figure 3.8b), which was defined by Keller and Reynolds (1986).

In soil sample C2, fibrous structure of illite within smectite flakes is observed and this may be attributed to illitic and smectitic matrix. Feldspar is another mineral observed in soil sample C2 (Figures 3.8c and 8d).

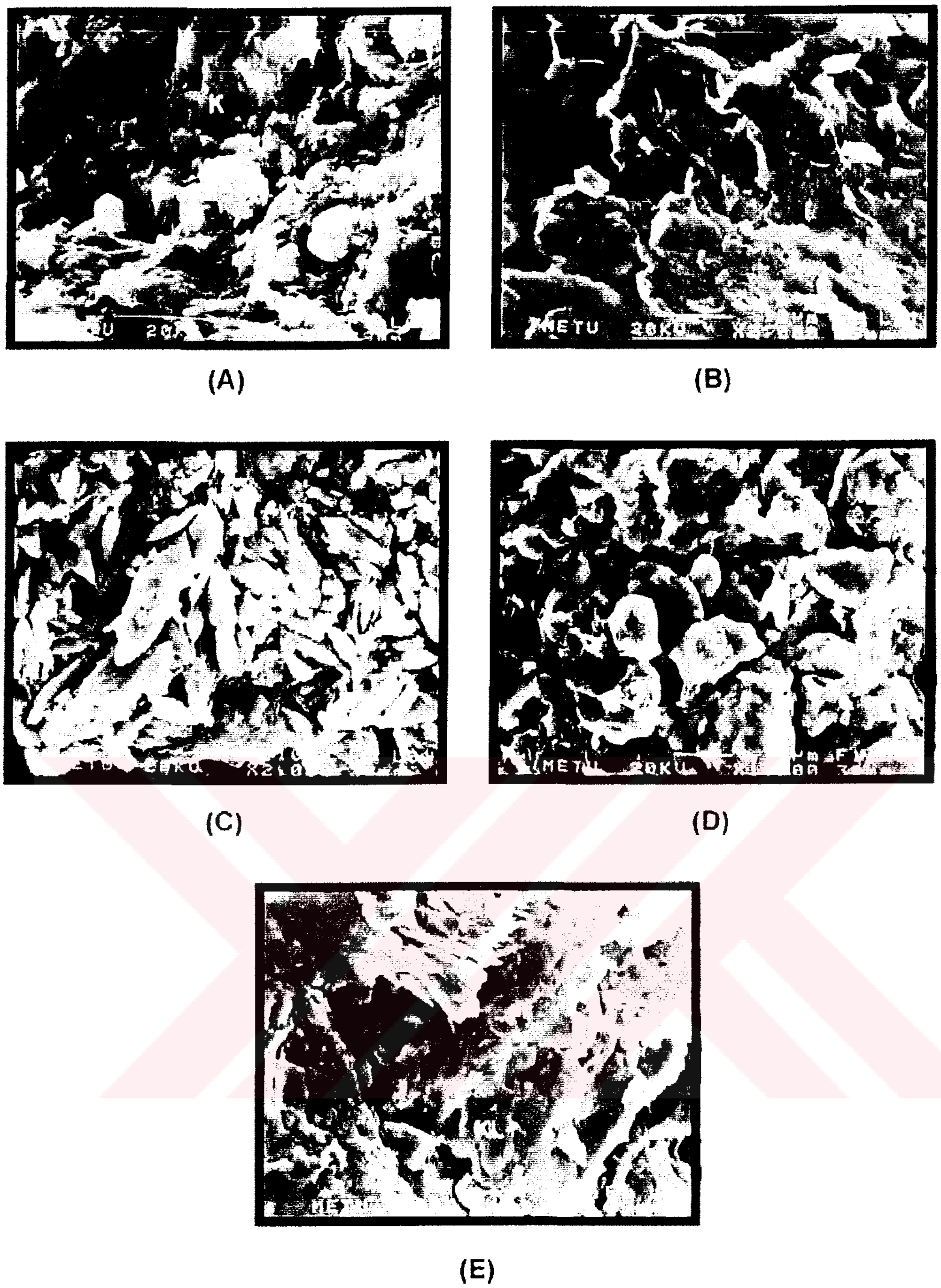

Figure 3.7. SEM images of soil samples A and B1 (**(a)** typical fine grained, thick morphology of clay in soil sample A "K: clay, C: calcite", **(b)** typical chlorite structure in soil sample A, **(c)** calcite minerals "C" in soil sample A, **(d)** rounded quartz "Q" grains in soil sample B1, **(e)** chlorite grains "KL" within feldspar "F" matrix in soil sample B1).

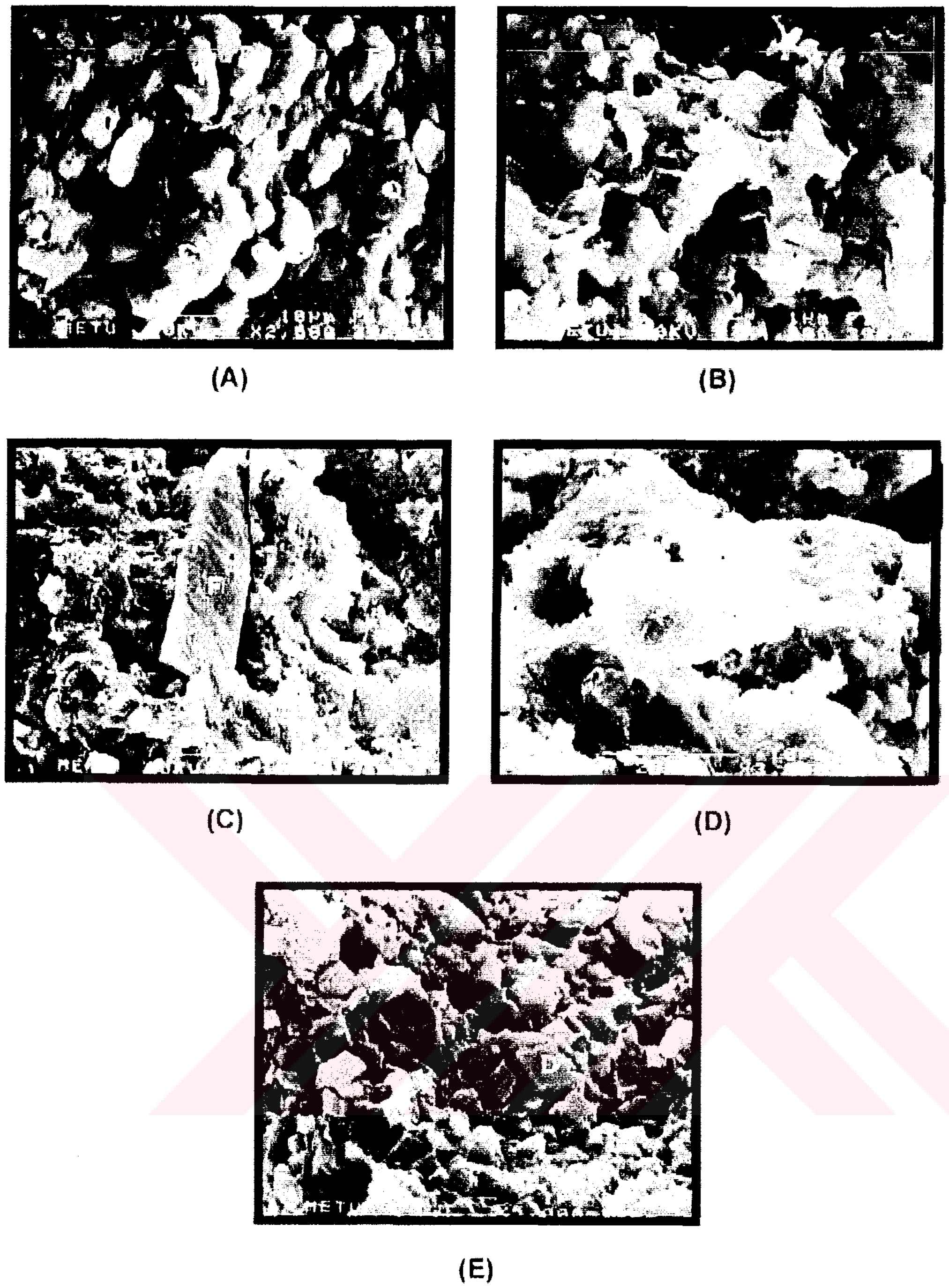

Figure 3.8. SEM images of soil samples B2 through C3 (**(a)** titanite "T", dolomite "D", calcite "C", feldspar "F", and quartz "Q" grains within smectitic matrix in soil sample B2, **(b)** typical smectite structure in soil sample C1, **(c)** feldspar grains "F" within illitic and smectitic matrix in soil sample C2, **(d)** a view of smectite in soil sample C2, **(e)** rhombohedral dolomite crystals in soil sample C3).

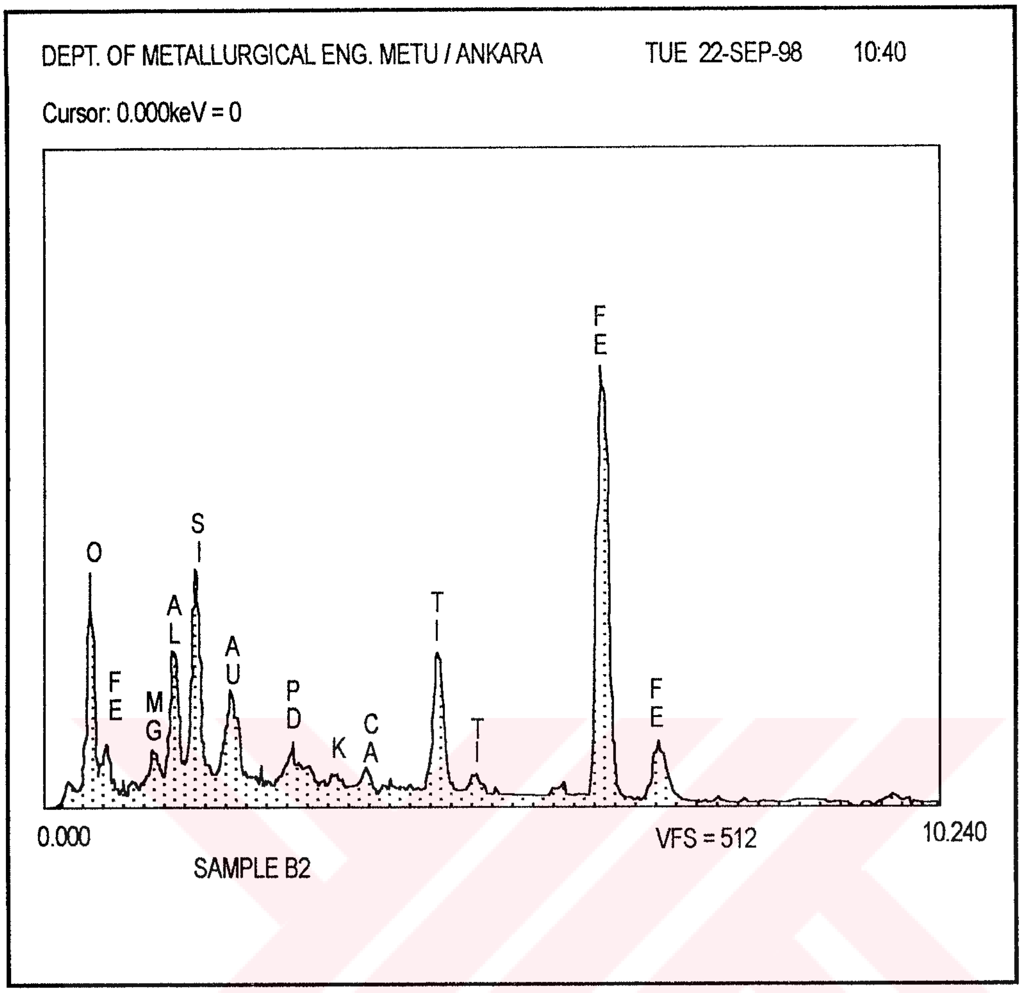

Figure 3.9. Energy dispersive X-ray (EDX) analysis of titanite in soil sample B2.

In soil sample C3, typical rhombohedral structure of dolomite is detected (Figure 3.8e). These rhombohedral dolomites are compacted and may lead to a low hydraulic conductivity, which will be investigated in Chapter 4.

CHAPTER 4

ENGINEERING PARAMETERS

4.1. Experimental Procedure

A series of index testing, standard compaction and falling head permeability tests were performed on six disturbed soil samples collected from Karakusunlar (soil sample A), Gölbaşı (soil samples B1 and B2) and Sincan (soil samples C1, C2, and C3) to determine the engineering properties of the soil samples. All the soil samples collected were kept in plastic bags under ambient room conditions (22 ± 2 °C, 30 ± 1 % relative humidity) in Engineering Geology Laboratories of Department of Geological Engineering, at Middle East Technical University, Ankara. Sample experimental data for soil sample A is presented as an example for all soil samples in Appendix A. The testing procedures and results are presented below.

4.1.1. Index tests

The following tests have been performed to obtain the index properties of soil samples:

1. Specific gravity of solids,

2. Particle size distribution, and

3. Atterberg limit tests [liquid limit (LL), plastic limit (PL), and plasticity index (PI)].

A total of 24 specific gravity tests were performed according to ASTM D854 standard. Particle size distribution, liquid limit and plastic limit of the soil samples were evaluated by a total of 6, 22, and 48 experiments, respectively.

Within this study, gravel is defined as a particle size larger than 4.75 mm (No. 4 sieve), sand as having a particle size between 4.75 mm (No. 4 sieve) and 0.075 mm (No. 200 sieve), fines as particles smaller than 0.075 mm (No. 200 sieve), and clay content as the percentage of particles smaller than 0.005 mm in accordance with Unified Soil Classification System (USCS). A typical particle size distribution curve for soil sample C1 is shown in Figure 4.1. The grading curves were obtained by performing sieve analysis for the gravel and sand particle size and hydrometer tests for the silt and clay fractions according to ASTM D422 standard. One sample copy of particle size distribution test for each soil sample is presented in Appendix A.

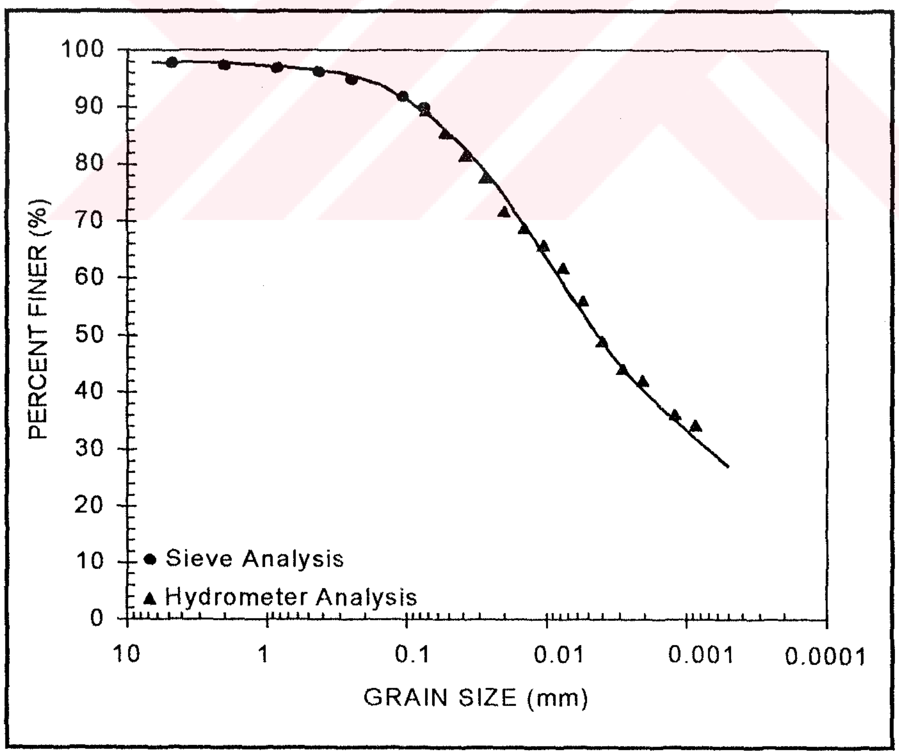

Figure 4.1. Grain size distribution curve for soil sample C1.

One of the most important index characteristics of a clayey soil is its plasticity. The extent to which natural clay exhibits plasticity depends upon its clay mineral composition and water content. Furthermore, the consistency of a natural clay is found to vary with water content, ranging from a solid state in the dry condition, through a semi-solid crumbly and non-plastic state at low water contents, to a plastic state at higher water contents, and finally an essentially liquid state at very high water contents. Atterberg limits are used to establish arbitrary divisions between these various states, which consist of the shrinkage limit, plastic limit, and liquid limit. The standard method used for the determination of plastic and liquid limits was ASTM D4318.

Results of the index tests are summarized in Table 4.1. The soils vary in specific gravity ($2.67 \leq G_s \leq 2.84$), plasticity ($42.4 \leq LL \leq 72.9$, $25.5 \leq PI \leq 34.8$), and particle size distribution (63.8% ≤ fines ≤ 89%, 44.2% ≤ clay ≤ 63.9%).

The liquid limit (LL) and plasticity index (PI) values were used for classifying the soil samples according to ASTM D2487 (Unified Soil Classification System-USCS). This system, developed originally by Casagrande in the forties for use in airfield construction, was modified in 1952 by the US Bureau of reclamation and the US Corps of Engineers to extend its range of application. In 1969 it was adopted by the American Testing and Materials as the standard method of classifying soils for engineering purposes. The results presented in Figure 4.2 show that soil sample A is classified as CH (fat clay with sand), the soil samples B1, B2, and C3 as CL (sandy lean clay), and the soil samples C1 and C2 as MH (elastic silt).

Table 4.1. Results of index tests and particle size distribution of disturbed soil samples obtained from the three sites. Mean specific gravity (G_s), mean percent liquid limit (LL), mean percent plastic limit (PL) and mean percent plasticity index (PI) ± one standard deviation. Numbers in parentheses represent the number of tests performed.

Sample number and location	G_s	LL (%)	PL (%)	PI (%)	Particle size distribution % Gravel	% Sand	% Fines	% Clay
A (Karakusunlar)	2.69 ± 0.03 (6)	53.6 ± 1.41 (4)	18.8 ± 3.25 (13)	34.8 ± 1.84	4.2	15.9	79.9	61.5
B1 (Gölbaşı)	2.73 ± 0.11 (3)	46.8 ± 0.74 (4)	14.7 ± 3.48 (4)	32.1 ± 2.74	11.0	22.9	66.1	48.7
B2 (Gölbaşı)	2.74 ± 0.06 (3)	42.4 ± 0.38 (4)	16.9 ± 2.62 (4)	25.5 ± 2.24	11.0	25.1	63.8	44.2
C1 (Sincan)	2.72 ± 0.06 (4)	64.4 ± 0.84 (3)	38.1 ± 2.55 (14)	26.3 ± 1.71	2.1	7.9	89.0	51.8
C2 (Sincan)	2.84 ± 0.07 (4)	72.9 ± 1.59 (3)	43.3 ± 2.46 (8)	29.6 ± 0.87	1.4	10.2	80.2	51.8
C3 (Sincan)	2.67 ± 0.09 (4)	49.5 ± 0.66 (4)	19.6 ± 5.09 (5)	29.9 ± 4.43	0	5.6	82.0	63.9

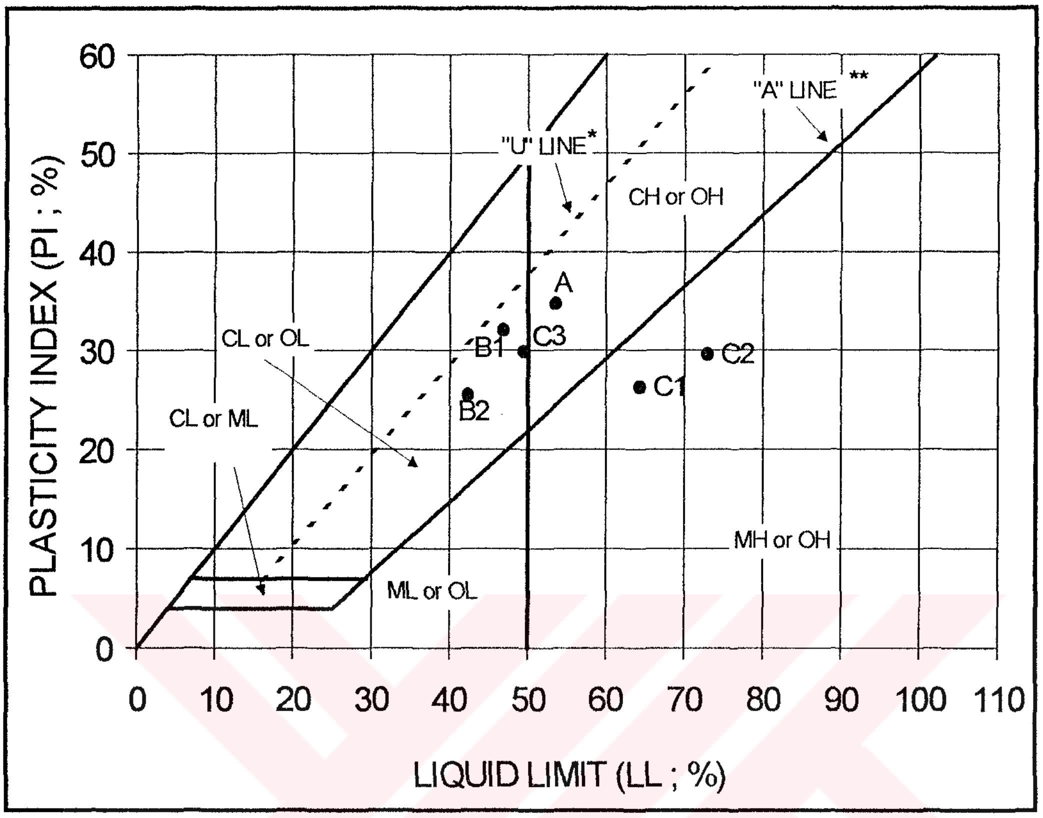

Figure 4.2. Unified Soil Classification System (USCS) plasticity chart for classification of fine grained soils and fine grained fraction of coarse grained soils (after ASTM D2487)

* Equation of "U-line" : Horizontal at PI=7 to LL=16, then PI=0.9(LL-8)

** Equation of "A-line" : Horizontal at PI=4 to LL=25.5, then PI=0.73(LL-20)

4.1.2. Compaction tests

The standard proctor compaction apparatus was used to compact the soil samples at various molding water contents. As suggested in ASTM D698, gravel and other particles too large to pass through No.4 Sieve were discarded. In general, the percentage of gravel-size particles was small, being at the most 11% and more commonly 0-4% (Table 4.1).

The crushed and moistened soils were brought to various water contents with deaired distilled water. The moistened soils were sealed in plastic bags and allowed to rest at least for 24 hours prior to compaction in order to attain uniform moisture through out the sample. After hydration, the soils were compacted using a Standard Proctor hammer.

The bulk density and water content of the compacted soil samples were determined in order to compute the corresponding dry unit weights. The compaction procedure was repeated at a minimum of five different water contents (w) which lead to five corresponding dry unit weights (γ_d). Then, the compaction characteristics of the soil samples were presented in the form of a plot of dry unit weight against water content.

The results of the standard compaction tests of each soil sample are shown in Figures 4.3a, b, c, d, e, and f. All curves exhibit an essentially similar characteristic: the dry unit weight initially increases with increasing water content until it reaches a peak value and then decreases with increasing water content. The peak point on the compaction curve defines the optimum water content (w_{opt}) and the corresponding maximum dry weight ($\gamma_{d(max)}$). The results of the compaction tests are summarized in Table 4.2.

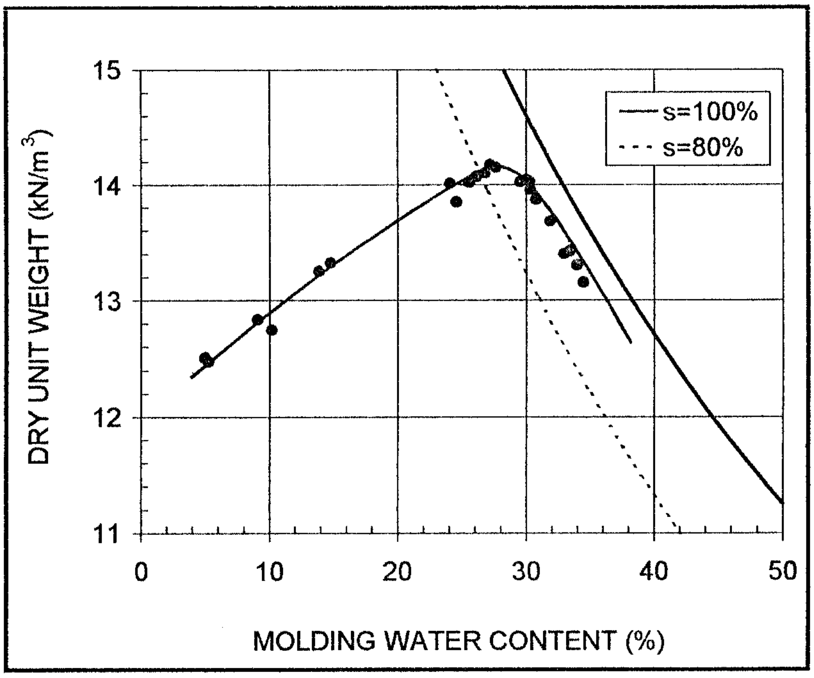

Figure 4.3a. Standard Proctor compaction curve for soil sample A (s: degree of saturation curve).

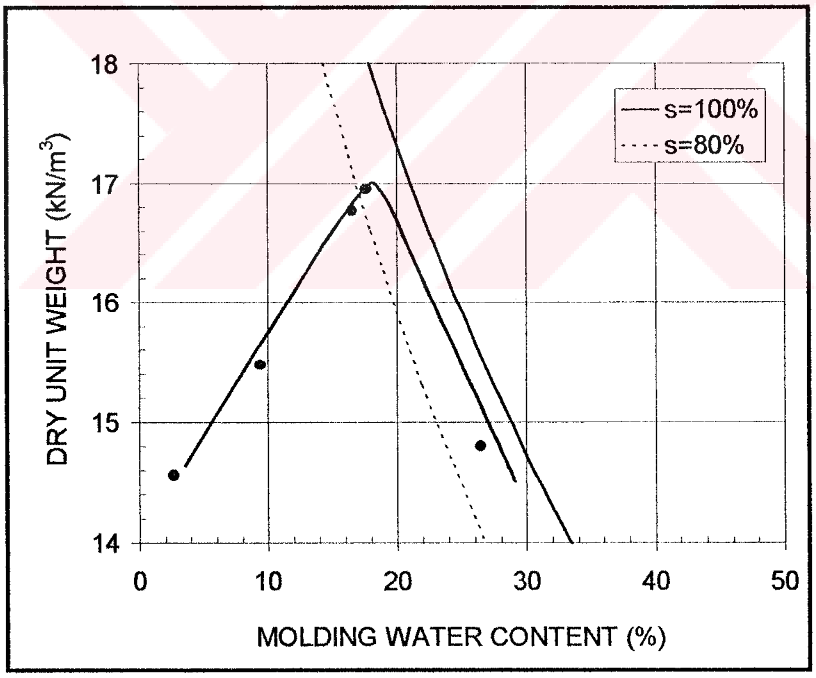

Figure 4.3b. Standard Proctor compaction curve for soil sample B1 (s: degree of saturation curve).

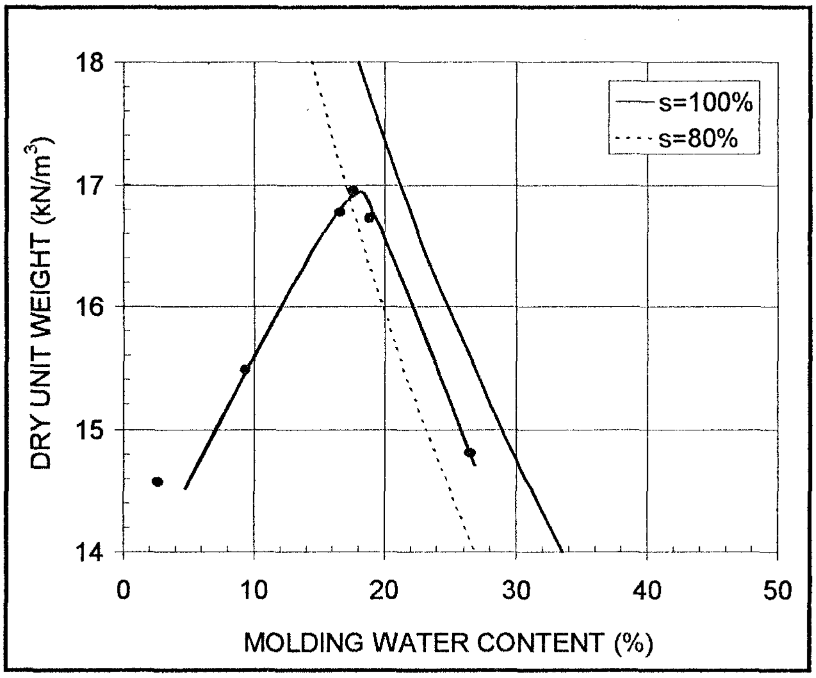

Figure 4.3c. Standard Proctor compaction curve for soil sample B2 (s: degree of saturation curve).

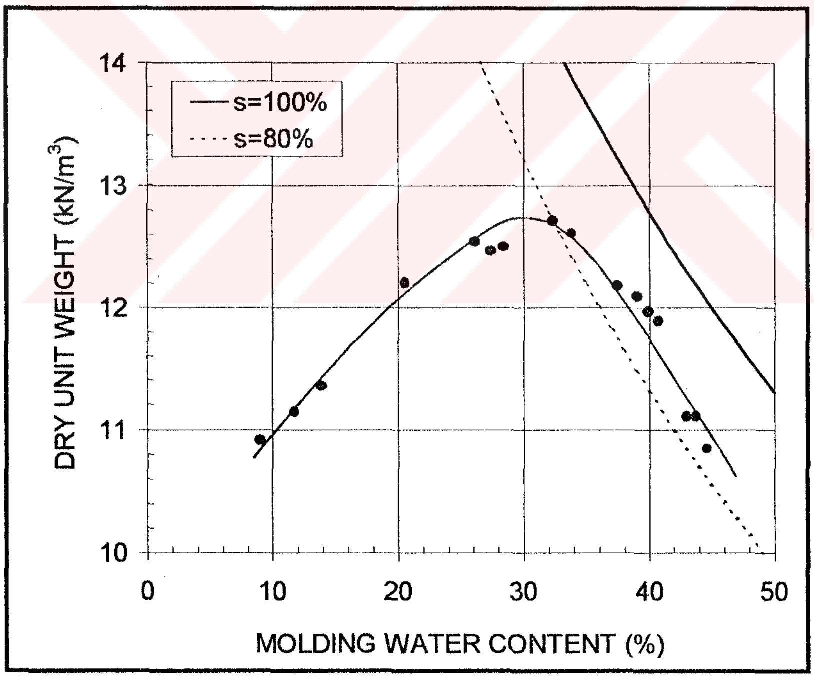

Figure 4.3d. Standard Proctor compaction curve for soil sample C1 (s: degree of saturation curve).

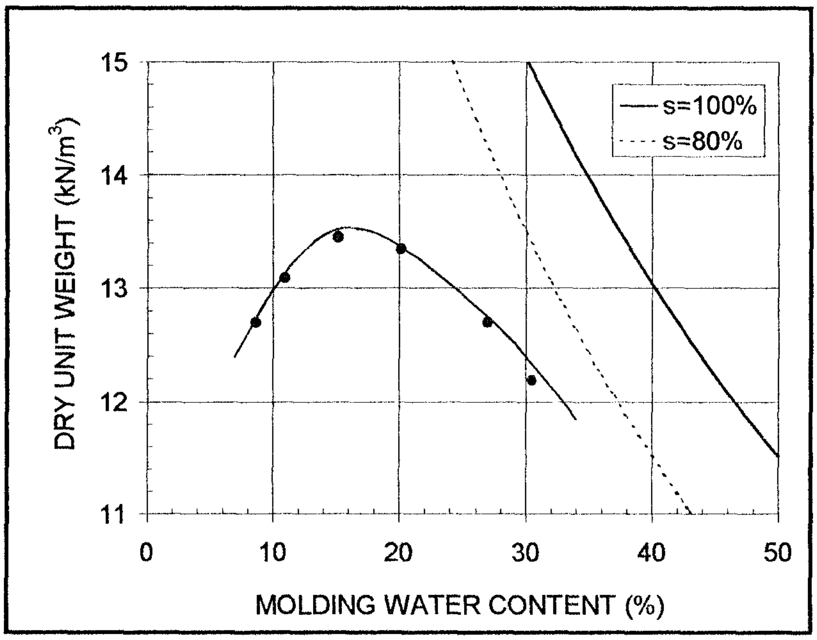

Figure 4.3e. Standard Proctor compaction curve for soil sample C2 (s: degree of saturation curve).

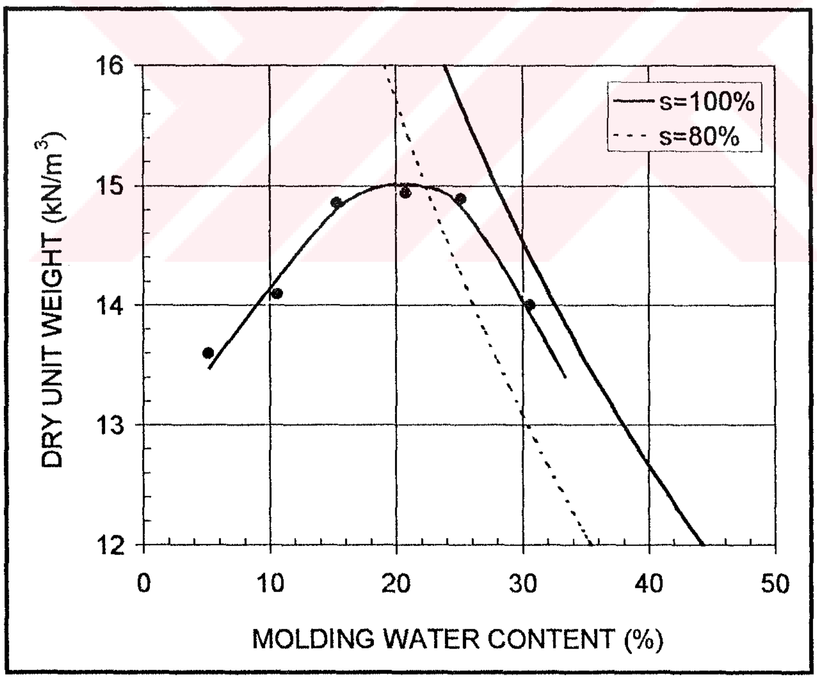

Figure 4.3f. Standard Proctor compaction curve for soil sample C3 (s: degree of saturation curve).

Table 4.2. Results of Standard Proctor compaction tests. Optimum moisture content (w_{opt}) and maximum dry unit weight ($\gamma_{d\ max}$) of disturbed soil samples obtained from the three sites. Numbers in parentheses represent the number of tests performed.

Sample number and location	w_{opt} (%)	$\gamma_{d\ max}$ (kN/m^3)
A (Karakusunlar)	28.0 (23)	14.2
B1 (Gölbaşı)	18.0 (5)	17.0
B2 (Gölbaşı)	18.0 (6)	16.8
C1 (Sincan)	30.0 (16)	12.6
C2 (Sincan)	16.0 (6)	13.6
C3 (Sincan)	21.0 (6)	15.0

4.1.3. Falling head permeability tests

The 100 mm diameter compacted soil specimens were placed in rigid-wall permeameters for hydraulic conductivity testing in accordance with ASTM D5856. Figures 4.4 and 4.5 show the falling head compaction permeameter arrangement setup. The test apparatus consists mainly of four compaction permeameters, deairing tank, four burettes, distilled water tank and vacuum pump. The apparatus is designed so that four hydraulic conductivity tests may be performed concurrently. The vacuum pump was used to pump water from the distilled water tank to the deairing tank, which freed the water from any air bubbles. The deairing tank was connected to burettes, which were used to measure the total heads for hydraulic conductivity measurements. The burettes had an inside diameter of 3 mm and a length of 227.5 mm. Each burette was

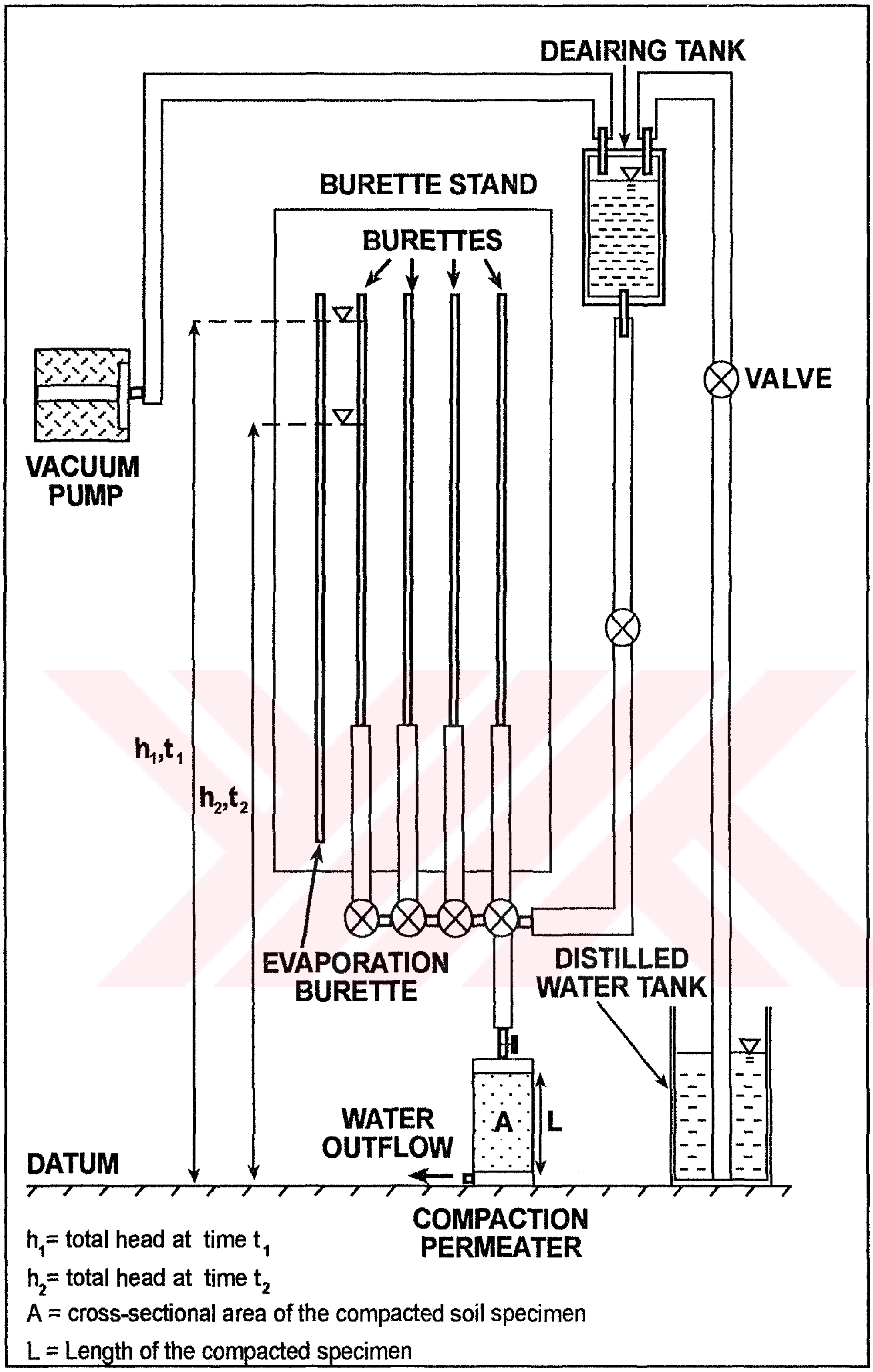

Figure 4.4. Schematic drawing of falling head compaction permeameter setup (not to scale).

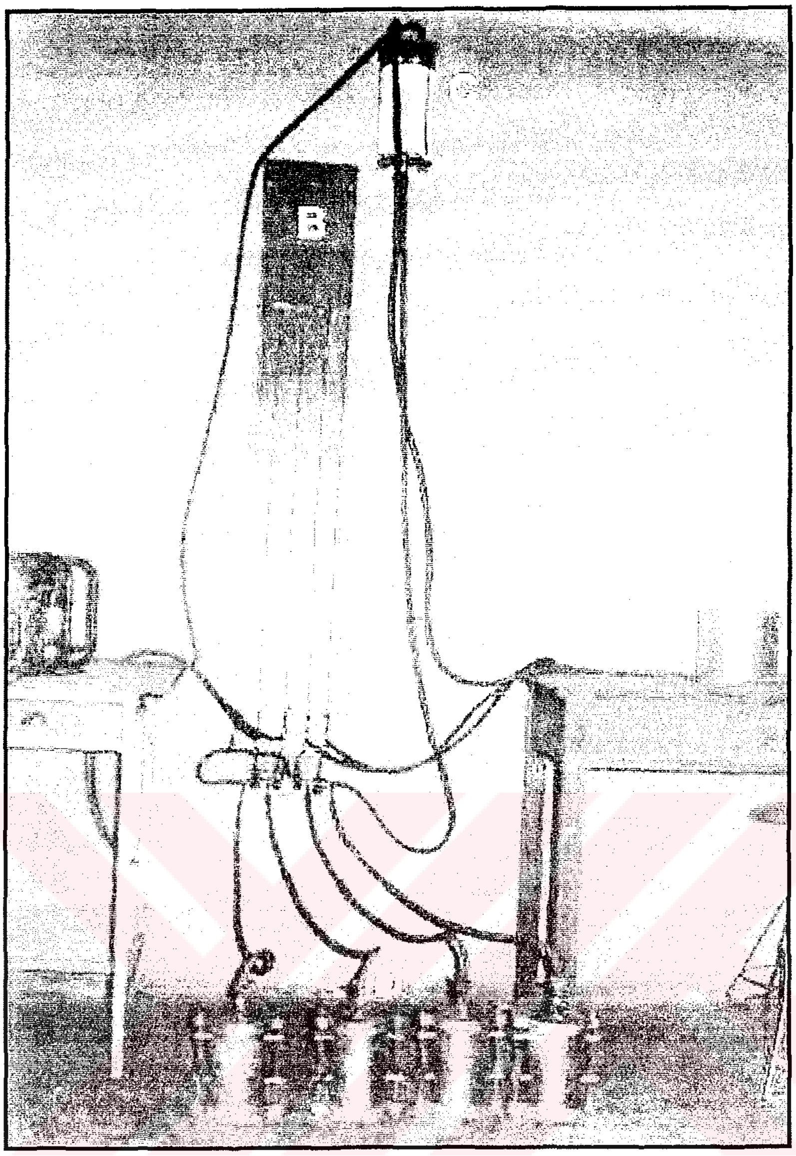

Figure 4.5. Equipment and instrumentation set up for a typical falling head permeability test. A: vacuum pump, B: burette stand, C: deairing tank, D: compaction permeameter, E: valve, and F: distilled water tank.

connected to one of the compaction permeameters by means of water hoses and valves. The evaporation burette was used to compensate for the rate of evaporation in order to correct the permeability values (such as, the amount of evaporation was added to the total head). The testing was performed on fully saturated soil samples. Distilled and deaired water was used as the permeant. Fully saturation can be distinguished from the water outflow coming through the outlets of compaction permeameter. It took 1 to 2 months for each soil sample to be fully saturated depending on its molding water content. Figure 4.6 shows the daily change in hydraulic conductivity for soil sample A, which was fully saturated after 29 days at molding water content of 30.3%.

The results of hydraulic conductivity tests measured at about 2 to 4% wet of optimum are tabulated in Table 4.3.

Table 4.3. Hydraulic conductivity values of soil samples.

Sample number	Hydraulic conductivity (m/s)
A (Karakusunlar)	8.20×10^{-11}
B1 (Gölbaşı)	2.94×10^{-10}
B2 (Gölbaşı)	2.60×10^{-10}
C1 (Sincan)	3.60×10^{-10}
C2 (Sincan)	3.04×10^{-10}
C3 (Sincan)	1.97×10^{-10}

The hydraulic conductivity (k) values were calculated according to ASTM D5856 and Das (1979) by Eq. 4.1:

$$k = \frac{aL}{A\,(t_2 - t_1)} \times \ln\left(\frac{h_1}{h_2}\right) \qquad \text{(Eq. 4.1)}$$

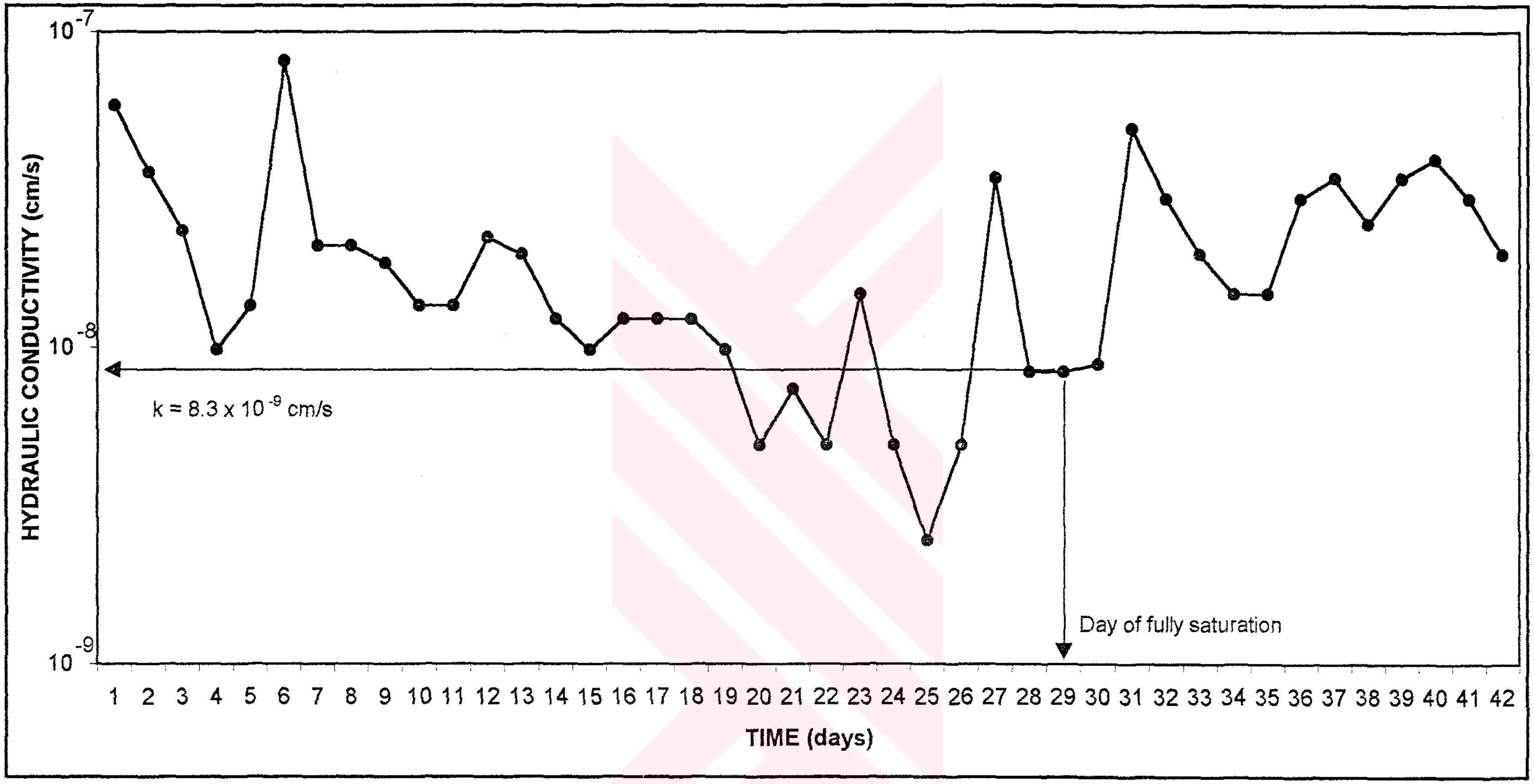

Figure 4.6. Daily change in hydraulic conductivity for soil sample A, at molding water content of 30.3%.

where; a is the inside cross-sectional area of the burette (cm^2), L is the length of the specimen (cm), A is the cross-sectional area of the compacted soil specimen (cm^2), h_1 is the total head (cm) at time t_1, and h_2 is the total head (cm) at time t_2.

4.2. Effects of Engineering Properties and Mineralogy on Hydraulic Conductivity

4.2.1. Engineering Properties:

Hydraulic conductivity values as a function of dry unit weight and molding water content for soil sample A are presented in Figure 4.7. A total of 19 tests have been performed. It is evident that the hydraulic conductivity is sensitive to molding water content, and the minimum hydraulic conductivity of soil sample A occurs approximately at 2% wet of optimum (at about a moisture content of 29%).

This trend is in agreement with that of Lambe (1954), Bjerrum and Huder (1954), Mitchell *et al.* (1965), Garcia-Bengochea *et al.* (1979), Acar and Oliveri (1990), Benson and Daniel (1990), and Daniel and Benson (1990) who observed that compacting clayey soils on the wet side of the line of optimums permits greater remolding of clods, elimination of large interclod voids and preferential re-orientation of clay particles, all of which result in lower hydraulic conductivity.

A relation between the degree of saturation of the compacted soil sample and hydraulic conductivity was also obtained by permeating 49 soil specimens from all three sampling locations at various molding water contents. The degree of saturation is computed from Eq. 4.2:

$$s = \frac{w}{\left(\frac{\gamma_w}{\gamma_d} - \frac{1}{G_s}\right)} \qquad \text{(Eq. 4.2)}$$

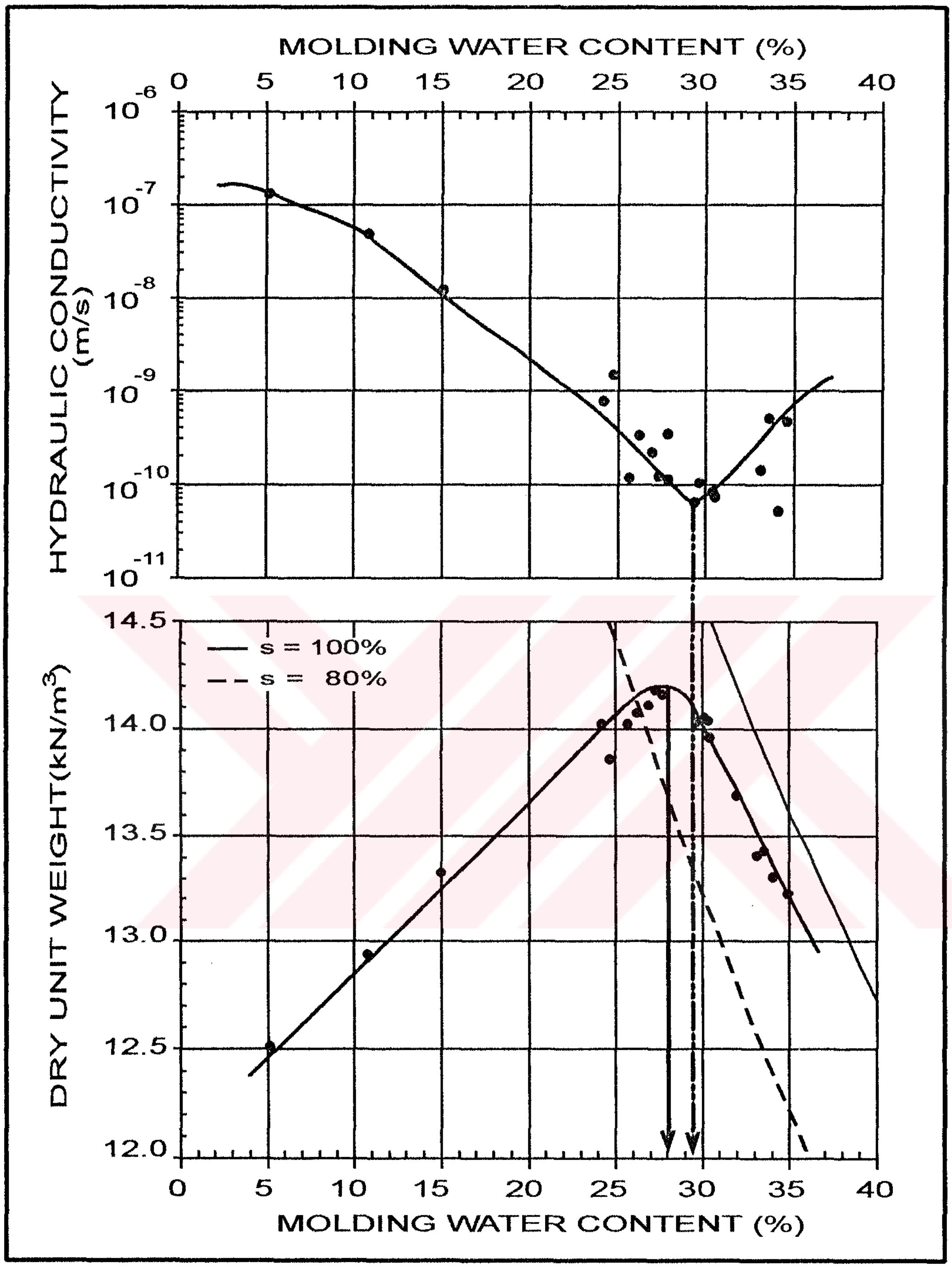

Figure 4.7. Relationship between molding water content (w), dry unit weight (γ_d) and hydraulic conductivity (k) for soil sample A (s: degree of saturation of soil sample).

where; w is the molding water content (%), γ_d is the dry unit weight (kN/m^3), γ_w is the unit weight of water (kN/m^3), and G_s is the specific gravity of solids.

Eq. 4.3 and Figure 4.8 give the best-fit curve and the correlation coefficient (r) for the hydraulic conductivity (k) as a function of the degree of saturation (s):

$$\log(k) = -4 - 2.973 \log(s) \; ; \; r = -0.770 \qquad \text{(Eq. 4.3)}$$

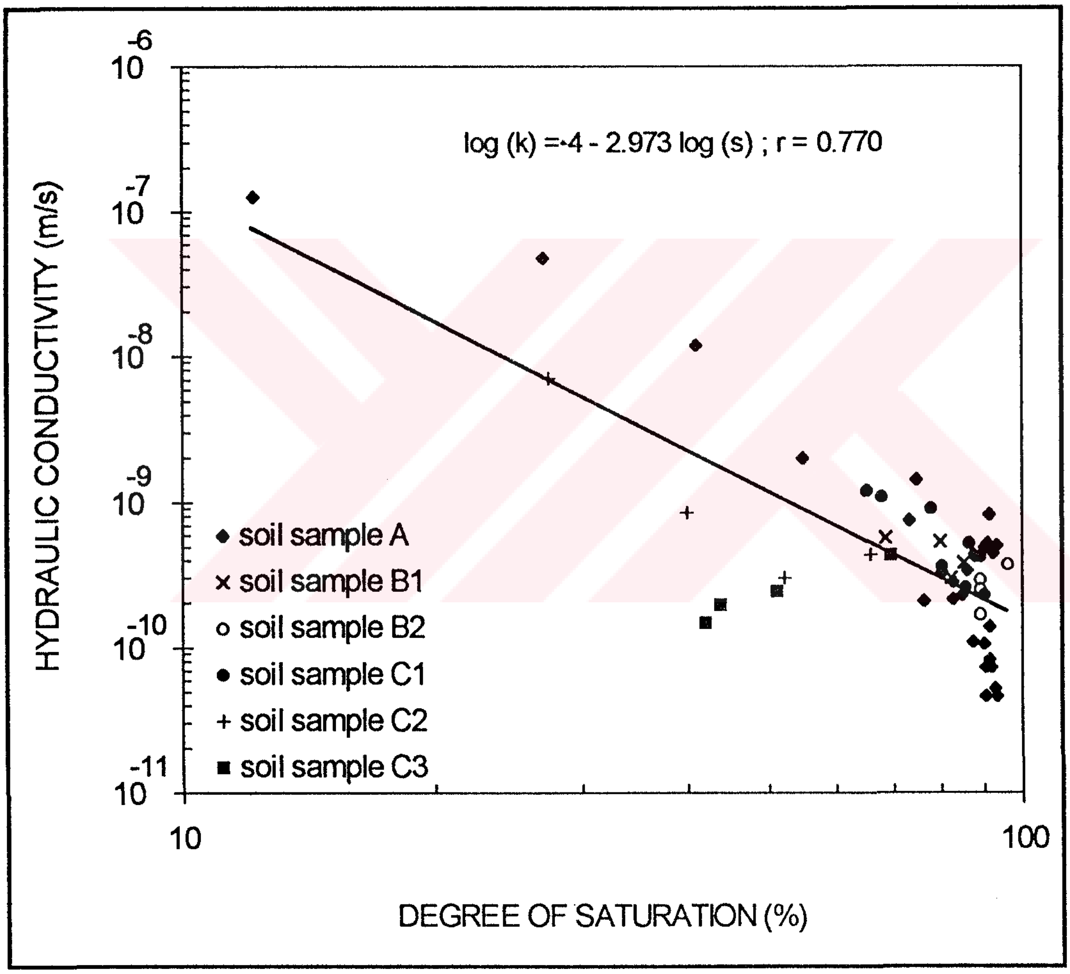

Figure 4.8. Hydraulic conductivity (k) versus degree of saturation (s) for soil samples.

Both Eq. 4.3 and Figure 4.8 show that the hydraulic conductivity decreases with increasing degree of saturation, obeying a power law.

Table 4.3 presents the hydraulic conductivity values of the soil samples obtained from all three sites and compacted 2 to 4 % wet of the optimum. The hydraulic conductivity values of the soil samples range from 3.60 x 10^{-10} to 8.20 x 10^{-11} m/s with an average value in the order of 10^{-10} m/s. Hydraulic conductivity values were plotted against liquid limit and plastic limit of all soil samples. Although hydraulic conductivity generally decreases with increasing plasticity index no meaningful relation between hydraulic conductivity and liquid limit could be obtained (Figures 4.9 and 4.10).

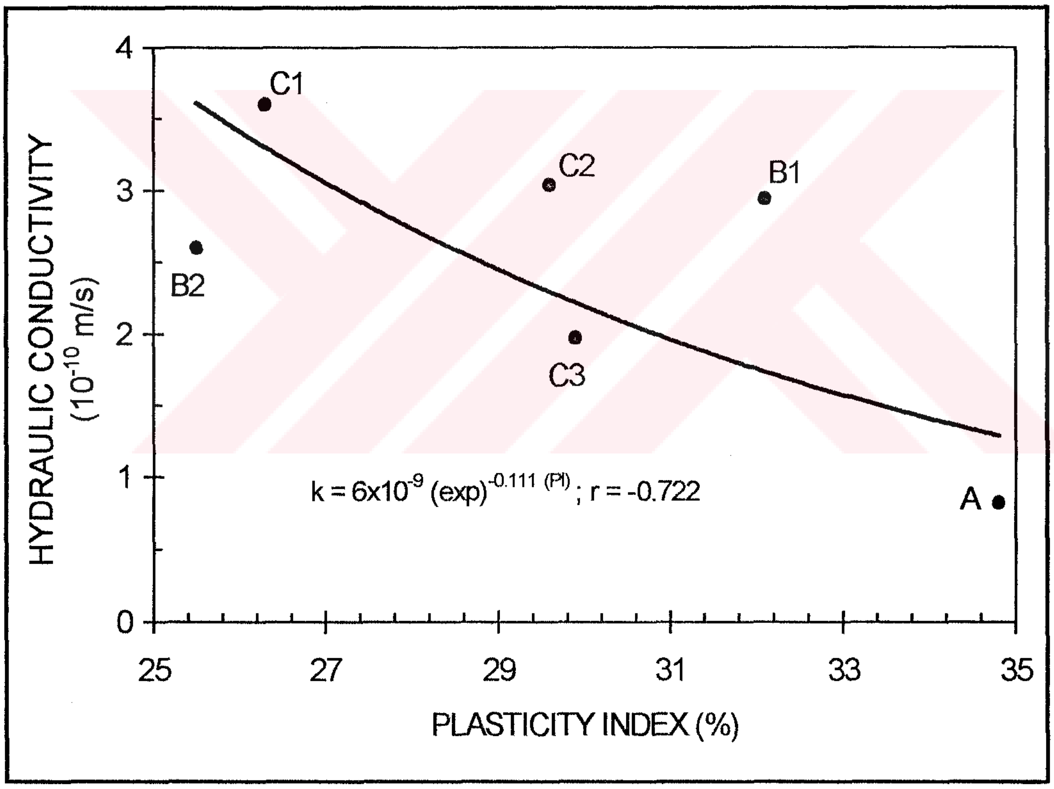

Figure 4.9. Hydraulic conductivity (k) versus plasticity index (PI) for soil samples.

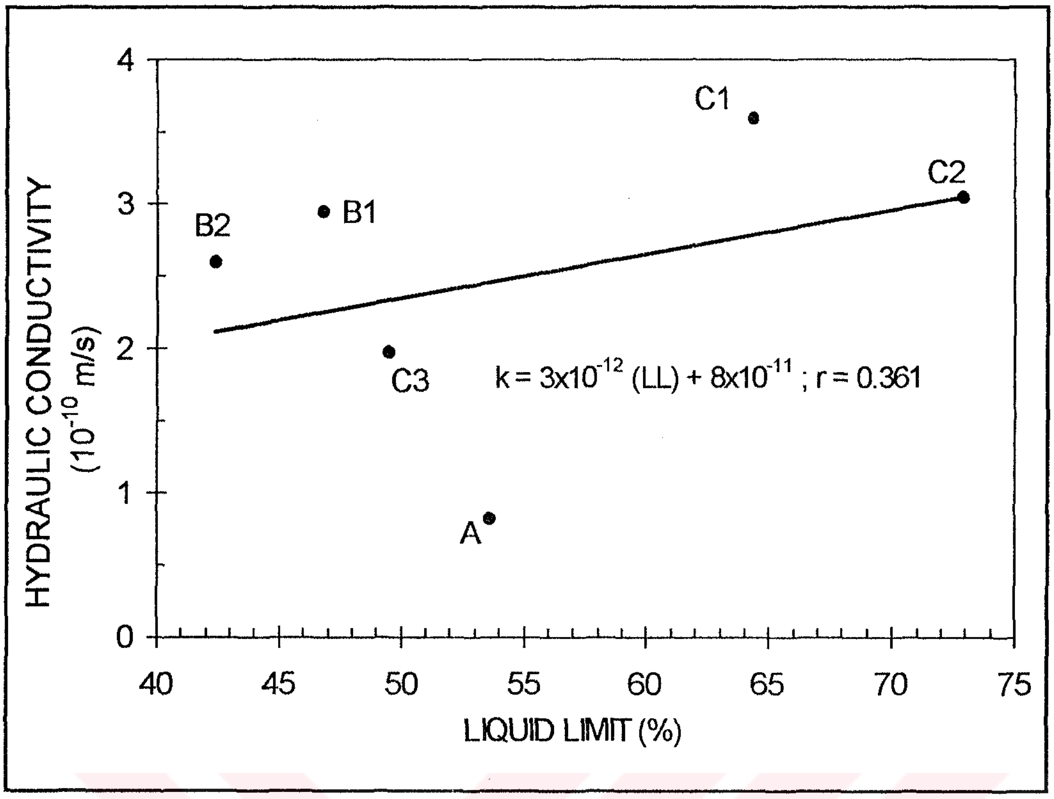

Figure 4.10. Hydraulic conductivity (k) versus liquid limit (LL) for soil samples.

Eqs. 4.4 and 4.5 give the best fit and the correlation coefficient (r) for hydraulic conductivity (k) as a function of plasticity index (PI) and liquid limit (LL), respectively. The data in Tables 4.1 and 4.3 are used to obtain the best fits through performing regression analyses:

$k = 6x10^{-9} (exp)^{-0,111\,(PI)}$; $r = -0.722$ (Eq. 4.4)

$k = 3x10^{-12} (LL) + 8x10^{-11}$; $r = 0.361$ (Eq. 4.5)

The trends shown in Figures 4.8 and 4.9 are similar to those reported by Lambe (1954), Mesri and Olson (1971), D'Appolonia (1980), Daniel (1987), Kenney *et al.* (1992), and Benson *et al.* (1994). Benson *et al.* (1994), for example, observed that increasing plasticity index from 10 to 30 and increasing liquid limit from 20 to 40 lead to a rapid decrease in hydraulic conductivity. Thereafter, the hydraulic conductivity was less sensitive to plasticity index and liquid limit.

Eq. 4.6 and Figure 4.11 show that an increase in clay content (CC) generally leads to a increase in plasticity index (PI), and a decrease in hydraulic conductivity:

$$(PI) = 4.074\,(CC)^{0,498}\ ;\ r = 0.594 \qquad \text{(Eq. 4.6)}$$

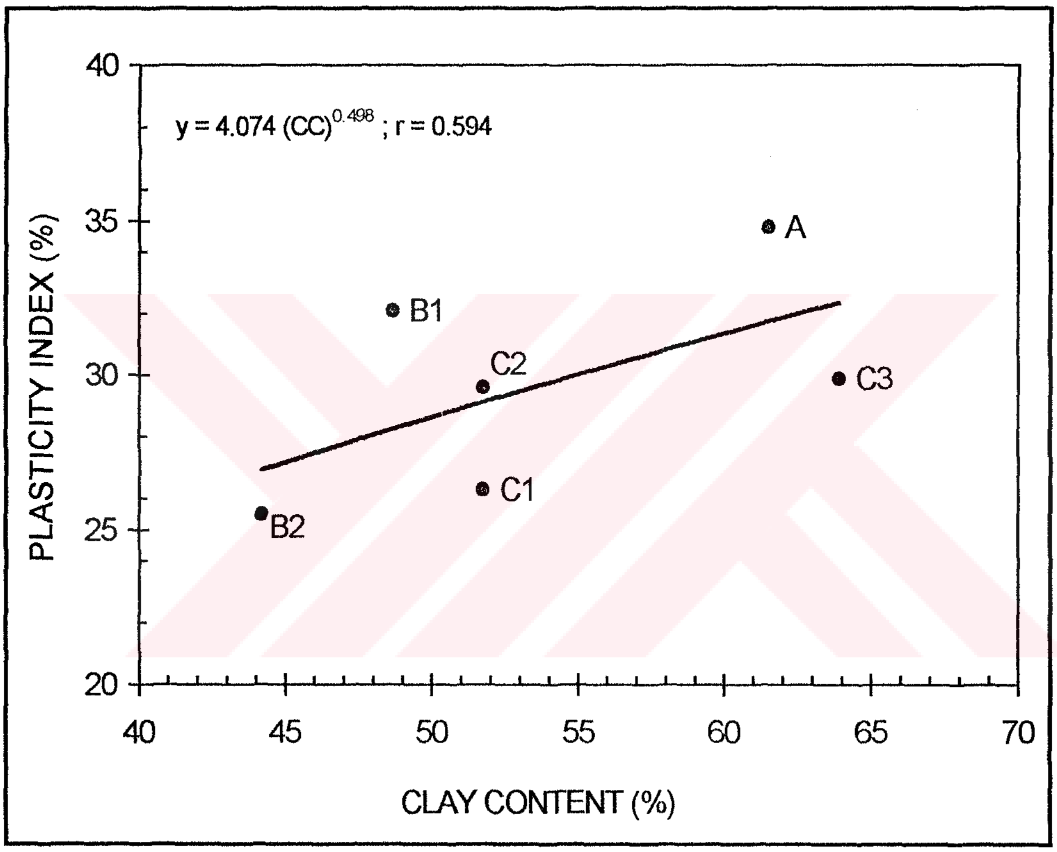

Figure 4.11. Clay content (CC) versus plasticity index (PI) for soil samples.

Figures 4.12 and 4.13 present hydraulic conductivity versus clay content (CC) and percentage of fines (PF), respectively. Definition of percentage of fines and clay content are given by the Unified Soil Classification System (USCS) (Holtz and Kovacs 1981). The hydraulic

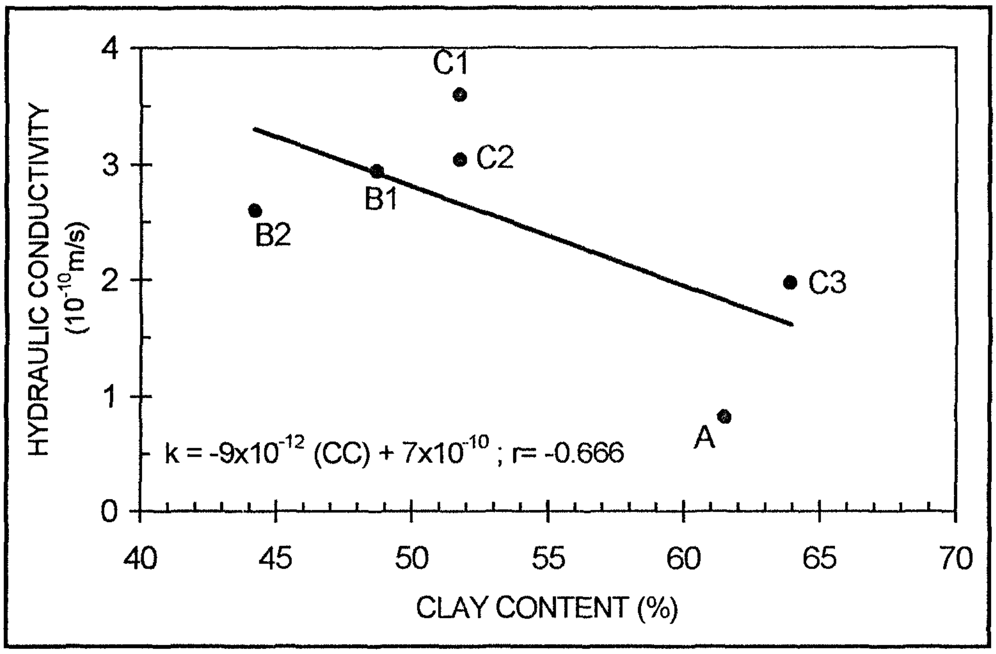

Figure 4.12. Hydraulic conductivity (k) versus clay content (CC) for soil samples.

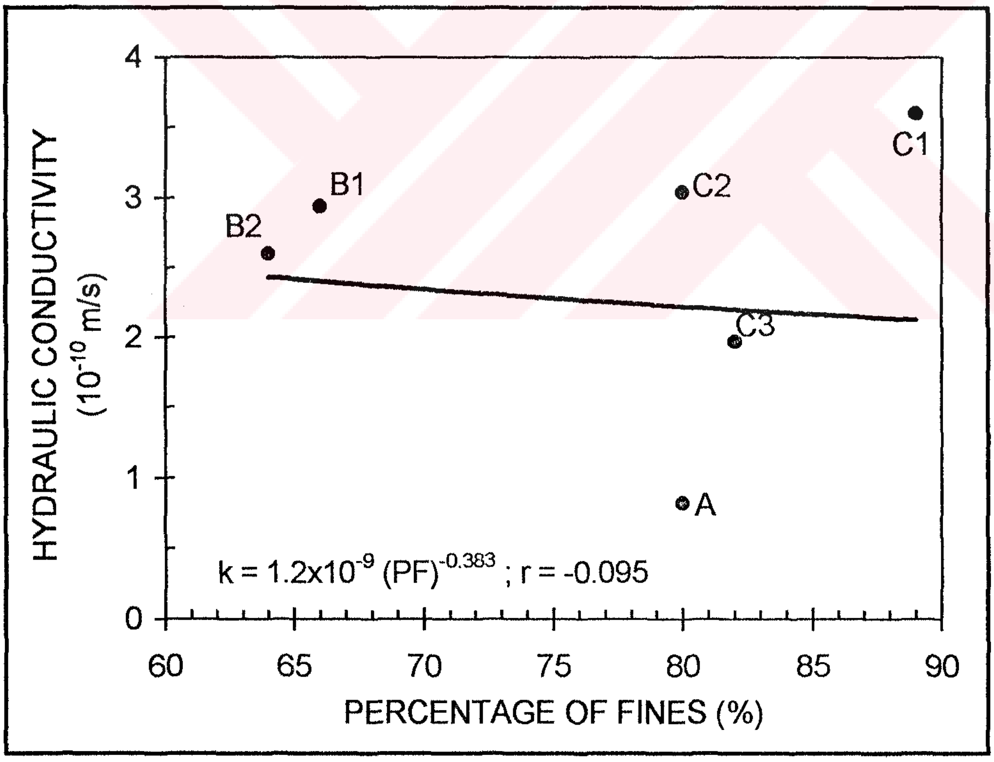

Figure 4.13. Hydraulic conductivity (k) versus percentage of fines (PF) for soil samples.

conductivity (k) decreases with increased clay content (CC) and increased percentage of fines (PF). A similar trend is also reported by Benson *et al.* (1994). Eqs. 4.7 and 4.8 give the regression equations:

$$k = -9\times10^{-12}(CC) + 7\times10^{-10}\ ; \ r = -0.666 \qquad \text{(Eq. 4.7)}$$

$$k = 1.2\times10^{-9}(PF)^{-0{,}383}\ ; \ r = -0.095 \qquad \text{(Eq. 4.8)}$$

As illustrated in Figure 4.13, the percentage of fines for all soil samples are more than 63.8% and it is not possible to suggest any relation between hydraulic conductivity and the percentage of fine, whereas, an inverse relationship is found between hydraulic conductivity and clay content (Figure 4.12). These results are in agreement with the study of Benson *et al.* (1994). According to their studies, they suggested that the pore structure controlling flow in soils containing a large quantity of fines (more than 50% fines) should be affected more by mineralogical composition and less by particle size distribution. The effect of mineralogical composition, therefore, will be investigated in the next section.

4.2.2. Mineralogy

The effect of mineral percentages on the hydraulic conductivity is investigated by the data presented in Table 3.4 and Table 4.3. Since major variation in the clay minerals of the samples occurs between smectite and illite, the tables are used to construct semi log plots of hydraulic conductivity versus smectite-illite ratio (Figure 4.14).

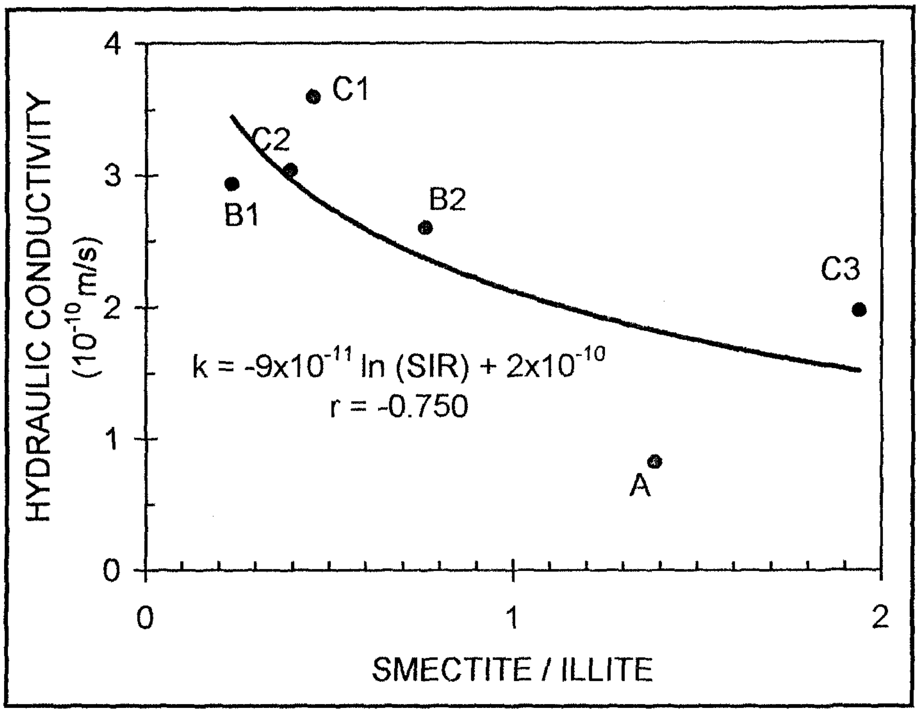

Figure 4.14. Hydraulic conductivity (k) versus smectite-illite ratio (SIR) for soil samples.

From Figure 4.14, it can be observed that the greater smectite content of soil samples A and C3 is partly responsible for their relatively lower hydraulic conductivity values. This result is in agreement with Rowe *et al.* (1995). Since smectites consist of very tiny particles, which produce a specific surface of up to 800 m^2/g, they may have very low hydraulic conductivities ($k \approx 10^{-11}$ to 10^{-15} m/s) even at high void ratios. For this reason they are marketed (like bentonites) for use as additives to sand to make clay liners (or in combination with geotextiles to form geosynthetic clay liners) (Rowe *et al.*, 1995). However greater smectite content of soil samples A and C3 should be taken into consideration in case of usage of these samples as compacted clay liners. Rowe *et al.* (1995) suggested that, as a result of domestic leachate migration through compacted clay liner, if significant K^+ retardation has been observed, c-axis contraction is suspected in smectite rich soils. Hence CEC of soil samples A and C3 should be assessed before and after leachate compatibility testing in order to determine whether these samples are susceptible to K^+ retardation or not. A drop in CEC would certainly signal the possibility of increased hydraulic conductivity values unless consolidation has occurred (Rowe *et al.*, 1995).

As the illite percentage increases in the soil samples, the hydraulic conductivity slightly increases from 8.2×10^{-11} m/s to 3.6×10^{-10} (Figure 4.14). It is well known that illite is efficiently compacted to form clayey soils having a hydraulic conductivity of 10^{-9} to 10^{-11} m/s, depending on the void ratio. It is also known that illite is one of the most desirable clay mineral for use in clay liners for municipal landfill sites since it remains inactive when it comes into contact with leachate (Rowe *et al.*, 1995).

Since kaolinite percentages in the soil samples do not vary, effect of kaolinite itself on hydraulic conductivity could not be observed. In fact, although the double layers around kaolinite may be fairly thick, this mineral is generally very inactive, has little adsorptive capacity and a hydraulic conductivity that is rarely less than 10^{-8} m/s, unless very pure and fine-grained (Lambe and Martin, 1955).

The chlorite percentage in the samples varies from only 1% to 4%. Hence it is not possible to make any comment on the effect of chlorite on hydraulic conductivity. However, it is widely accepted that chlorite is often favored as an effective, nonreactive barrier clay for municipal solid wastes (Rowe *et al.*, 1995).

The regression equations in Section 4.2 are presented to observe whether the relation between hydraulic conductivity and each engineering parameter shows increasing or decreasing trend. The equations can not be used to infer the hydraulic conductivity depending on only one engineering parameter. To obtain such relations advanced statistical thecniques should be used.

CHAPTER 5

DESIGN IMPLICATIONS AND CONSTRUCTION RECOMMENDATIONS

5.1. Design Implications

5.1.1. Leakage through landfill liners

The falling head permeability test results reported in Chapter 3 show that soil samples collected from all three sites in Ankara are suitable for being utilized as compacted clay liners as far as the hydraulic conductivity values are concerned. However, it is necessary to calculate the expected leakage rate through a lining system (for example, clay-only, geomembrane-only or geomembrane/clay composite liner) in order to determine the best system in which one of the six soil samples might be incorporated as a component of the lining system in landfill sites considered in Ankara.

Leakage due to fluid permeation through a clay-only liner can be calculated from Darcy's law as follows:

$$Q_s = k_s \frac{h}{H_s} A \qquad \text{(Eq. 5.1)}$$

where Q_s is the leakage rate through the clay liner (m^3/s); k_s is the hydraulic conductivity of clay (m/s); h is the leachate head acting on top of the liner (m); H_s is the thickness of the clay liner (m); and A is the area of the liner considered (m^2).

The expected leakage rates for geomembrane-only and geomembrane/clay composite liners were calculated using the equations described and presented by Bonaparte *et al.* (1989) and Giroud and Bonaparte (1989a, b).

Bonaparte *et al.* (1989) suggested that the expected leakage rate through holes in a geomembrane-only clay liner can be calculated from Bernoulli's equation for free flow using Eq. 5.2:

$$Q_G=nC_Ba(2gh)^{0.5} \quad \text{(Eq. 5.2)}$$

where Q_G is the expected leakage through holes in a geomembrane (m^3/s); n is the number of holes in the geomembrane; C_B is a dimensionless coefficient depending on the shape of the orifice, assumed to equal to 0.6; a is the area of the hole (m^2); g is the acceleration due to gravity (m/s^2); and h is the leachate head acting on top of liner (m).

For the case of geomembrane/clay composite liner with very good contact (Bonaparte *et al.*, 1989), the expected leakage rate through holes in the geomembrane above the intact clay liner can be empirically expressed by Eq. 5.3:

$$Q_C=0.21na^{0.1}h^{0.9}k_s^{0.74} \quad \text{(Eq. 5.3)}$$

where Q_C is the expected leakage rate through holes in the geomembrane component of a geomembrane/clay composite clay liner (m^3/s); k_s is the hydraulic conductivity of clay (m/s); n, a, and h are the parameters described in Eq. 5.2.

For the sake of comparison of the expected leakage rates through clay-only, geomembrane only, and geomembrane/clay composite liners, a frequency of ten holes per hectare (10,000 m^2) is assumed. The diameter of the holes is assumed to be equal to the thickness of the geomembrane, which is taken as 2 mm. To determine the unitized leakage rate, the area is taken as 10,000 m^2.

As suggested by the Turkish regulatory (Resmi Gazete, 1991), the thickness of the clay liner is taken as 0.6 m. All of the possible lining systems described above for municipal landfill sites are subjected to leachate heads of 1 m, 0.1 m, and 0.01 m to determine the unitized expected leakage rates. These heads cover the spectrum of likely possibilities above the clay liner in a landfill with different leachate collection layer configurations (Akgün, 1997). The hydraulic conductivity of the clay liner is taken to be 10^{-10} m/s, which represents an average value from the three sites considered.

The calculated unitized expected leakage rates through the liners are tabulated in Table 5.1. Results show that the calculated utilized leakage rates through clay-only or geomembrane-only liners can be reduced by two to four orders of magnitude by the use of a composite liner. Hence, the best performance is obtained with a geomembrane/clay composite liner system under all plausible leachate heads (such as, 1 m, 0.1 m, and 0.01 m) considered.

Table 5.1. Unitized expected leakage rates (q; $m^3/s/10,000\ m^2$)

Liner type	Liner thickness (m)	Leachate head (m)		
		0.01	0.1	1
Clay-only (Eq. 5.1)	0.600	1.67×10^{-8}	1.67×10^{-7}	1.67×10^{-6}
Geomembrane-only (Eq. 5.2)	0.002	8.35×10^{-6}	2.64×10^{-5}	8.35×10^{-5}
Geomembrane/ clay composite (Eq. 5.3)	0.602	3.73×10^{-10}	2.96×10^{-9}	2.35×10^{-8}

5.1.2. Design of a landfill profile by the HELP Model

In this section, landfill profiles are designed to simulate liquid movement through sanitary landfills. For this purpose, the Hydrologic Evaluation of Landfill Performance (HELP) model is used. This model was developed to help landfill designers and evaluators to estimate the magnitude of water-balance components and the height of the water-saturated soil above barrier soil layers (Schroeder *et al.*, 1984a, b). The HELP model computes sequential daily runoff, evapotranspiration, percolation, and lateral drainage from landfills to obtain daily, monthly, and annual water balances. The hydrologic considerations include precipitation of any form, such as, surface evaporation, runoff, snowmelt, infiltration, vegetation, rooting depth, plant transpiration, and soil evaporation. The program handles each of these considerations, often in a simplified manner, to estimate runoff, evapotranspiration, vertical drainage to liners, percolation through liners, and lateral drainage from layers above liners. The user should provide soil, design and weather data as inputs to the HELP model. Brief explanations of each data set are given in the following sections.

5.1.2.1. Data description

5.1.2.1.1. Soil and design data

Three different landfill profiles were created and evaluated. A geomembrane/clay composite lining system was used in all profiles to contain the waste since it was demonstrated in Section 5.1 that such a lining system shows the best performance when compared to a clay-only or geomembrane-only liner. The hydraulic conductivity of the compacted clay was taken to be 10^{-10} m/s. The landfill area was taken as 1 hectare (10,000 m^2) and the thicknesses of the top soil, compacted clay liner, waste, and geomembrane liner were selected as 1 m, 0.6 m, 7.5 m, and 0.002 m, respectively. Table 5.2 gives a tabulation of the required layer parameters for the HELP model. Except for the barrier soil layer (compacted clay liner), the porosity and hydraulic conductivity values of the other layers were provided from the HELP model.

Figure 5.1 represents a sketch for the first landfill profile considered. This profile is made up of three subprofiles containing a total of four layers in the following order. From top to bottom; one layer (topsoil) in the top subprofile, one layer (waste) in the second subprofile, and two layers (geomembrane liner and compacted clay liner forming a composite lining system) in the bottom subprofile.

The second profile considered contains five layers (Figure 5.2). While the middle and bottom subprofile configurations are same as the first profile, two layers (topsoil and compacted clay liner) are added to the top subprofile.

Table 5.2. Layer parameters used in three profiles (Figures 5.1, 5.2, and 5.3, show the profiles considered).

Layer type	Thickness (m)	Porosity (vol/vol)	Hydraulic conductivity (m/s)
Vertical percolation layer (top soil)	1	0.475	1.7×10^{-7}
Lateral drainage layer (sand)	0.3	0.457	1.0×10^{-5}
Geomembrane liner	0.002	0.000	4.0×10^{-15}
Barrier soil layer (compacted clay liner)	0.6	0.462	1×10^{-10}
Vertical percolation layer (waste)	7.5	0.671	1.0×10^{-5}
Lateral drainage net	0.005	0.850	1×10^{-1}

The third profile considered contains seven layers (Figure 5.3). In this profile, the top subprofile contains topsoil and compacted clay liners. The middle one contains the waste and the drainage system (such as, lateral drainage layer, and lateral drainage net) for leachate collection, while the bottom subprofile is same as the other first two profiles. This profile was created to satisfy the minimum requirements for the middle and bottom subprofiles suggested by Resmi Gazete (1991).

Since there is no requirement for a cap cover configuration in Resmi Gazete (1991), all of three profiles were created to present suitable configurations for the cap cover system. The effect of topsoil within the

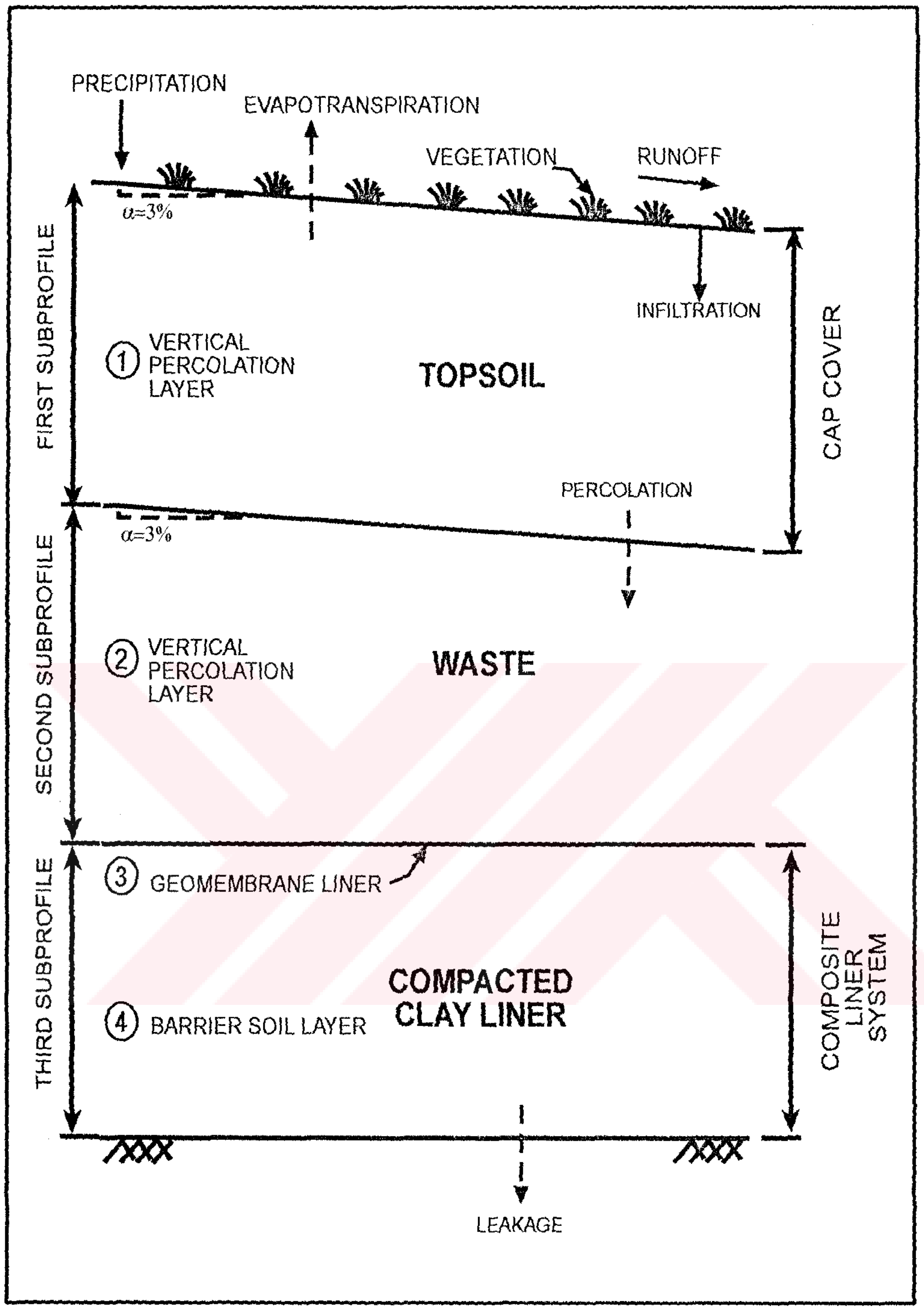

Figure 5.1. Sketch of Profile No.1.(Table 5.2 gives layer parameters)

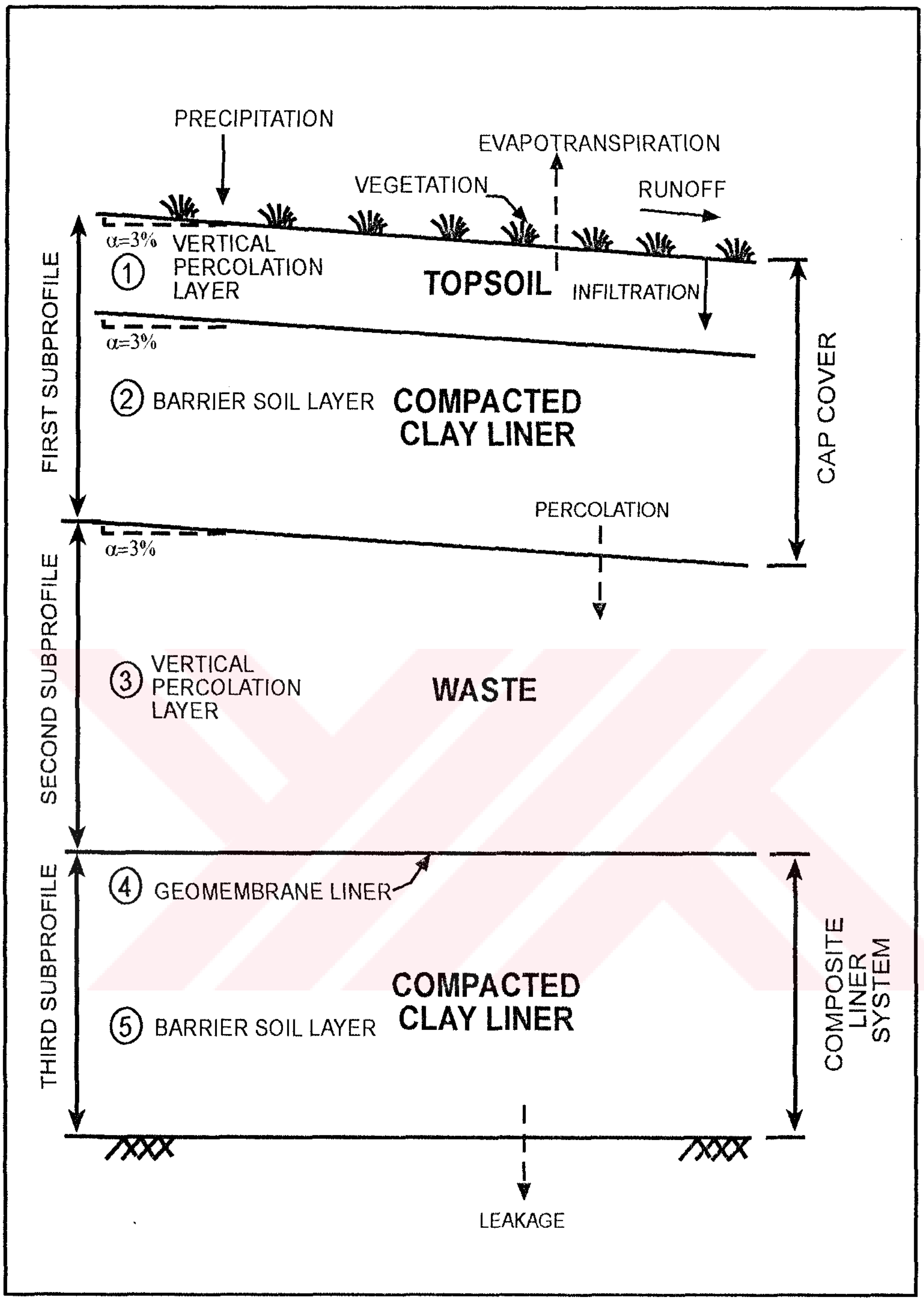

Figure 5.2. Sketch of Profile No.2. (Table 5.2 gives layer parameters)

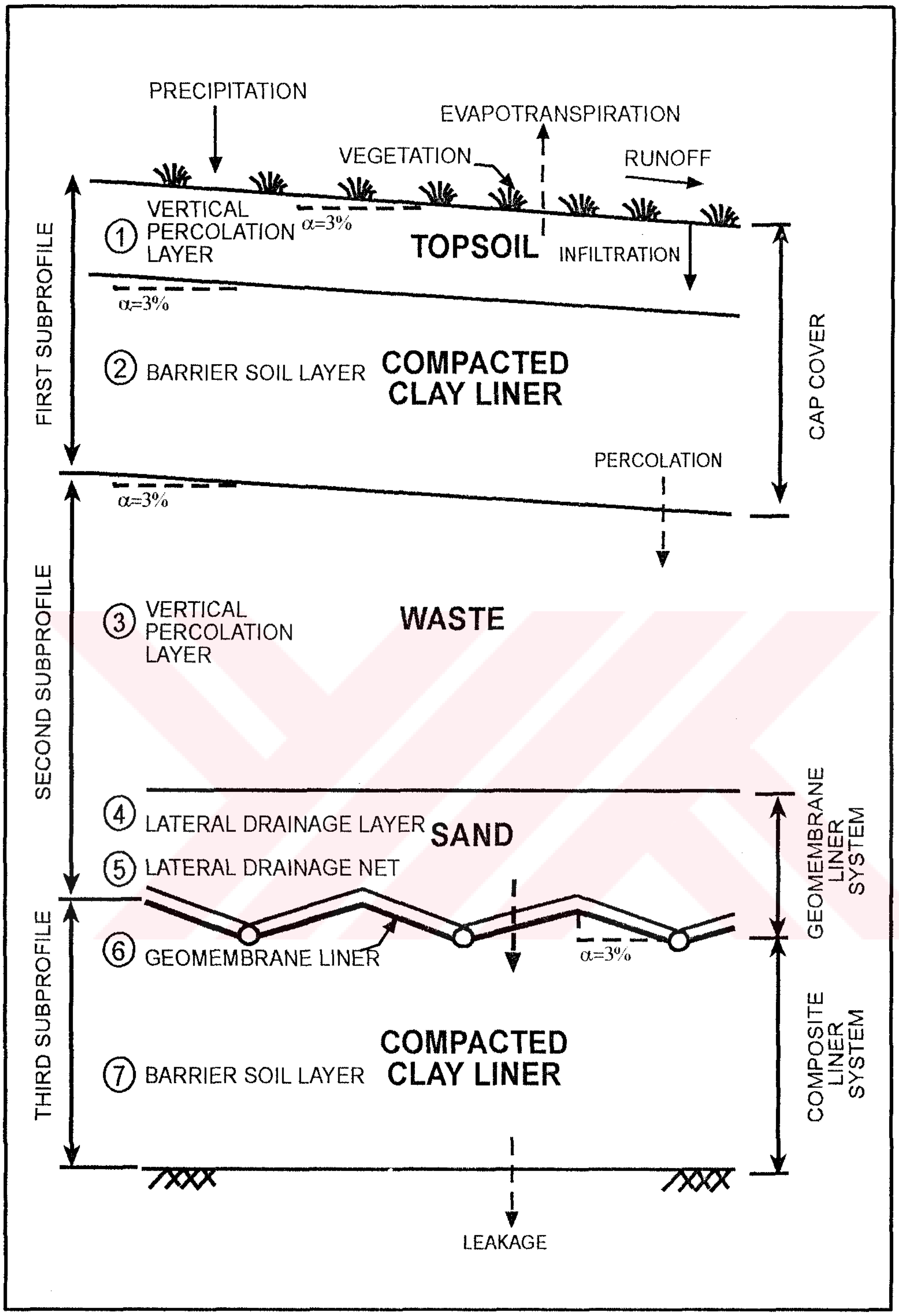

Figure 5.3. Sketch of Profile No.3.(Table 5.2 gives layer parameters.)

cap cover was investigated in the first profile. The cap cover was improved by adding a compacted clay liner to the top subprofiles in Profiles No.2 and No.3.

5.1.2.1.2. Weather data

The weather data required by the HELP model are classified into three groups: evapotranspiration, precipitation, and temperature data.

Evapotranspiration data is composed of evaporative zone depth, maximum leaf area index, dates starting and ending the growing season, normal average annual wind speed and normal average quarterly relative humidity. The evaporative zone depth is the maximum depth from which water may be removed by evapotranspiration. This value was taken as 0.91 m, as suggested by Schroeder *et al.* (1994) for clayey topsoils. Maximum leaf area index (LAI) is defined as the dimensionless ratio of the leaf area of actively transpiring vegetation to the nominal surface area of the land on which the vegetation is growing. In this study, LAI was taken as 2.0 assuming presence of a fair stand of grass on the topsoil. The rest of the evapotranspiration data for Ankara were provided by General Directorate of State Meteorological Works.

The precipitation and temperature data of Ankara were also provided by General Directorate of State Meteorological Works for the years 1979 through 1998 (Figures 5.4 and 5.5). Cumulative departure curve from average annual totals for Ankara suggest that, the precipitation data contains the wet and dry periods of precipitation (Figure 5.4). In this analysis, it is assumed that the precipitation and temperature distribution between 1979 and 1998 is representative of the next 20 years.

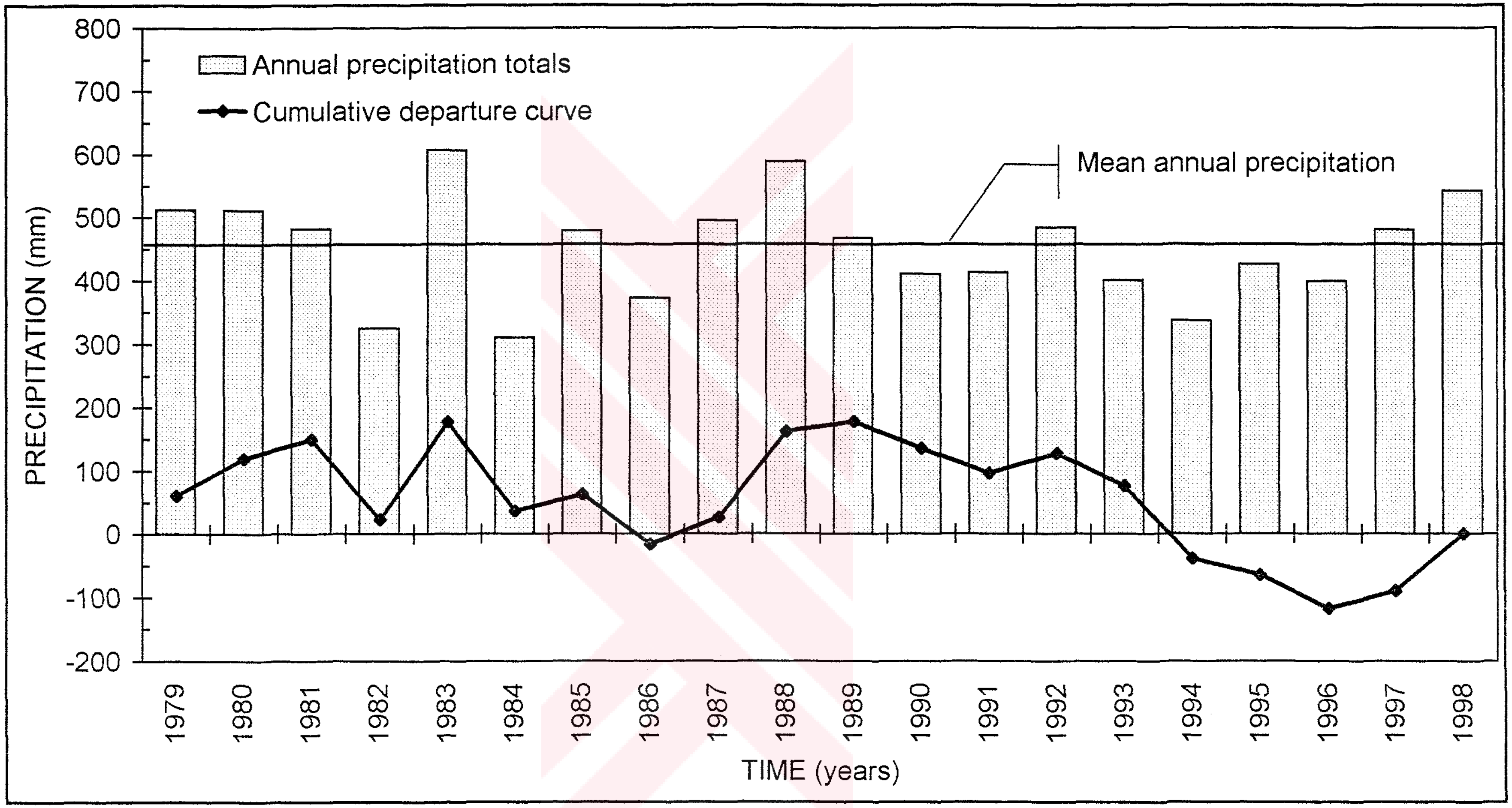

Figure 5.4. Annual precipitation totals for Ankara between 1979 and 1998.

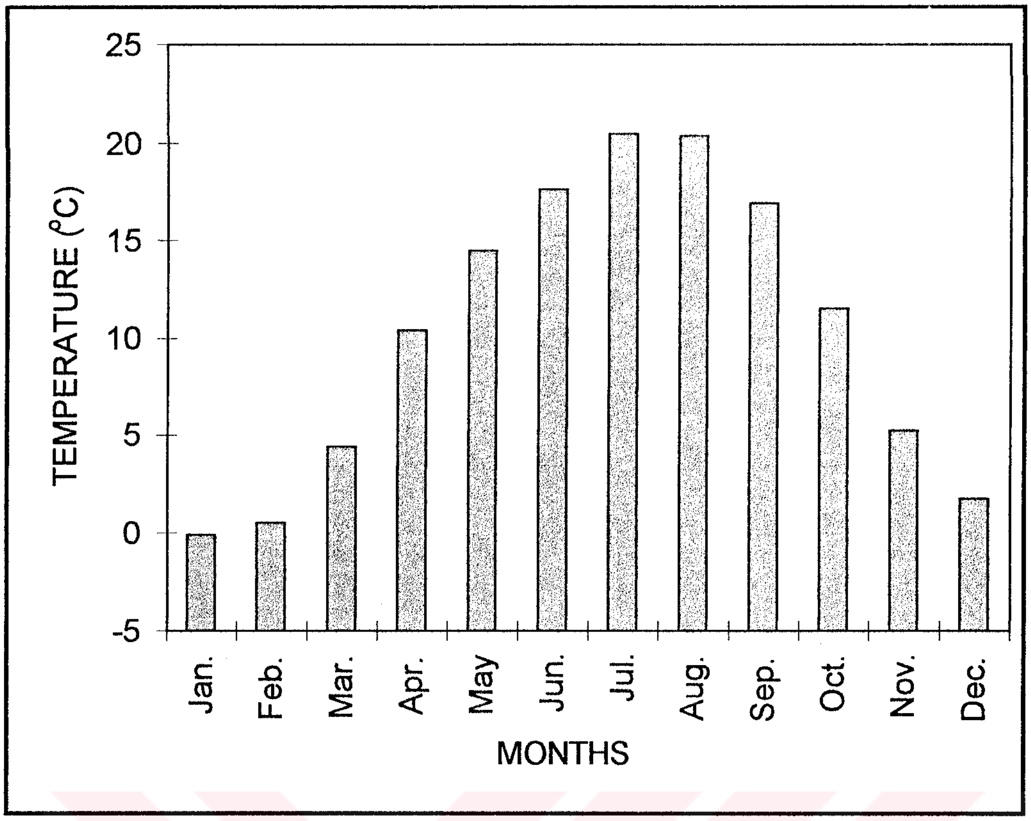

Figure 5.5. Mean monthly temperatures for Ankara between 1979 and 1988.

5.1.2.2. Evaluation of profiles

All the layer, design and weather data were used to evaluate the performance of the clay liner in all three profiles considered for a period of 20 years.

Figures 5.6 and 5.7 give plots of the cumulative expected leakage rate through the bottommost compacted clay liner (CCL) and the cumulative average head acting on the bottom CCL for all three profiles considered. Profile No.1 has the highest expected leakage rate and average head. The expected leakage rate and average heads decrease going from Profiles No.2 to No.3.

From Figures 5.6 and 5.7, an increase in the average head acting on the bottommost CCL leads to a gradual increase in the expected leakage

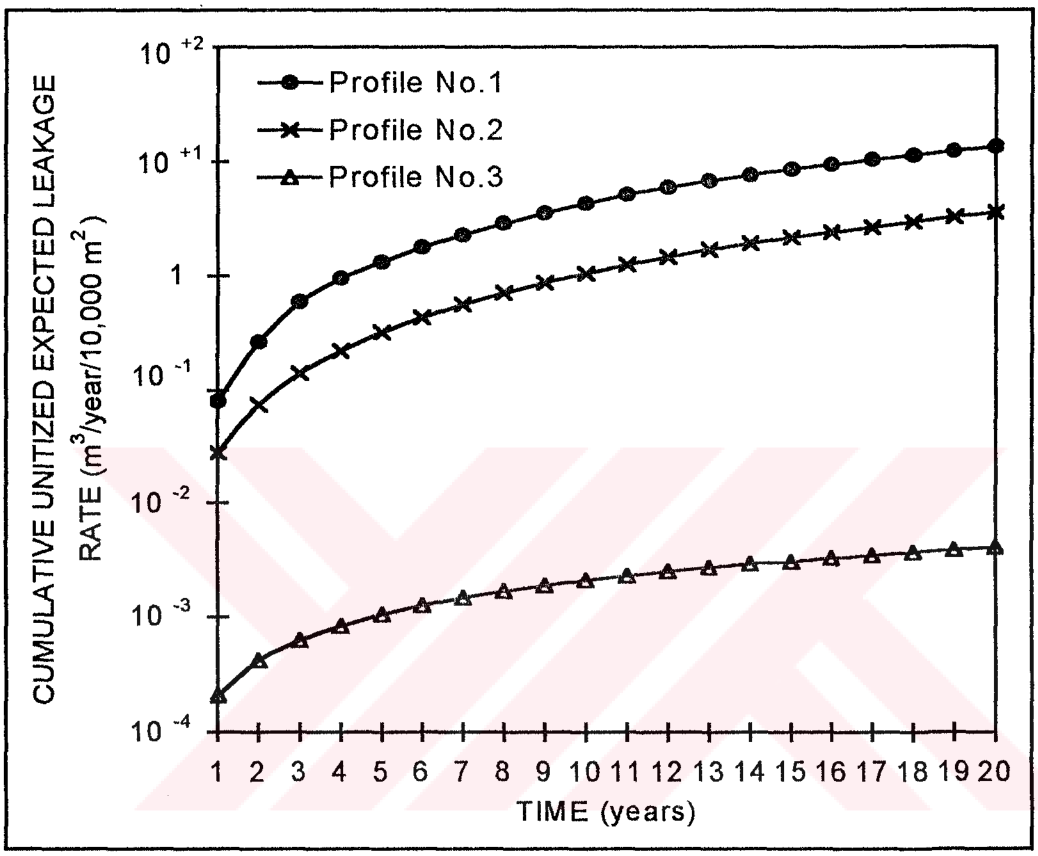

Figure 5.6. Cumulative unitized expected leakage rate through the bottommost CCL versus time for all three profiles considered.

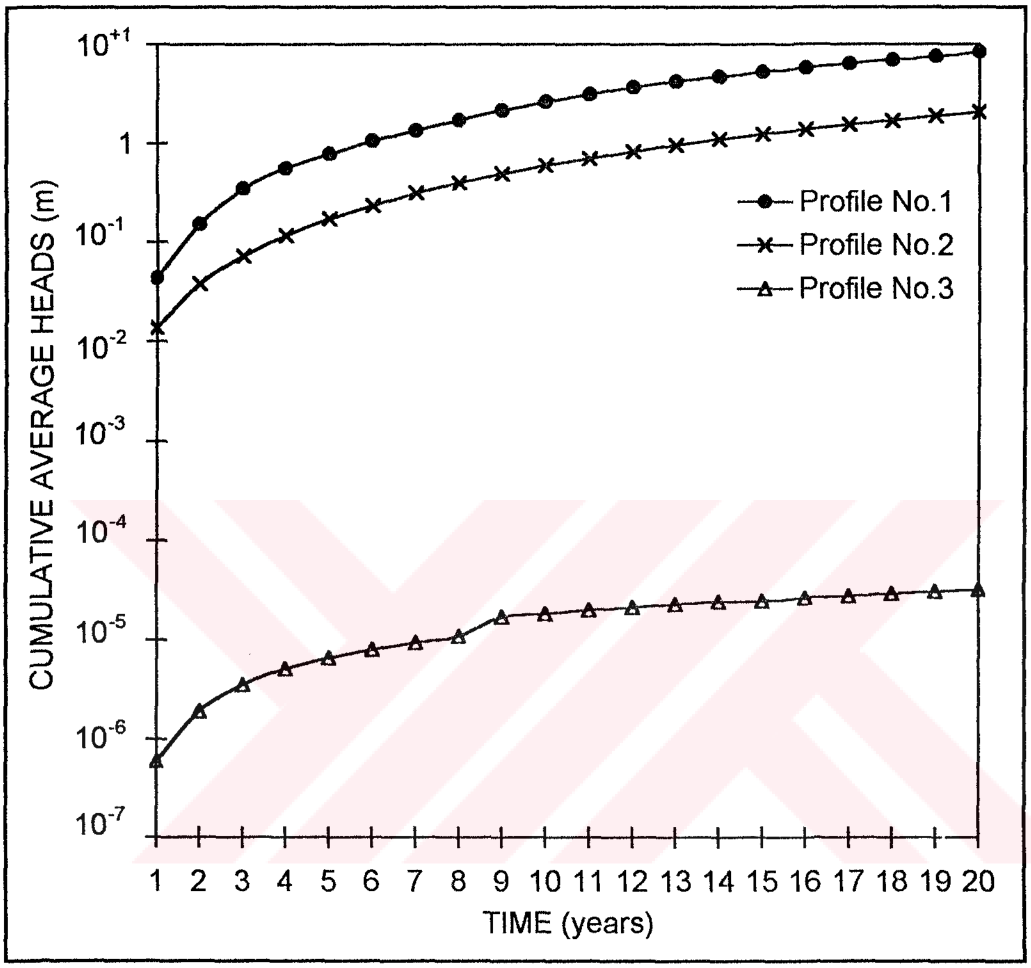

Figure 5.7. Calculated annual totals of average heads acting on top of CCL versus time for all three profiles considered.

leakage rate. Moreover, it can be seen that Profile No.1 and Profile No.2 show the same trend, while Profile No.3 follows a nearly parallel trend with the others, with lower unitized expected leakage rate and the average head values.

The unitized expected leakage rate and the average head for Profile No.1 at the end of 20 years may increase up to 1.18 m^3/year/10,000 m^2 and 0.743 m, respectively. Profile No.2 has initially lower unitized expected leakage rate and average head than Profile No.1 reaching an unitized expected leakage rate and an average head of $3.12x10^{-1}$ m^3/year/10,000 m^2 and 0.185 m, respectively. Therefore, it is evident that the presence of compacted clay liners in cap cover systems leads to better long-term performance of the containment system. The unitized expected leakage rate for Profile No.3 reaches to $2.10x10^{-4}$ m^3/year/10,000 m^2 at the end of 20 years, whereas, for Profile No.2 it is $3.12x10^{-2}$ m^3/year/10,000 m^2. Similarly, the difference between the average heads of Profile No.2 and Profile No.3 at the end of 20 years is approximately six orders of magnitude. This difference results from the utilization of leachate collection layers (layers No.4 and No.5, in Figure 5.3) for Profile No.3. The HELP model outputs for all of three profiles considered are presented in Appendices B1 through B3.

To determine the sensitivity of Profile No.3 to porosity of topsoil layer, porosity was varied from 0.2 to 0.8. As it might be expected, the results in Appendix C show that, the expected leakage rate increases as the porosity increases. It is also expected that, Profile No.3 should not be sensitive to the hydraulic conductivity of the compacted clay liner, since the measured hydraulic conductivity values reported in Chapter 4 are very close to each other. Sensitivity of Profile No.3 to hydraulic conductivity was tested by varying the hydraulic conductivity value of compacted clay liner for each soil sample location at the highest hydraulic conductivity value in the HELP model, and the results are illustrated in Appendix C

5.1.2.3. Accuracy of the HELP model

The accuracy of the expected leakage rate results obtained from the HELP model was checked by using the Water Balance Method. Water Balance Method is the most commonly used method for estimating the leakage rate generated by wastes.

The basic equation in this method is given in Eq. 5.4:

$$I=P-R_o \qquad \text{(Eq. 5.4)}$$

where; I is the infiltration into cover (mm), P is the precipitation (mm), and R_o is the surface runoff (mm). Figure 5.8 illustrates these parameters in a typical sanitary landfill site.

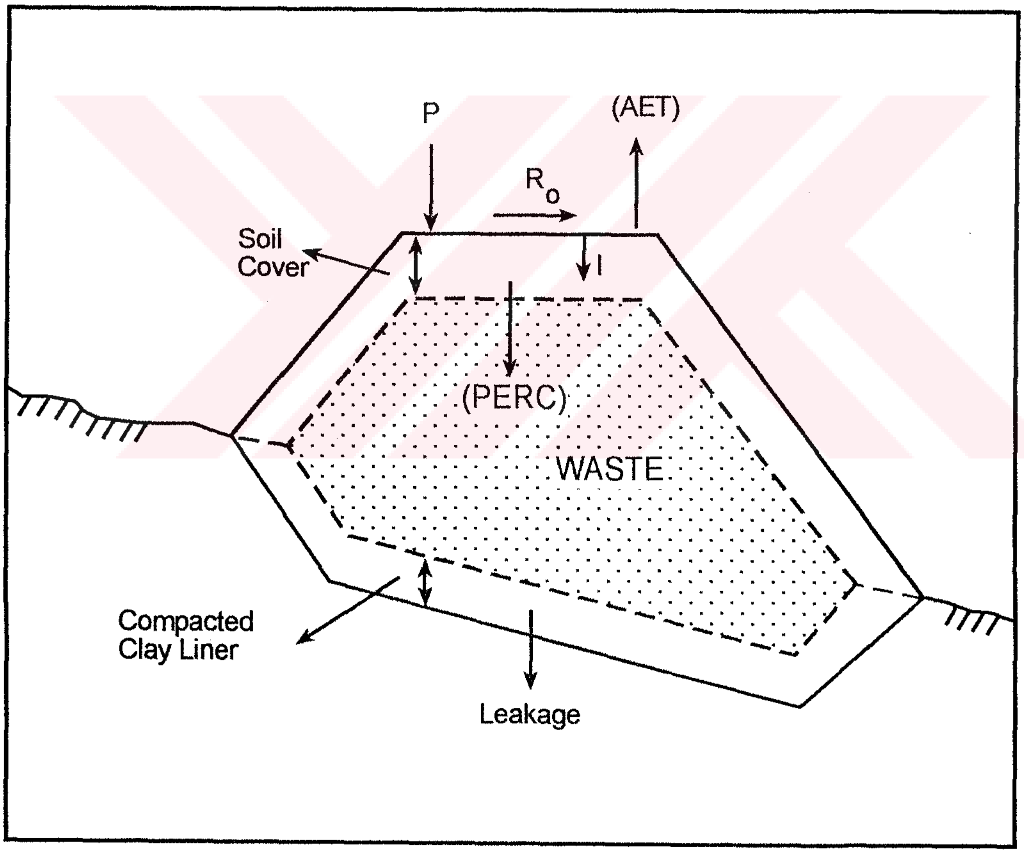

Figure 5.9. Sketch of leachate generation parameters in a sanitary lanfill (After Oweis and Khera,1990). P: Precipitation, I: Infiltration, R_o: Runoff, AET: Evapotranspiration, PERC: Percolation).

Precipitation (P) is estimated based on the average monthly values at the closest meteorological monitoring point(s). Surface runoff (R_o) on the other hand is estimated from an empirical equation, suggested by Lu *et al.* (1985):

$$R_o = C x P \qquad \text{(Eq. 5.5)}$$

where; C is a runoff coefficient that depends on surface vegetation and slope (Table 5.3).

Table 5.3. Runoff coefficients (C; Lu *et al.*, 1985).

Area type	Flat slope <2%	Rolling slope 2-10%	Hilly slope >10%
Grassed	0.25	0.30	0.30
Earth	0.60	0.65	0.70
Cultivated			
(clay)	0.50	0.55	0.60
(loam)	0.25	0.30	0.35

Evapotranspiration (PET) may be computed from the Thornthwaite equation (Rowe, 1996):

$$(PET)=16[10t/(TE)]^{a} \quad (\text{for } t > 0\ ^{o}C) \qquad \text{(Eq. 5.6a)}$$

$$(PET) = 0 \quad (\text{for } t \leq 0\ ^{o}C) \qquad \text{(Eq. 5.6b)}$$

where; PET (mm) is the unadjusted potential evapotranspiration for a standard 12 hour day, t is the mean monthly temperature (^{o}C), (TE) is

$$(TE)=\sum_{i=1}^{12} I_t \quad \text{(Eq. 5.7)}$$

where; I_t is monthly value of heat index and it is computed from Eqs. 5.8a and 5.8b as follows:

$$I_t=(t/5)^{1.514} \quad (\text{for } t > 0\ °C) \quad \text{(Eq. 5.8a)}$$

$$I_t= 0 \quad (\text{for } t \leq 0\ °C) \quad \text{(Eq. 5.8.b)}$$

$$a=0.000000675(TE)^3-0.0000771(TE)^2+0.01792(TE)+0.4923 \quad \text{(Eq. 5.9)}$$

Since PET is standardized for 12 hours of daylight per day, it needs to be adjusted for unequal day and night duruations. Adjusted evapotranspiration (AdjPET; mm) is obtained by Eq. 5.10:

$$(AdjPET)=(AdjFAC)x(PET) \quad \text{(Eq. 5.10)}$$

where; (AdjFAC) is the adjustment factor for potential evapotranpiration. Table 5.4 gives a tabulation of (AdjFAC) values (Rowe, 1996).

The actual loss due to evapotranspiration (AET; mm) is given by (Oweis and Khera, 1990):

$$(AET)= (AdjPET) \ (\text{for wet months}) \quad \text{(Eq. 5.11a)}$$

$$(AET)=I-dS_T \quad (\text{for dry months}) \quad \text{(Eq. 5.11b)}$$

The portion of the infiltration that will percolate into the landfill is then calculated by:

$$(PERC)=I-(AET)-dS_T \quad \text{for } dS_T \geq 0 \quad \text{(Eq. 5.12a)}$$

$$(PERC)=0 \quad \text{for } dS_T<0 \quad \text{(Eq. 5.12b)}$$

Table 5.4. Adjustment factors (AdjFAC) for potential evapotranspiration (PET) (Rowe, 1996).

Latitude	Jan.	Feb.	Mar.	Apr.	May.	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
0	1.04	0.94	1.04	1.01	1.04	1.01	1.04	1.04	1.01	1.04	1.01	1.04
10	1.00	0.91	1.03	1.03	1.08	1.06	1.08	1.07	1.02	1.02	0.98	0.99
20	0.95	0.90	1.03	1.05	1.13	1.11	1.14	1.11	1.02	1.00	0.93	0.94
30	0.90	0.87	1.03	1.08	1.18	1.17	1.20	1.14	1.03	0.98	0.89	0.88
35	0.87	0.85	1.03	1.09	1.21	1.21	1.23	1.16	1.03	0.97	0.86	0.85
40	0.84	0.83	1.03	1.11	1.24	1.25	1.27	1.18	1.04	0.96	0.83	0.81
45	0.80	0.81	1.02	1.13	1.28	1.29	1.31	1.21	1.04	0.94	0.79	0.75
50	0.74	0.78	1.02	1.15	1.33	1.36	1.37	1.25	1.06	0.92	0.76	0.70

where; (PERC) is the percolation amount and (AET) is the evapotranspiration, which depends on the adjusted potential evapotranspiration (AdjPET) and the change in moisture storage in the cover (dS_t).

Table 5.5 gives an example calculation of percolation through a 1 m thick vertical percolation layer of the cap cover system (Figures 5.1 to 5.3) using the Water Balance Method. The annual percolation amount (PERC), is calculated to be equal to 135.27 mm, which is about 6% less than calculated using the HELP model. The HELP model output for this particular problem is presented in Appendix B4.

Peyton and Schroeder (1988) performed long-term simulations ranging between a periods of 1 to 8 years at 17 landfill cells in six different sites in the United States using the HELP model. They correlated the field data from landfill sites with the results computed by the HELP model. In their studies, the HELP model overestimated the runoff by about 25% and underestimated evapotranspiration by approximately 10%. Hence, a 6% difference obtained between the water balance method and the HELP models suggest that computations made by the HELP model are within tolerable limits and that the HELP model leads to accurate results for the three profiles considered herein.

5.1.2.4. Limits of application

The modeling procedures in the HELP model are based on many simplifying assumptions. Generally, these assumptions are reasonable and consistent with the objective of the program when applied to standard landfill design. The major assumptions and limitations of the program are summarized below:

The HELP program assumes Darcian flow for vertical drainage through homogenous soil and waste layers. It does not consider preferential flow through channels such as cracks, root holes or animal

Table 5.5. Determination of percolation through 1 m thick vertical percolation layer of the cap cover system using Water Balance Method (After Owesis and Khera, 1990).

Parameters	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total
Temperature (^oC)	-0.40	0.00	5.80	12.20	17.00	22.10	24.90	23.90	19.70	13.20	8.50	1.30	
I_t	0.00	0.00	1.25	3.86	6.38	9.49	11.37	10.68	7.97	4.35	2.23	0.13	57.71
(PET) (Eq. 5.6)	0.00	0.00	16.11	45.62	72.57	104.77	123.80	116.90	89.20	50.93	27.51	1.99	649.41
(AdjFAC) (Table 5.4)	0.84	0.83	1.03	1.11	1.24	1.25	1.27	1.18	1.04	0.96	0.83	0.81	
(AdjPET) (Eq. 5.10)	0.00	0.00	16.60	50.63	89.99	130.96	157.23	137.95	92.77	48.90	22.83	1.61	749.47
P (mm)	74.93	54.36	124.71	70.36	81.53	112.52	52.83	97.28	118.87	49.02	20.57	102.62	959.60
C (Table 5.3)	0.55	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	
R_o (mm) (Eq. 5.5)	41.21	16.31	37.41	21.11	24.46	33.76	15.85	29.18	35.66	14.71	6.17	30.79	306.61
I (Eq. 5.4)	33.72	38.05	87.30	49.25	57.07	78.76	36.98	68.10	83.21	34.31	14.40	71.83	652.99
I-(AdjPET)	33.72	38.05	70.70	-1.38	-32.92	-52.20	-120.25	-69.85	-9.56	-14.58	-8.43	70.22	-96.48
ΣNEG(I-(AdjPET))			0.00	-1.38	-34.30	-86.50	-206.75	-276.60	-286.16	-300.74	-309.17		
S_t (Table 5.6)	113.00	113.00	113.00	111.62	83.56	51.75	18.06	9.87	9.11	8.00	7.45	84.87	
dS_t	0.00	0.00	0.00	-1.38	-28.06	-31.81	-33.69	-8.19	-0.76	-1.11	-0.55	77.42	
(AET) (mm) (Eq. 5.11a & b)	0.00	0.00	16.60	50.63	85.13	110.57	70.67	76.29	83.97	35.42	14.95	1.61	545.85
(PERC) (mm) (Eq. 5.12a & b)	33.72	38.05	70.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-7.20	135.27

Table 5.6. Soil moisture retention after potential evapotranspiration has occurred (Oweis and Khera, 1990).

	S_T(mm)**					
ΣNEG(I-PET)*	25	50	75	100	125	150
0	25	50	75	100	125	150
10	16	41	65	90	115	140
20	10	33	57	81	106	131
30	7	27	50	74	98	122
40	4	21	43	66	90	114
50	3	17	38	60	83	107
60	2	14	33	54	76	100
70	1	11	28	49	70	93
80	1	9	25	44	65	87
90	1	7	22	40	60	82
100		6	19	36	55	76
150		2	10	22	37	54
200		1	5	13	24	39
250			2	8	16	28
300			1	5	11	20
350			1	3	7	14
400				2	5	10
450				1	3	7
500				1	2	5
600					1	3
700						1
800						1

*NEG(I*PET) is lack of infiltration water needed for vegetation.
**S_T, soil moisture storage at field capacity.

burrows. As such, the program will tend to overestimate the storage of water during the early part of the simulation and overestimate the time required for the leachate to be generated. The effects of these limitations can be minimized by specifying a larger effective saturated hydraulic conductivity and smaller field capacity.

The HELP model assumes that the condition of the landfill, soil properties, thicknesses, geomembrane hole density, maximum level of vegetation etc. are constant throughout the simulation period.

5.2. Construction Requirements

5.2.1. Compaction requirements

The objective of compaction is to remold chunks (clods) of soil into a homogenous mass that is free of large, continuous, interclod voids. If this objective is accomplished with suitable soil materials, low hydraulic conductivity values ($<1x10^{-9}$ m/s) will be obtained.

As suggested in Chapter 3, the water content of the soil, method of compaction, and compactive effort have a major influence on the hydraulic conductivity of compacted clay liners. Laboratory studies in Chapter 3 show that low hydraulic conductivity is achieved when the soil is compacted at 2 to 4% wet of the optimum water content. The soil must be sufficiently wet that, upon compaction, clods of clayey soil could mold together, eliminating larger inter-clod pores.

The minimum requirements to achieve a suitably low hydraulic conductivity, generally less than $1x10^{-9}$ m/s, for clay liners are presented in Chapter 1. All soil samples tested in this study satisfy these minimum requirements with Soil A giving the lowest hydraulic conductivity (Table 5.7).

Table 5.7. Results of index tests of disturbed soil samples and minimum requirements for clay liners. (LL: percent liquid limit, PI: percent plasticity index, and NS: not suggested by the researcher).

Sample Number	LL (%)	PI (%)	Particle size distribution		
and location			% Gravel	% Fines	% Clay
A (Karakusunlar)	53.6	34.8	4.2	79.9	61.5
B1 (Gölbaşı)	46.8	32.1	11.0	66.1	48.7
B2 (Gölbaşı)	42.4	25.5	11.0	63.8	44.2
C1 (Sincan)	64.4	26.3	2.14	89.0	51.8
C2 (Sincan)	72.9	29.6	1.4	80.2	51.8
C3 (Sincan)	49.5	29.9	0.0	82.0	63.9
Requirements					
Gordon *et al.* (1990)	>30	>15	NS	>50	>25
Daniel (1990)	NS	>10	<10	>30	NS

A critical step in constructing a compacted clay liner is the determination of the range of acceptable water content and dry unit weight of the soil. If the soil is too dry at the time of compaction, a suitably low hydraulic conductivity may not be achieved. If the soil is too wet, problems such as, construction equipment operating on soft, weak soils and potential slope instability of low strength soil may arise. Once an acceptable dry unit weight and water content range has been selected, the soil must be compacted with adequate compactive energy to compress large voids and to remold clods of soil into a homogenous, relatively impermeable mass. A problem during field compaction stage is that in relation to the change of in-situ water content of the soil, the compactive energy delivered to the soil may show variations, and hence, precise duplication of field compaction in the laboratory is not possible. Accordingly, the recommended approach of Daniel and Benson (1990) was followed for establishing the required water content and dry unit weight in the field, from laboratory tests. The following gives an algorithm of this approach:

Figures 5.9a and 5.9b give compaction and hydraulic conductivity plots for soil sample A, respectively. The compaction data points are replotted in Figure 5.9c with the solid symbols showing test specimens that have adequately low hydraulic conductivity and the open symbols representing those that are too permeable. An "acceptable zone" is drawn which encompasses the solid points, based on the suitable hydraulic conductivity range. Hence in the field the lowest hydraulic conductivity for sample soil A may be obtained within the limits of this "acceptable zone", which is a function of the allowable moisture content and dry unit weight. Keeping in mind that the lowest hydraulic conductivity is attained above the optimum moisture content, the allowable moisture content for Soil A may vary between 28% and 35% in the field (Figure 5.9c).

5.2.2. Construction of compacted clay liner

During the construction stage of compacted clay liners, the common procedures that are recommended to be followed are given below.

5.2.2.1. Processing

Benson and Daniel (1990) suggested that some liner materials need to be processed to break down clods of soil, to sieve out stones and

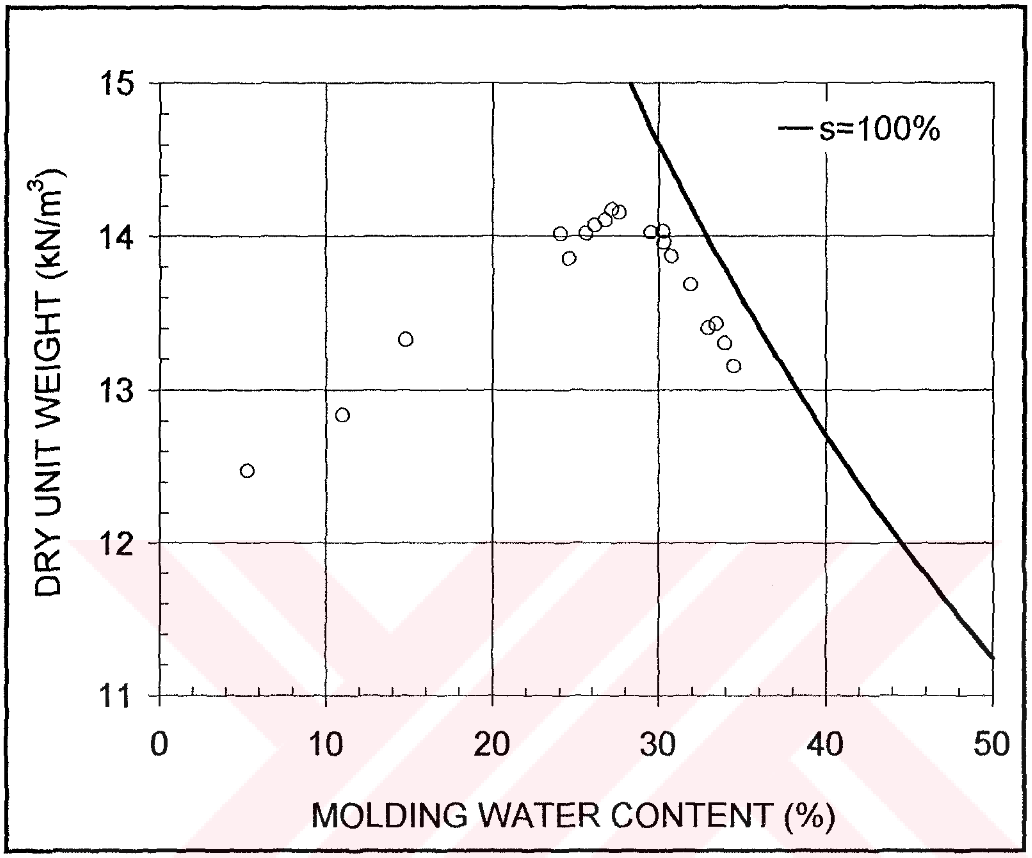

Figure 5.9a. Standard compaction data pair plot for soil sample A (A total of 19 tests have been performed, s: degree of saturation curve).

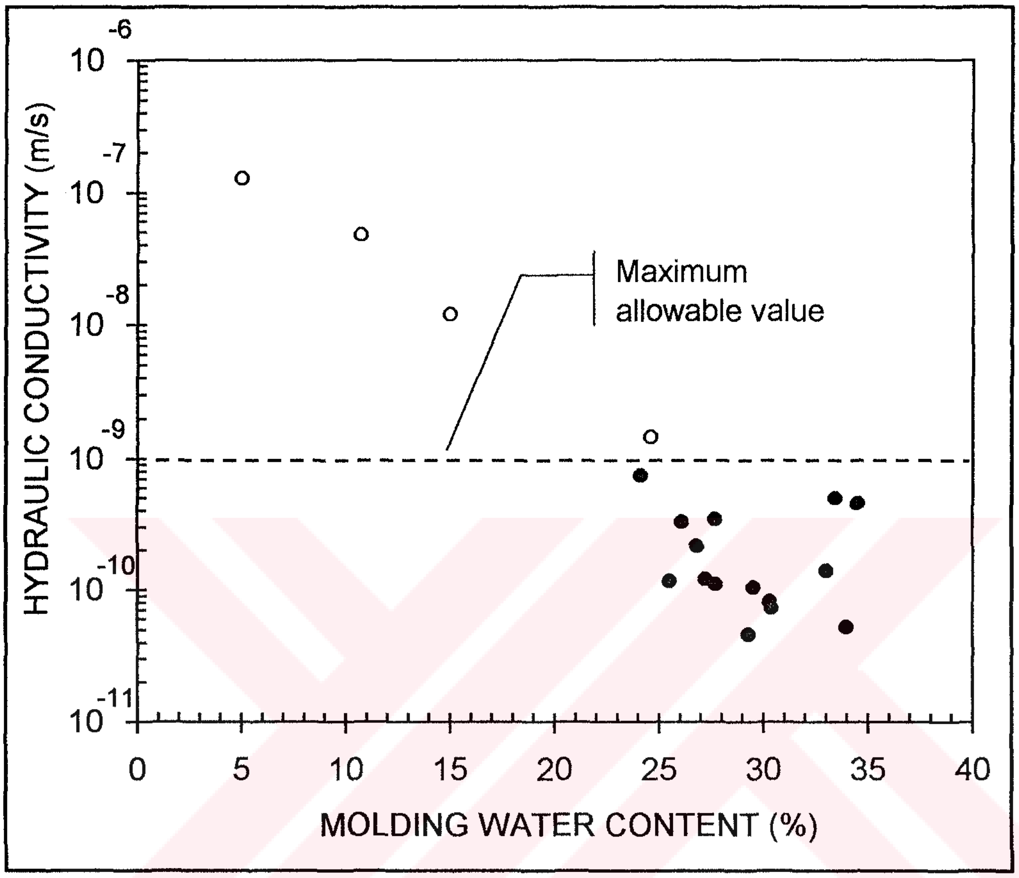

Figure 5.9b. Hydraulic conductivity measurements for soil sample A.

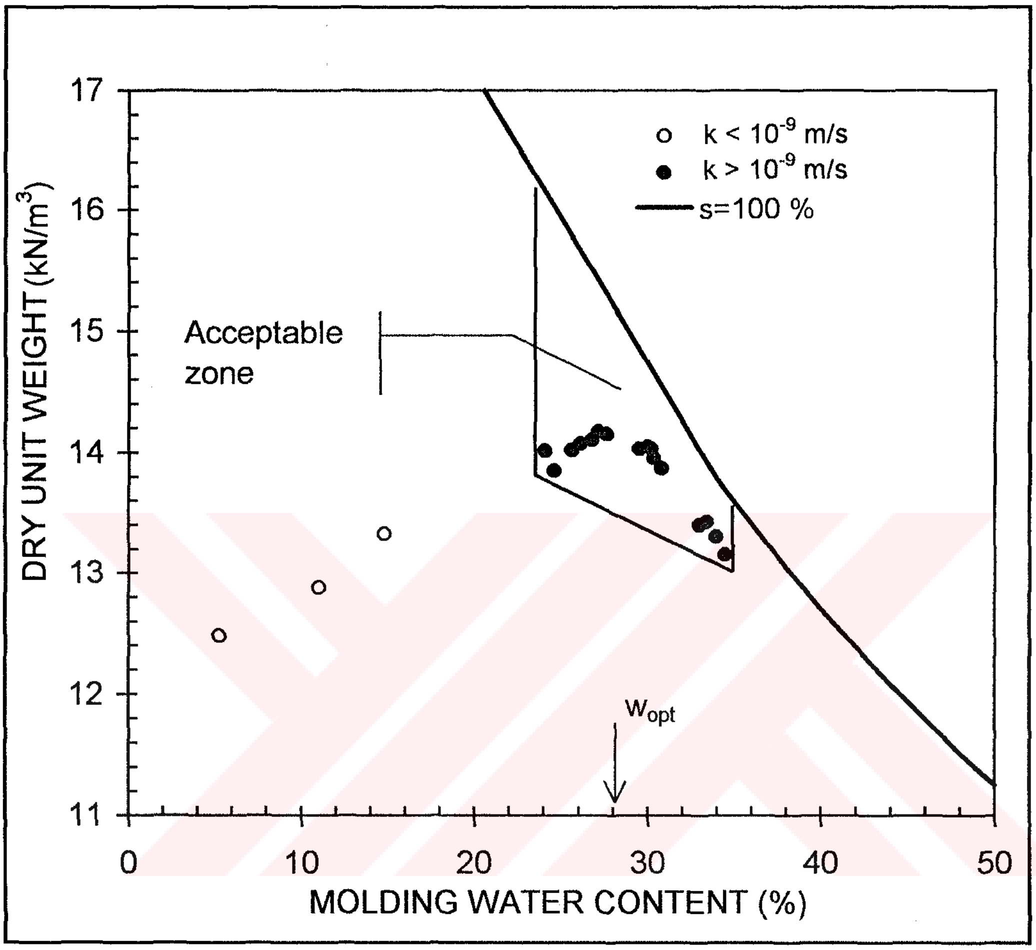

Figure 5.9c. Acceptable zone boundaries for soil sample A (k: hydraulic conductivity, s: degree of saturation curve, w_{opt}: optimum moisture content).

rocks, or to moisten the soil. Clods of soil can be broken down with tilling equipment. Stones can be sieved out of the soil with large vibratory sieves or mechanized "rock pickers" passed over a loose lift of soil. In this respect soil samples A, B1, and B2 may require sieving in the field, since sieve analysis of soil samples A, B1, and B2 indicates gravel percentage of 4.2%, 11%, and 11%, respectively (Table 5.7).

Another important point is the water content. It is not always easy to obtain the required water content in the field. If the soil must be wetted or dried more than 2 to 3 %, the soil should be processed by spreading it in a loose lift about 300 mm thick. Water can be added and mixed into the soil with tiller, or the soil can be disced or tilled to allow it to dry uniformly. It is essential that time be allowed for the soil to wet or dry uniformly. At least 1 to 3 days is usually needed for adequate hydration or dehydration. During winter time, frozen soil should never be used to construct a clay liner (Daniel, 1993).

Compacted clay liners should be constructed in horizontal layers, called lifts. Each lift should effectively bond to the overlying and underlying lifts. The surface of a previously compacted lift must be rough rather than smooth. The surface should be disturbed to a depth of 20-30 mm with a disc or other suitable device, in case the surface is too smooth (Daniel, 1993).

For compaction of the clay, heavy-footed compactors with large feet that fully penetrate a loose lift of soil should be used. Recommended specifications of the compactors are 18,000 kgf for the weight, 180-200 mm for the minimum foot length, and 5 for the minimum number of passes. A "pass" is defined as one pass of the compactor over a given area, and the recommended minimum of five passes is for a vehicle with front and rear drums. Caterpillar 815B and 825C are widely used compactors which are known to lead to satisfactory results (Daniel, 1993).

5.2.2.2. Protection

After compacting a lift, the clay must be protected from desiccation and freezing especially in climates like in Ankara. As stated in Chapter 1, desiccation can cause cracking of the clay leading to increase in the hydraulic conductivity. There are several ways for minimizing desiccation (Daniel, 1993):

- The lift can be temporarily covered with a sheet of plastic,
- The final surface can be smooth-rolled from to form relatively impermeable layer at the surface, and
- The final surface can be periodically moistened.

The destructive effects of freezing can be avoided by temporarily covering the final surface with an insulating layer of material.

CHAPTER 6

DISCUSSIONS

The samples show slight variation in clay mineral content. Soil sample A and C3 are rich in smectite content whereas illite is the major clay mineral constituent of soil samples B1, B2, C1, and C2. Smectite-illite mixed layering is also suspected by the X-ray diffraction (XRD) and scanning electron microscope (SEM) analyses (Figures 3.1 to 3.6 and Figures 3.7 and 3.8). Chlorite is a minor clay mineral in soil samples A, B1, and B2. 3 to 4% of kaolinite is detected in all soil samples. Hence, variations occur in smectite and illite contents in all of the soil samples (Table 3.4).

The hydraulic conductivity of compacted clays can vary tremendously depending on several parameters including the index properties, the conditions under which they are compacted and soil composition (Lambe, 1954; Mitchell *et al.*, 1965; Garcia-Bengochea *et al.*, 1979; Acar and Oliveri, 1990; Benson *et al.*, 1994). The results of the falling head permeability tests reported in Chapter 4 suggest that hydraulic conductivity is sensitive to the molding water content, and the minimum hydraulic conductivity occurs approximately 2% above the optimum moisture content (Figure 4.7). Lambe (1954), Bjerrum and Huder (1954), Mitchell *et al.* (1965), Garcia-Bengochea *et al.* (1979), Acar and Oliveri (1990), Benson and Daniel (1990), Daniel and Benson (1990), and

Benson and Trast (1995) observed approximately the same trend and suggested that compacting clayey soils on the wet side of optimums permit greater remolding of clods, elimination of large interclod voids, and preferential re-orientation of clay particles, all of which result in lower hydraulic conductivity. In addition, a decrease in the hydraulic conductivity is observed as a result of increasing degree of saturation (Figure 4.8). This trend is similar to that reported by Benson and Trast (1995).

Correlation of plasticity index with hydraulic conductivity of the soil samples shows that hydraulic conductivity generally decreases with increasing plasticity index (Figure 4.9). Such a trend is expected because the plasticity index is directly related to the mineralogy of the soil and clay content. An increase in clay content generally corresponds to a decrease in the size of microscale pores, which control the flow in soils compacted on the wet side of the line of optimums resulting in lower hydraulic conductivity (Lambe, 1954). Figure 4.10 shows no significant relation between hydraulic conductivity and liquid limit. The trends of plasticity index and liquid limit with respect to hydraulic conductivity are similar to the studies of Lambe (1954), Mesri and Olson (1971), D'Appolonia (1980), Daniel (1987), Kenney *et al.* (1992), and Benson *et al.* (1994). Benson *et al.* (1994), for example, observed that hydraulic conductivity was less sensitive to the liquid limit and plasticity index after a liquid limit of 40% and a plasticity index of 30%. Therefore, meaningless relation between hydraulic conductivity and liquid limit can be explained by the studies of Benson *et al.* (1994), since the liquid limit of the soil samples ranges from 42.4% to 72.9%.

A decreasing trend of hydraulic conductivity with respect to increasing clay content is observed in Figure 4.12. However, no meaningful relation is observed between hydraulic conductivity and percentage of fines in Figure 4.13. These trends are in agreement with those reported by Benson *et al.* (1994), who suggested that the pore structure controlling flow in soils containing a large quantity of fines (more than 50%) should be affected more by the mineralogical composition and less by particle size distribution. The percentage of fine for all soil samples are more than 63.8% in this study.

Smectite content in soil samples is inversely proportional to the hydraulic conductivity, which is in agreement with Rowe *et al.* (1995) (Figure 4.13). Since smectites consist of very tiny particles, which produce a specific surface of up to 800 m^2/g, they may have very low hydraulic conductivities ($k \approx 10^{-11}$ to 10^{-15} m/s) even at high void ratios.

Increase in the illite content increases the hydraulic conductivity. It is well known that illites exhibit a hydraulic conductivity of 10^{-9} to 10^{-11} m/s in-situ (Rowe *et al.*, 1995). Soil samples with high illite content (soil samples B1, B2, C1, and C2) that were permeability tested in this study fall in this range.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

Soil samples A, B1, and B2 are more plastic than the soil samples C1, C2, and C3, which were collected from Sincan (30.8% compared to 28.6%). The average liquid limit (LL) of soil samples A, B1, and B2 is 47.6%, and 62.3% for soil samples C1, C2, and C3. Plasticity index and liquid limit measurements suggest that soil sample A is classified as CH (fat clay with sand), soil samples B1, B2, and C3 as CL (sandy lean clay) and soil samples C1 and C2 as MH (elastic silt). The soils also vary in particle size distribution. Soil samples A, B1, and B2 have both lower percentage of fines and percentage of clay than soil samples C1, C2, and C3. In terms of these index parameters, all of the soil samples seem to be suitable as compacted clay liners.

Standard Proctor compaction tests show that optimum moisture contents of the soil samples range from 14.5% to 30.0%. Maximum dry unit weights are within the range of 12.8 to 17.0 kN/m^3. To attain minimum hydraulic conductivity values, field compaction should normally be 4% above the optimum moisture content. Since precise duplication of field compaction in the laboratory is not possible, an allowable moisture content range should be defined for the soil samples (for example, the allowable moisture content for soil sample A may vary between 28% to 35% in the field).

Cation exchange capacities (CEC) of the soil samples range between 12 and 27 meq/100 g soil. It is well known that CEC of 25 meq/100 g soil is adequate to permit adsorption of undesirable species such as heavy metals. Hence, except for soil sample C3 having a CEC of 27 meq/100 g soil, all of the soil samples seem to be suitable for being utilized as compacted clay liners.

Quartz, feldspar, and calcite are the non-clay minerals detected by X-ray diffraction (XRD) analyses in all of the soil samples. Dolomite is another non-clay mineral observed only in soil sample C3. XRD analyses also show that smectite is the major constituent in soil samples A and C3, whereas illite is the major constituent in the other soil samples. Kaolinite is detected in minor amounts in all of the soil samples. Chlorite is only observed in soil samples of A, B1, and B2. Major variations occur between smectite and illite content. Smectite is recommended for its very low hydraulic conductivity, even at high void ratios. Illite remains inactive when it comes into contact with leachate. Therefore, as far as the mineralogical content are concerned, all the soil samples are suitable to be used as compacted clay liners in sanitary landfill sites.

The hydraulic conductivities of the soil samples range between 3.6×10^{-10} and 8.2×10^{-11} m/s with an average value in the order of about 10^{-10} m/s. The lowest hydraulic conductivities are obtained for soil samples A and C3, as a result of the presence of high amount of smectite. The average hydraulic conductivity value of the soil samples is lower than the required hydraulic conductivity value for sanitary landfill sites, which is 10^{-8} m/s in Turkey (Resmi Gazete, 1991) and 1×10^{-9} m/s in the United States (USEPA, 1993).

The unitized leakage rate calculations show that all of the soil samples give the best performance with a geomembrane/clay composite liner system under all plausible leachate heads considered.

Simulation of several landfill profiles containing geomembrane/clay composite liner systems by the HELP model for a period of 20 years suggest that sanitary landfills should also have leachate collection layers (such as lateral drainage layer and lateral drainage net). Moreover, in the cap cover system, a compacted clay liner should be included to increase long term performance. Expected unitized leakage rate through the bottommost compacted clay liner and the average head acting on bottom compacted clay liner calculations suggest that all of the soil samples tested herein are suitable for being utilized as compacted clay liners in sanitary landfills. At the end of 20 years, the total expected unitized leakage rate and average head are calculated by the HELP model as 4.12×10^{-3} m^3/year/10,000 m^2 and 3.21×10^{-5} m, respectively, for the recommended landfill profile (Profile No.3).

As far as the engineering properties are concerned, all of the soil samples satisfy the minimum requirements for compacted clay liners. Therefore, the clayey soils investigated in this study can be recommended to be utilized as compacted clay liners due to their widespread distribution and low economic values.

In order to draw stronger conclusions about the hydraulic conductivity values reported herein, the hydraulic conductivities of the soil samples should be measured by using leachate as the permeant, instead of distilled water. Since, wet of optimum compaction produces chemical shrinkage especially in soils having abundant smectite minerals exposed to certain leachates, care should be taken for soil samples A and C3, that are rich in smectite. As a result of leachate migration through a compacted clay liner, if significant K^+ retardation has been observed, c-axis contraction may be suspected in soils A and C3, leading to a sudden increase in their hydraulic conductivities. Hence, in case of usage as compacted clay liner in sanitary landfills, CEC of soil samples A and C3 should also be assessed after leachate compatibility testing in order to determine whether these samples are susceptible to K^+ retardation or not, as a future study.

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APPENDIX A

SAMPLE EXPERIMENTAL DATA

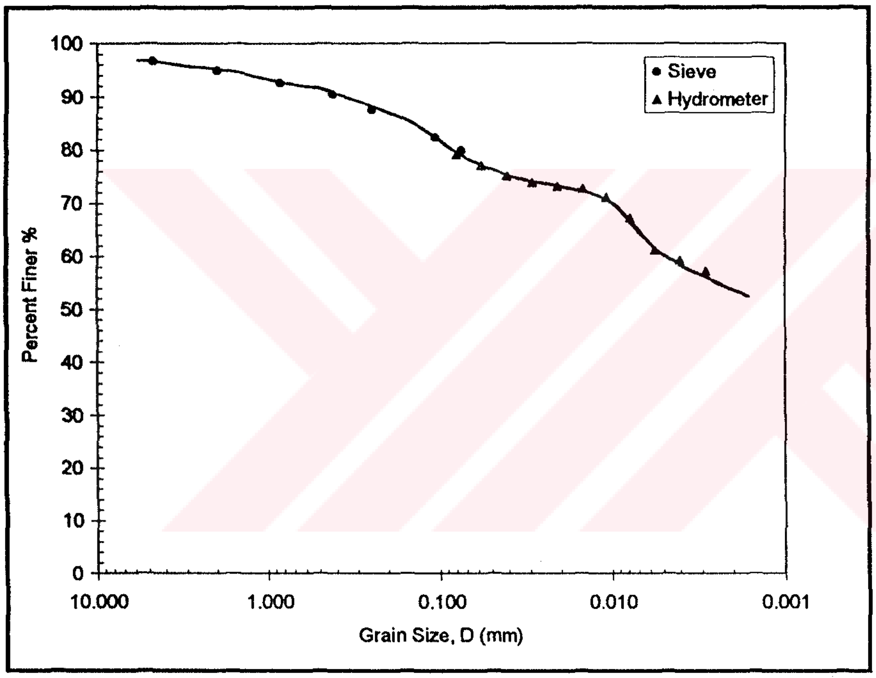

Figure A1. Grain size distribution for soil sample A.

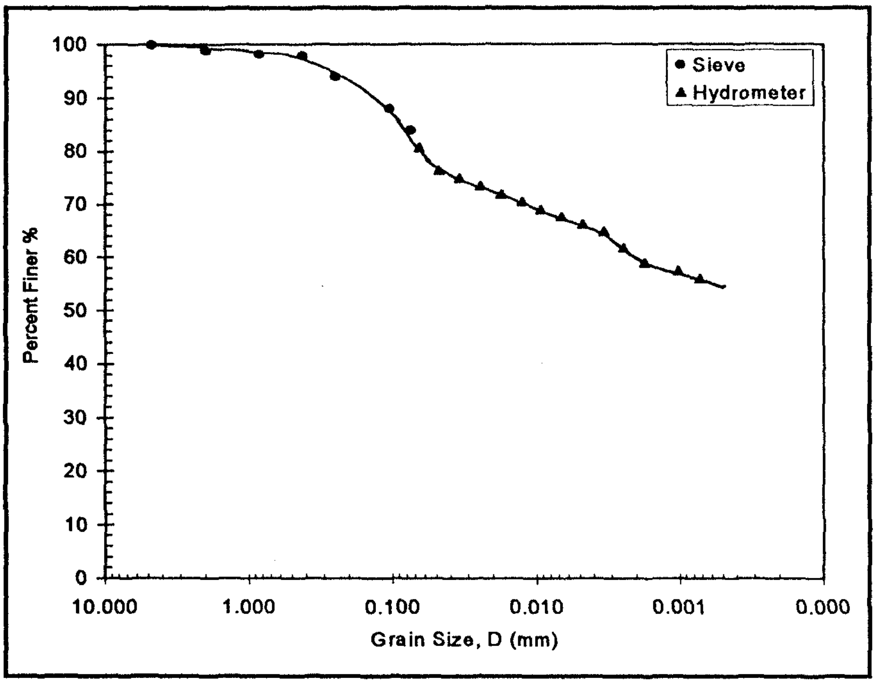

Figure A2. Grain size distribution for soil sample B1.

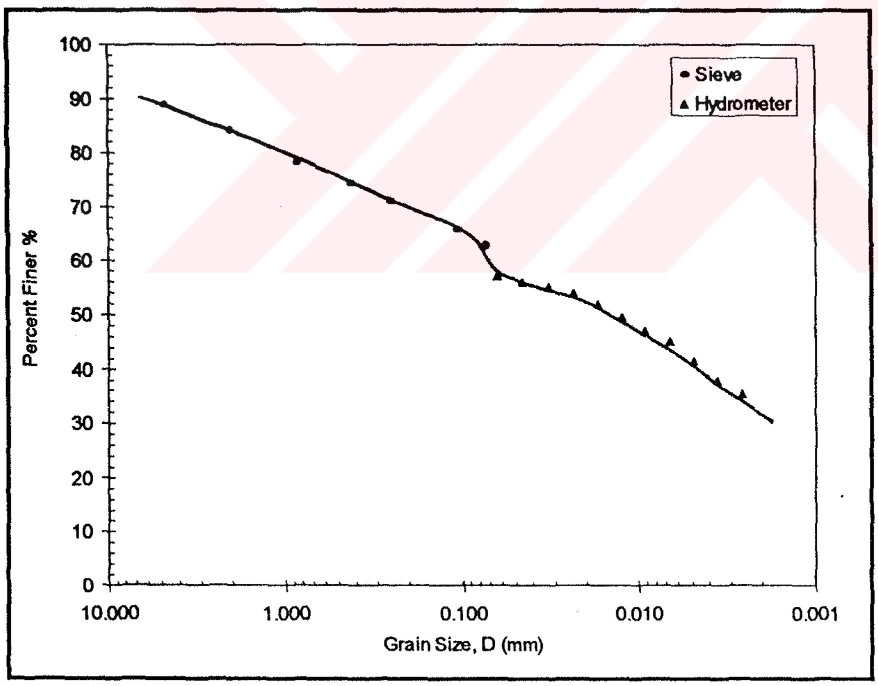

Figure A3. Grain size distribution for soil sample B2.

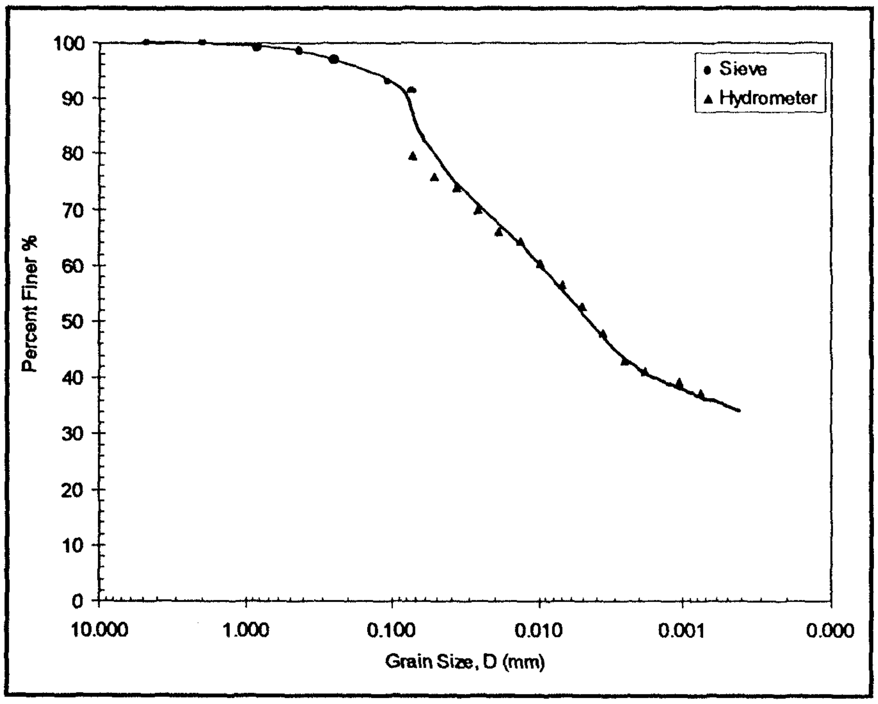

Figure A4. Grain size distribution for soil sample C2.

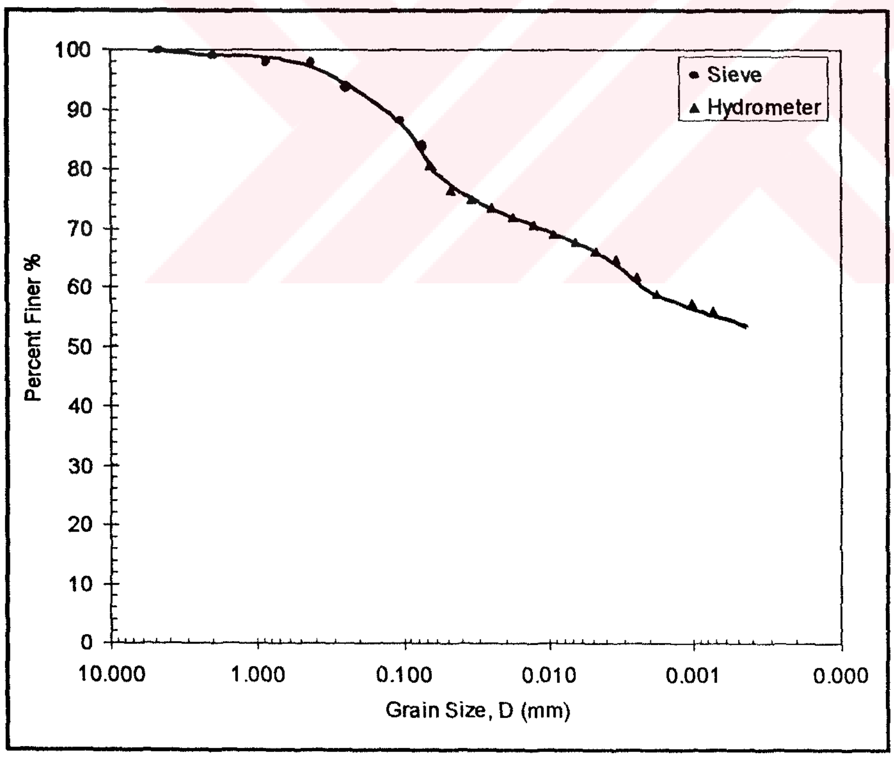

Figure A5. Grain size distribution for soil sample C3.

Table A1. Specific gravity testing for soil sample A.

EGLF#2

	METU Engineering Geology Laboratories	SPECIFIC GRAVITY			
Project Name:	Msc. Thesis				
Description of Soil:	Ankara Clay				
Location:	Karakusunlar				
Sample No:	A1-2			Date:	01.06.98
Volume of Flask at 20 C:	500 ml			Tested by:	met
TEST No:	1	2	3	4	5
Volumetric Flask No:	1	1	1	1	2
Weight of Flask + Water filled to mark, W_1 (g)	622	622	622	622	617
Weight of Flask + soil +water Filled to Mark, W_2 (g)	659	678	672	652	647
Weight of Dry Soil, W_3 (g)	59	89	79	48	48
Temperature of Test, T_1 (°C)	18	18	18	18	20
G_s (at T_1) = $W_3 / ((W_1 + W_3) - W_2)$	2.68	2.70	2.72	2.67	2.67
A	1.004	1.004	1.004	1.004	1
Gs (at 20°C) = G_s (at T°C) x A	2.69	2.71	2.74	2.68	2.67

Values of A:

Temperature, T_1 (°C)	A
18	1.004
19	1.002
20	1
22	0.9996
24	0.9991
26	0.9986
28	0.998

Table A2. Specific gravity testing for soil sample A.

EGLF#2

	METU Engineering Geology Laboratories	SPECIFIC GRAVITY			
Project Name:	MSc. Thesis				
Description of Soil:	Ankara Clay				
Location:	Karakusunlar				
Sample No:	A1-2			Date:	01.06.98
Volume of Flask at 20 C:	500 ml			Tested by:	met
TEST No:	6				
Volumetric Flask No:	2				
Weight of Flask + Water filled to mark, W_1 (g)	617				
Weight of Flask + soil +water Filled to Mark, W_2 (g)	647				
Weight of Dry Soil, W_3 (g)	48				
Temperature of Test, T_1 (°C)	20				
G_s (at T_1) = $W_3 / ((W_1 + W_3) - W_2)$	2.67				
A	1				
Gs (at 20°C) = G_s (at T°C) x A	2.67				

Values of A:

Temperature, T_1 (°C)	A
18	1.004
19	1.002
20	1
22	0.9996
24	0.9991
26	0.9986
28	0.998

Average Gs:	2.69
Std Dev:	0.03

Table A3. Sieve analysis for soil sample A.

EGLF#3

	METU Engineering Geology Laboratories	SIEVE ANALYSIS			
Project Name:	MSc. Thesis				
Description of Soil:	Ankara Clay				
Sample No:	A1-2				
Location:	Karakusunlar				
Weight of Oven Dry Sample, W	50			Date:	24.06.98
	10 g. retains on No. 200 sieve after washing			Tested By:	met
Sieve No.	Sieve Opening (mm)	Weight Retained on Each Sieve (g)	Percent of Weight Retained on Each Sieve	Cumulative Percent Retained	Percent Finer
4	4.75	1.65	3.3	3.3	96.7
10	2	0.85	1.7	5	95
20	0.85	1.15	2.3	7.3	92.7
40	0.425	1.15	2.3	9.6	90.4
60	0.25	1.45	2.9	12.5	87.5
140	0.106	2.55	5.1	17.6	82.4
200	0.075	1.2	2.4	20	80
PAN		40	80	100	0

Table A4. Hydrometer analysis for soil sample A.

EGLF#4

	METU Engineering Geology Laboratories	HYDROMETER ANALYSIS					
Project Name:	MSc. Thesis						
Description of Soil:	Ankara Clay				Meniscus Correction, F_m	1	
Sample No:	A1-2				Temp. Correction, F_T	0.9	
Location:	Karakusunlar				Zero Correction, F_z	4	
Hydrometer Type:	ASTM 152H				Gs:	2.69	
Temp. of Test, T (°C)	23				Date:	19.06.98	
Dry Weight of Soil, W_s (g)	40				Tested By:	met	
Time (min)	Hydrometer Reading, R	R_{cp}	Percent Finer $aR_{cp}/W_s \times 100$	R_{cL}	L (cm)	A	D (mm)
0.25	43	39.9	79.09	44	9.1	0.01343	0.08103
0.5	42	38.9	77.11	43	9.28	0.01343	0.05786
1	41	37.9	75.12	42	9.4	0.01343	0.04118
2	40.4	37.3	73.93	41.4	9.55	0.01343	0.02935
4	40	36.9	73.14	41	9.6	0.01343	0.02081
8	39.8	36.7	72.74	40.8	9.67	0.01343	0.01477
15	39	35.9	71.16	40	9.75	0.01343	0.01083
30	37	33.9	67.19	38	10.1	0.01343	0.00779
60	34	30.9	61.25	35	10.6	0.01343	0.00564
120	33	29.9	59.27	34	10.75	0.01343	0.00402
240	32	28.9	57.28	33	10.9	0.01343	0.00286
480	31	27.9	55.30	32	10.9	0.01343	0.00202
1440	30	26.9	53.32	31	11.05	0.01343	0.00118
2880	25	21.9	43.41	26	12	0.01343	0.00087

Table A5. Liquid limit test for soil sample A.

EGLF#5

	METU Engineering Geology Laboratories	LIQUID LIMIT TEST				
Project Name:	MSc. Thesis					
Description of Soil:	Ankara Clay					
Sample No:	A1-2			Date:	01.06.1998	
Location:	Karakusunlar			Tested By:	met	
Can No.	Weight of Can, W_1 (g)	Weight of Can & Wet Soil, W_2 (g)	Weight of Can & Dry Soil, W_3 (g)	Moisture Content w (%)	Number of Blows (N)	LL w=25%
5	22.6	49	39.9	52.60	35	
2	22.52	39.4	33.4	55.15	20	54.22
7	26.9	46.6	39.5	56.35	15	
6	25.7	46.1	39	53.38	42	
2	22.52	43.53	36	55.86	20	55.03
7	26.9	46.6	39.5	56.35	15	
8	21.9	36.3	31.4	51.58	26	
3	26.92	53	43.9	53.59	15	51.72
6	25.7	44.2	37.7	54.17	13	
5	22.6	49	39.9	52.60	35	
4	26.61	45.6	39	53.27	26	53.44
1	26.65	45.2	38.7	53.94	21	

Average LL: 53.6
Std. Dev: 1.41

Table A6. Plastic limit test for soil sample A.

EGLF#6

	METU Engineering Geology Laboratories	PLASTIC LIMIT TEST		
Project Name:	MSc. Thesis			
Description of Soil:	Ankara Clay			
Sample No:	A1-2		**Date:**	10.06.98
Location:	Karakusunlar		**Tested By:**	met
Can No.	**Weight of Can, W_1 (g)**	**Weight of Can & Wet Soil, W_2 (g)**	**Weight of Can & Dry Soil, W_3 (g)**	**PL = $100 \times (W_2 - W_3) / (W_3 - W_1)$**
5	22.6	27.6	26.7	28.30
6	25.7	32	31	18.87
4	26.61	34.2	33	18.78
1	26.65	32.6	31.7	17.82
3	26.92	34.5	33.3	18.81
7	26.9	33.4	32.3	20.37
2	22.52	28.5	27.6	17.72
8	21.9	26.8	26	19.51
2	22.52	26.1	25.6	16.23
4	26.61	29.8	29.3	18.59
7	26.9	30.1	29.7	14.29
1	26.65	30.5	29.9	18.46
6	25.7	29.2	28.7	16.67
			Average PL	18.80
			Std. Dev.	3.25

Table A7. Standard Proctor Compaction test for soil sample A.

EGLF#10

	METU Engineering Geology Laboratories	STANDARD PROCTOR COMPACTION TEST						
Project Name:	MSc. Thesis							
Description of Soil:	Ankara Clay				**Weight of Hammer:**	3,936 kg		
Sample No:	A1-1,2				**No. of Layers:**	3		
Location:	Karakusunlar				**Gs:**	2.69		
Volume of Mold (V-cm3):	956.04				**Date:**	24.04.98		
No. of blows/layer:	25				**Tested By:**	met		
TEST NO.	**Weight of Mold, W_1 (kg)**	**Weight of Mold, & Moist Soil, W_2 (kg)**	**Weight of Moist Soil W_2-W_1 (kg)**	**Moist Unit Weight W_2-W_1 / V (g/cm^3)**	**Moisture Content w(%)**	**Dry Unit Weight γ_d (kN/m^3)**	**Void Ratio e**	**Porosity n**
1	3.669	4.949	1.28	1.339	4.996	12.509	1.110	0.526
2	3.669	4.949	1.28	1.339	5.263	12.477	1.115	0.527
3	3.669	5.034	1.365	1.428	9.080	12.840	1.055	0.513
4	3.669	5.038	1.369	1.432	10.204	12.747	1.070	0.517
5	3.669	5.140	1.471	1.539	13.889	13.253	0.991	0.498
6	3.669	5.160	1.491	1.560	14.815	13.325	0.980	0.495
7	3.702	5.397	1.695	1.773	24.074	14.018	0.883	0.469
8	3.696	5.378	1.682	1.759	24.587	13.853	0.905	0.475
9	3.669	5.385	1.716	1.795	25.596	14.020	0.882	0.469
10	3.669	5.399	1.73	1.810	26.140	14.073	0.875	0.467
11	3.651	5.394	1.743	1.823	26.778	14.107	0.871	0.465
12	3.651	5.408	1.757	1.838	27.176	14.176	0.861	0.463
13	3.669	5.43	1.761	1.842	27.648	14.156	0.864	0.464
14	3.669	5.440	1.771	1.852	29.530	14.029	0.881	0.468
15	3.669	5.449	1.78	1.862	30.000	14.050	0.878	0.468
16	3.669	5.450	1.781	1.863	30.247	14.031	0.881	0.468
17	3.696	5.469	1.773	1.855	30.332	13.959	0.890	0.471
18	3.669	5.437	1.768	1.849	30.769	13.873	0.902	0.474
19	3.669	5.428	1.759	1.840	31.893	13.685	0.928	0.481
20	3.696	5.433	1.737	1.817	32.990	13.402	0.969	0.492
21	3.669	5.415	1.746	1.826	33.421	13.428	0.965	0.491
22	3.702	5.439	1.737	1.817	33.963	13.305	0.983	0.496
23	3.651	5.375	1.724	1.803	34.459	13.156	1.006	0.501

Table A8. Water content measurements for Standard Proctor Compaction test for soil sample A.

EGLF#1

	METU Engineering Geology Laboratories	MOISTURE CONTENT TEST		
Project Name:	MSc Thesis			
Description of Soil:	Ankara Clay			
Sample No:	A1-1,2		**Date:**	24.04.1998
Location:	Karakusunlar		**Tested By:**	met
No. of Can	**Wt of Can W_1 (g)**	**Wt of Can + Wet Soil W_2 (g)**	**Wt of Can + Dry Soil, W_3 (g)**	**w(%) = $100 \times (W_2-W_3) / (W_3-W_1)$**
7	26.9	89.95	86.95	4.996
4-5	26	66	64	5.263
3	26.92	80.02	75.6	9.080
6-7	22	76	71	10.204
9-10	22	63	58	13.889
1-1.5	22	53	49	14.815
8	21.9	58.75	51.6	24.074
3	26.92	85.7	74.1	24.587
2	22.52	69.65	60.045	25.596
7	26.9	70.04	61.1	26.140
5	22.6	52.9	46.5	26.778
7	26.9	60.5	53.32	27.176
6	25.7	71.5	61.58	27.648
5	22.6	41.9	37.5	29.530
4-5	26	65	56	30.000
4	26.61	65.15	56.2	30.247
2	22.52	56.25	48.4	30.332
10-11	22	56	48	30.769
1	26.65	70.9	60.2	31.893
8	21.9	47.7	41.3	32.990
7	26.9	77.8	65.05	33.421
3	26.92	56.7	49.15	33.963
6	25.7	65.5	55.3	34.459

APPENDIX B

THE HELP MODEL OUTPUTS

B1. Output of Profile No.1

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.04   (13 MARCH 1995)                 **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**              FOR USEPA RISK REDUCTION ENGINEERING LABORATORY             **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************
PRECIPITATION DATA FILE:     C:\GEOLOGY\HELP3\ANKA.D4
TEMPERATURE DATA FILE:       C:\GEOLOGY\HELP3\ANKA.D7
SOLAR RADIATION DATA FILE:   C:\GEOLOGY\HELP3\ANKA.D13
EVAPOTRANSPIRATION DATA:     C:\GEOLOGY\HELP3\ANKA.D11
SOIL AND DESIGN DATA FILE:   C:\GEOLOGY\HELP3\PROFILE1.D10
OUTPUT DATA FILE:            C:\GEOLOGY\HELP3\anka1.OUT
TIME:  23:20     DATE:   6/15/1999
******************************************************************************
     TITLE:  Profile No.1
******************************************************************************
     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.
                                  LAYER  1
                                  --------
                    TYPE 1 - VERTICAL PERCOLATION LAYER
                        MATERIAL TEXTURE NUMBER  15
           THICKNESS                    =    100.00   CM
           POROSITY                     =      0.4750 VOL/VOL
           FIELD CAPACITY               =      0.3780 VOL/VOL
           WILTING POINT                =      0.2650 VOL/VOL
           INITIAL SOIL WATER CONTENT   =      0.3403 VOL/VOL
           EFFECTIVE SAT. HYD. COND.    =  0.170000003000E-04 CM/SEC
         NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  3.00
                  FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.
                                  LAYER  2
                                  --------
                    TYPE 1 - VERTICAL PERCOLATION LAYER
                        MATERIAL TEXTURE NUMBER  18
           THICKNESS                    =    750.00   CM
           POROSITY                     =      0.6710 VOL/VOL
           FIELD CAPACITY               =      0.2920 VOL/VOL
           WILTING POINT                =      0.0770 VOL/VOL
           INITIAL SOIL WATER CONTENT   =      0.2934 VOL/VOL
           EFFECTIVE SAT. HYD. COND.    =  0.100000005000E-02 CM/SEC
```

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                         LAYER  3
                         --------
                TYPE 4 - FLEXIBLE MEMBRANE LINER
                  MATERIAL TEXTURE NUMBER  35
   THICKNESS                      =      0.20   CM
   POROSITY                       =      0.0000 VOL/VOL
   FIELD CAPACITY                 =      0.0000 VOL/VOL
   WILTING POINT                  =      0.0000 VOL/VOL
   INITIAL SOIL WATER CONTENT     =      0.0000 VOL/VOL
   EFFECTIVE SAT. HYD. COND.      =  0.199999996000E-12 CM/SEC
   FML PINHOLE DENSITY            =      1.00   HOLES/HECTARE
   FML INSTALLATION DEFECTS       =     10.00   HOLES/HECTARE
   FML PLACEMENT QUALITY          =  3 - GOOD
                         LAYER  4
                         --------
                  TYPE 3 - BARRIER SOIL LINER
   MATERIAL TEXTURE NUMBER  45
   THICKNESS                      =     60.00   CM
   POROSITY                       =      0.4620 VOL/VOL
   FIELD CAPACITY                 =      0.2450 VOL/VOL
   WILTING POINT                  =      0.0590 VOL/VOL
   INITIAL SOIL WATER CONTENT     =      0.4620 VOL/VOL
   EFFECTIVE SAT. HYD. COND.      =  0.999999994000E-08 CM/SEC
           GENERAL DESIGN AND EVAPORATIVE ZONE DATA
           ----------------------------------------
  NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
         SOIL DATA BASE USING SOIL TEXTURE #15 WITH A
         FAIR STAND OF GRASS, A SURFACE SLOPE OF  3.%
         AND A SLOPE LENGTH OF  100. METERS.
 SCS RUNOFF CURVE NUMBER                =     90.00
 FRACTION OF AREA ALLOWING RUNOFF       =    100.0    PERCENT
 AREA PROJECTED ON HORIZONTAL PLANE     =      1.0000 HECTARES
 EVAPORATIVE ZONE DEPTH                 =     91.0    CM
 INITIAL WATER IN EVAPORATIVE ZONE      =     30.623  CM
 UPPER LIMIT OF EVAPORATIVE STORAGE     =     43.225  CM
 LOWER LIMIT OF EVAPORATIVE STORAGE     =     24.115  CM
 INITIAL SNOW WATER                     =      0.000  CM
 INITIAL WATER IN LAYER MATERIALS       =    281.813  CM
 TOTAL INITIAL WATER                    =    281.813  CM
 TOTAL SUBSURFACE INFLOW                =      0.00   MM/YR
            EVAPOTRANSPIRATION AND WEATHER DATA
            -----------------------------------
  NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
         ANKARA                      TURKEY
     STATION LATITUDE                         =  39.77 DEGREES
     MAXIMUM LEAF AREA INDEX                  =   2.00
     START OF GROWING SEASON (JULIAN DATE)    =    85
     END OF GROWING SEASON (JULIAN DATE)      =   301
     EVAPORATIVE ZONE DEPTH                   =  91.0  CM
     AVERAGE ANNUAL WIND SPEED                =   7.20 KPH
     AVERAGE 1ST QUARTER RELATIVE HUMIDITY    =  73.00 %
     AVERAGE 2ND QUARTER RELATIVE HUMIDITY    =  60.67 %
     AVERAGE 3RD QUARTER RELATIVE HUMIDITY    =  55.33 %
     AVERAGE 4TH QUARTER RELATIVE HUMIDITY    =  70.67 %
  NOTE:  PRECIPITATION DATA FOR     ANKARA              TURKEY
         WAS ENTERED BY THE USER.
  NOTE:  TEMPERATURE DATA WAS FOR     ANKARA              TURKEY
         WAS ENTERED BY THE USER.
         NORMAL MEAN MONTHLY TEMPERATURE (DEGREES CELSIUS)
```

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
-0.1	0.5	4.4	10.4	14.5	17.6
20.5	20.4	16.9	11.5	5.2	1.8

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ANNUAL TOTALS FOR YEAR 1979

	MM	CU. METERS	PERCENT
PRECIPITATION	512.50	5125.001	100.00
RUNOFF	27.221	272.205	5.31
EVAPOTRANSPIRATION	474.641	4746.415	92.61
PERC./LEAKAGE THROUGH LAYER 4	0.008018	0.080	0.00
AVG. HEAD ON TOP OF LAYER 3	42.8086		
CHANGE IN WATER STORAGE	10.630	106.300	2.07
SOIL WATER AT START OF YEAR	2818.134	28181.344	
SOIL WATER AT END OF YEAR	2828.764	28287.643	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0002	0.002	0.00

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ANNUAL TOTALS FOR YEAR 1980

	MM	CU. METERS	PERCENT
PRECIPITATION	511.30	5113.001	100.00
RUNOFF	67.563	675.634	13.21
EVAPOTRANSPIRATION	391.460	3914.600	76.56
PERC./LEAKAGE THROUGH LAYER 4	0.018750	0.187	0.00
AVG. HEAD ON TOP OF LAYER 3	107.1147		
CHANGE IN WATER STORAGE	52.258	522.579	10.22
SOIL WATER AT START OF YEAR	2828.764	28287.643	
SOIL WATER AT END OF YEAR	2881.022	28810.221	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0001	0.001	0.00

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ANNUAL TOTALS FOR YEAR 1981

	MM	CU. METERS	PERCENT
PRECIPITATION	482.10	4821.001	100.00
RUNOFF	41.326	413.261	8.57
EVAPOTRANSPIRATION	420.215	4202.154	87.16
PERC./LEAKAGE THROUGH LAYER 4	0.033187	0.332	0.01
AVG. HEAD ON TOP OF LAYER 3	197.3378		
CHANGE IN WATER STORAGE	20.526	205.257	4.26
SOIL WATER AT START OF YEAR	2881.022	28810.221	
SOIL WATER AT END OF YEAR	2901.548	29015.479	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.0003	-0.003	0.00

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ANNUAL TOTALS FOR YEAR 1982

	MM	CU. METERS	PERCENT
PRECIPITATION	324.70	3247.001	100.00
RUNOFF	34.037	340.369	10.48
EVAPOTRANSPIRATION	353.622	3536.222	108.91
PERC./LEAKAGE THROUGH LAYER 4	0.036149	0.361	0.01
AVG. HEAD ON TOP OF LAYER 3	216.3380		
CHANGE IN WATER STORAGE	-63.017	-630.167	-19.41
SOIL WATER AT START OF YEAR	2901.548	29015.479	
SOIL WATER AT END OF YEAR	2838.531	28385.312	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0215	0.215	0.01

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ANNUAL TOTALS FOR YEAR 1983

	MM	CU. METERS	PERCENT

	MM	CU. METERS	PERCENT
PRECIPITATION	606.70	6067.000	100.00
RUNOFF	51.627	516.272	8.51
EVAPOTRANSPIRATION	445.375	4453.750	73.41
PERC./LEAKAGE THROUGH LAYER 4	0.036275	0.363	0.01
AVG. HEAD ON TOP OF LAYER 3	217.1377		
CHANGE IN WATER STORAGE	109.662	1096.615	18.08
SOIL WATER AT START OF YEAR	2838.531	28385.312	
SOIL WATER AT END OF YEAR	2948.193	29481.926	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	0.000	0.00

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ANNUAL TOTALS FOR YEAR 1984

	MM	CU. METERS	PERCENT
PRECIPITATION	310.60	3106.001	100.00
RUNOFF	10.638	106.380	3.42
EVAPOTRANSPIRATION	373.636	3736.364	120.29
PERC./LEAKAGE THROUGH LAYER 4	0.047256	0.473	0.02
AVG. HEAD ON TOP OF LAYER 3	286.4600		
CHANGE IN WATER STORAGE	-73.722	-737.217	-23.74
SOIL WATER AT START OF YEAR	2948.193	29481.926	
SOIL WATER AT END OF YEAR	2874.471	28744.711	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0002	0.002	0.00

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ANNUAL TOTALS FOR YEAR 1985

	MM	CU. METERS	PERCENT
PRECIPITATION	478.10	4781.000	100.00
RUNOFF	49.606	496.058	10.38
EVAPOTRANSPIRATION	344.750	3447.505	72.11
PERC./LEAKAGE THROUGH LAYER 4	0.047993	0.480	0.01
AVG. HEAD ON TOP OF LAYER 3	292.0046		
CHANGE IN WATER STORAGE	83.696	836.957	17.51
SOIL WATER AT START OF YEAR	2874.471	28744.711	
SOIL WATER AT END OF YEAR	2958.167	29581.666	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0001	0.001	0.00

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ANNUAL TOTALS FOR YEAR 1986

	MM	CU. METERS	PERCENT
PRECIPITATION	372.50	3725.000	100.00
RUNOFF	62.729	627.285	16.84
EVAPOTRANSPIRATION	355.795	3557.946	95.52
PERC./LEAKAGE THROUGH LAYER 4	0.059425	0.594	0.02
AVG. HEAD ON TOP OF LAYER 3	365.4216		
CHANGE IN WATER STORAGE	-46.082	-460.823	-12.37
SOIL WATER AT START OF YEAR	2958.167	29581.666	
SOIL WATER AT END OF YEAR	2912.084	29120.844	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.0003	-0.003	0.00

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ANNUAL TOTALS FOR YEAR 1987

	MM	CU. METERS	PERCENT
PRECIPITATION	494.60	4946.001	100.00
RUNOFF	73.338	733.382	14.83
EVAPOTRANSPIRATION	350.715	3507.146	70.91

	MM	CU. METERS	PERCENT
PERC./LEAKAGE THROUGH LAYER 4	0.068836	0.688	0.01
AVG. HEAD ON TOP OF LAYER 3	425.8327		
CHANGE IN WATER STORAGE	70.478	704.783	14.25
SOIL WATER AT START OF YEAR	2912.084	29120.844	
SOIL WATER AT END OF YEAR	2982.563	29825.627	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0001	0.001	0.00

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ANNUAL TOTALS FOR YEAR 1988

	MM	CU. METERS	PERCENT
PRECIPITATION	588.30	5882.999	100.00
RUNOFF	59.461	594.605	10.11
EVAPOTRANSPIRATION	475.100	4750.998	80.76
PERC./LEAKAGE THROUGH LAYER 4	0.076213	0.762	0.01
AVG. HEAD ON TOP OF LAYER 3	472.2155		
CHANGE IN WATER STORAGE	53.664	536.636	9.12
SOIL WATER AT START OF YEAR	2982.563	29825.627	
SOIL WATER AT END OF YEAR	3036.226	30362.262	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.0002	-0.002	0.00

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ANNUAL TOTALS FOR YEAR 1989

	MM	CU. METERS	PERCENT
PRECIPITATION	467.00	4670.000	100.00
RUNOFF	19.193	191.930	4.11
EVAPOTRANSPIRATION	432.224	4322.241	92.55
PERC./LEAKAGE THROUGH LAYER 4	0.082622	0.826	0.02
AVG. HEAD ON TOP OF LAYER 3	514.7823		
CHANGE IN WATER STORAGE	15.500	155.003	3.32
SOIL WATER AT START OF YEAR	3036.226	30362.262	
SOIL WATER AT END OF YEAR	3024.726	30247.262	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	27.000	270.004	5.78
ANNUAL WATER BUDGET BALANCE	-0.0001	-0.001	0.00

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ANNUAL TOTALS FOR YEAR 1990

	MM	CU. METERS	PERCENT
PRECIPITATION	409.70	4097.000	100.00
RUNOFF	44.256	442.562	10.80
EVAPOTRANSPIRATION	413.190	4131.901	100.85
PERC./LEAKAGE THROUGH LAYER 4	0.083534	0.835	0.02
AVG. HEAD ON TOP OF LAYER 3	520.7716		
CHANGE IN WATER STORAGE	-47.830	-478.297	-11.67
SOIL WATER AT START OF YEAR	3024.726	30247.260	
SOIL WATER AT END OF YEAR	3003.897	30038.967	
SNOW WATER AT START OF YEAR	27.000	270.004	6.59
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.0001	-0.001	0.00

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ANNUAL TOTALS FOR YEAR 1991

	MM	CU. METERS	PERCENT
PRECIPITATION	412.80	4128.000	100.00
RUNOFF	32.139	321.388	7.79
EVAPOTRANSPIRATION	373.276	3732.762	90.43
PERC./LEAKAGE THROUGH LAYER 4	0.083526	0.835	0.02
AVG. HEAD ON TOP OF LAYER 3	520.7186		
CHANGE IN WATER STORAGE	7.301	73.013	1.77
SOIL WATER AT START OF YEAR	3003.897	30038.967	

SOIL WATER AT END OF YEAR	3011.198	30111.979	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0002	0.002	0.00

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ANNUAL TOTALS FOR YEAR 1992

	MM	CU. METERS	PERCENT
PRECIPITATION	483.40	4834.000	100.00
RUNOFF	29.211	292.112	6.04
EVAPOTRANSPIRATION	434.432	4344.318	89.87
PERC./LEAKAGE THROUGH LAYER 4	0.083760	0.838	0.02
AVG. HEAD ON TOP OF LAYER 3	520.7505		
CHANGE IN WATER STORAGE	19.673	196.734	4.07
SOIL WATER AT START OF YEAR	3011.198	30111.979	
SOIL WATER AT END OF YEAR	3030.871	30308.713	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.0001	-0.001	0.00

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ANNUAL TOTALS FOR YEAR 1993

	MM	CU. METERS	PERCENT
PRECIPITATION	400.40	4003.999	100.00
RUNOFF	53.961	539.613	13.48
EVAPOTRANSPIRATION	362.533	3625.331	90.54
PERC./LEAKAGE THROUGH LAYER 4	0.084603	0.846	0.02
AVG. HEAD ON TOP OF LAYER 3	527.6071		
CHANGE IN WATER STORAGE	-16.179	-161.791	-4.04
SOIL WATER AT START OF YEAR	3030.871	30308.713	
SOIL WATER AT END OF YEAR	3014.692	30146.924	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	0.000	0.00

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ANNUAL TOTALS FOR YEAR 1994

	MM	CU. METERS	PERCENT
PRECIPITATION	337.30	3373.001	100.00
RUNOFF	10.081	100.810	2.99
EVAPOTRANSPIRATION	306.859	3068.593	90.98
PERC./LEAKAGE THROUGH LAYER 4	0.087004	0.870	0.03
AVG. HEAD ON TOP OF LAYER 3	543.0438		
CHANGE IN WATER STORAGE	20.151	201.515	5.97
SOIL WATER AT START OF YEAR	3014.692	30146.924	
SOIL WATER AT END OF YEAR	3034.844	30348.437	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.1213	1.213	0.04

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ANNUAL TOTALS FOR YEAR 1995

	MM	CU. METERS	PERCENT
PRECIPITATION	425.70	4257.001	100.00
RUNOFF	7.491	74.909	1.76
EVAPOTRANSPIRATION	430.932	4309.324	101.23
PERC./LEAKAGE THROUGH LAYER 4	0.094493	0.945	0.02
AVG. HEAD ON TOP OF LAYER 3	591.0009		
CHANGE IN WATER STORAGE	-12.818	-128.178	-3.01
SOIL WATER AT START OF YEAR	3034.844	30348.437	
SOIL WATER AT END OF YEAR	3022.026	30220.260	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0001	0.001	0.00

ANNUAL TOTALS FOR YEAR 1996

	MM	CU. METERS	PERCENT
PRECIPITATION	398.60	3986.002	100.00
RUNOFF	20.361	203.607	5.11
EVAPOTRANSPIRATION	344.203	3442.033	86.35
PERC./LEAKAGE THROUGH LAYER 4	0.097204	0.972	0.02
AVG. HEAD ON TOP OF LAYER 3	606.9273		
CHANGE IN WATER STORAGE	33.939	339.388	8.51
SOIL WATER AT START OF YEAR	3022.026	30220.260	
SOIL WATER AT END OF YEAR	3055.965	30559.648	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0002	0.002	0.00

ANNUAL TOTALS FOR YEAR 1997

	MM	CU. METERS	PERCENT
PRECIPITATION	480.10	4801.000	100.00
RUNOFF	9.117	91.170	1.90
EVAPOTRANSPIRATION	435.487	4354.874	90.71
PERC./LEAKAGE THROUGH LAYER 4	0.096998	0.970	0.02
AVG. HEAD ON TOP OF LAYER 3	607.3085		
CHANGE IN WATER STORAGE	35.398	353.982	7.37
SOIL WATER AT START OF YEAR	3055.965	30559.648	
SOIL WATER AT END OF YEAR	3091.363	30913.631	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0004	0.004	0.00

ANNUAL TOTALS FOR YEAR 1998

	MM	CU. METERS	PERCENT
PRECIPITATION	541.90	5419.001	100.00
RUNOFF	45.308	453.075	8.36
EVAPOTRANSPIRATION	473.164	4731.638	87.32
PERC./LEAKAGE THROUGH LAYER 4	0.118320	1.183	0.02
AVG. HEAD ON TOP OF LAYER 3	742.8466		
CHANGE IN WATER STORAGE	23.310	233.100	4.30
SOIL WATER AT START OF YEAR	3091.363	30913.631	
SOIL WATER AT END OF YEAR	3114.673	31146.730	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0005	0.005	0.00

B2. Output of Profile No.2

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******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.04   (13 MARCH 1995)                 **
**                 DEVELOPED BY ENVIRONMENTAL LABORATORY                    **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************
PRECIPITATION DATA FILE:     C:\GEOLOGY\HELP3\ANKA.D4
TEMPERATURE DATA FILE:       C:\GEOLOGY\HELP3\ANKA.D7
SOLAR RADIATION DATA FILE:   C:\GEOLOGY\HELP3\ANKA.D13
EVAPOTRANSPIRATION DATA:     C:\GEOLOGY\HELP3\ANKA.D11
SOIL AND DESIGN DATA FILE:   C:\GEOLOGY\HELP3\PROFILE2.D10
OUTPUT DATA FILE:            C:\GEOLOGY\HELP3\anka2.OUT
TIME:  23:27     DATE:   6/15/1999
******************************************************************************
     TITLE:  Profile No.2
******************************************************************************
     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.
                                   LAYER  1
                                   --------
                    TYPE 1 - VERTICAL PERCOLATION LAYER
                        MATERIAL TEXTURE NUMBER  15
           THICKNESS                    =    100.00   CM
           POROSITY                     =      0.4750 VOL/VOL
           FIELD CAPACITY               =      0.3780 VOL/VOL
           WILTING POINT                =      0.2650 VOL/VOL
           INITIAL SOIL WATER CONTENT   =      0.3467 VOL/VOL
           EFFECTIVE SAT. HYD. COND.    =  0.170000003000E-04 CM/SEC
        NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  3.00
                FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.
                                   LAYER  2
                                   --------
                        TYPE 3 - BARRIER SOIL LINER
                        MATERIAL TEXTURE NUMBER   0
           THICKNESS                    =     60.00   CM
           POROSITY                     =      0.4620 VOL/VOL
           FIELD CAPACITY               =      0.2450 VOL/VOL
           WILTING POINT                =      0.0590 VOL/VOL
           INITIAL SOIL WATER CONTENT   =      0.4620 VOL/VOL
           EFFECTIVE SAT. HYD. COND.    =  0.999999994000E-08 CM/SEC
                                   LAYER  3
                                   --------
                    TYPE 1 - VERTICAL PERCOLATION LAYER
                        MATERIAL TEXTURE NUMBER  18
           THICKNESS                    =    750.00   CM
           POROSITY                     =      0.6710 VOL/VOL
           FIELD CAPACITY               =      0.2920 VOL/VOL
           WILTING POINT                =      0.0770 VOL/VOL
           INITIAL SOIL WATER CONTENT   =      0.2925 VOL/VOL
           EFFECTIVE SAT. HYD. COND.    =  0.100000005000E-02 CM/SEC
                                   LAYER  4
                                   --------
                      TYPE 4 - FLEXIBLE MEMBRANE LINER
                        MATERIAL TEXTURE NUMBER  35
           THICKNESS                    =      0.20   CM
           POROSITY                     =      0.0000 VOL/VOL
           FIELD CAPACITY               =      0.0000 VOL/VOL
           WILTING POINT                =      0.0000 VOL/VOL
           INITIAL SOIL WATER CONTENT   =      0.0000 VOL/VOL
           EFFECTIVE SAT. HYD. COND.    =  0.199999996000E-12 CM/SEC
           FML PINHOLE DENSITY          =      1.00   HOLES/HECTARE
           FML INSTALLATION DEFECTS     =     10.00   HOLES/HECTARE
           FML PLACEMENT QUALITY        =  3 - GOOD
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                    LAYER  5
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             TYPE 3 - BARRIER SOIL LINER
             MATERIAL TEXTURE NUMBER  45
   THICKNESS                 =     60.00   CM
   POROSITY                  =      0.4620 VOL/VOL
   FIELD CAPACITY            =      0.2450 VOL/VOL
   WILTING POINT             =      0.0590 VOL/VOL
   INITIAL SOIL WATER CONTENT  =    0.4620 VOL/VOL
   EFFECTIVE SAT. HYD. COND.   = 0.999999994000E-08 CM/SEC
         GENERAL DESIGN AND EVAPORATIVE ZONE DATA
         ----------------------------------------
 NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
        SOIL DATA BASE USING SOIL TEXTURE #15 WITH A
        FAIR STAND OF GRASS, A SURFACE SLOPE OF  3.%
        AND A SLOPE LENGTH OF  100. METERS.
 SCS RUNOFF CURVE NUMBER            =     90.00
 FRACTION OF AREA ALLOWING RUNOFF   =    100.0    PERCENT
 AREA PROJECTED ON HORIZONTAL PLANE =      1.0000 HECTARES
 EVAPORATIVE ZONE DEPTH             =     91.0    CM
 INITIAL WATER IN EVAPORATIVE ZONE  =     30.628  CM
 UPPER LIMIT OF EVAPORATIVE STORAGE =     43.225  CM
 LOWER LIMIT OF EVAPORATIVE STORAGE =     24.115  CM
 INITIAL SNOW WATER                 =      0.000  CM
 INITIAL WATER IN LAYER MATERIALS   =    309.450  CM
 TOTAL INITIAL WATER                =    309.450  CM
 TOTAL SUBSURFACE INFLOW            =      0.00   MM/YR
          EVAPOTRANSPIRATION AND WEATHER DATA
          -----------------------------------
 NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
        ANKARA                   TURKEY
      STATION LATITUDE                        =  39.77 DEGREES
      MAXIMUM LEAF AREA INDEX                 =   2.00
      START OF GROWING SEASON (JULIAN DATE)   =   85
      END OF GROWING SEASON (JULIAN DATE)     =  301
      EVAPORATIVE ZONE DEPTH                  =  91.0  CM
      AVERAGE ANNUAL WIND SPEED               =   7.20 KPH
      AVERAGE 1ST QUARTER RELATIVE HUMIDITY   =  73.00 %
      AVERAGE 2ND QUARTER RELATIVE HUMIDITY   =  60.67 %
      AVERAGE 3RD QUARTER RELATIVE HUMIDITY   =  55.33 %
      AVERAGE 4TH QUARTER RELATIVE HUMIDITY   =  70.67 %
 NOTE:  PRECIPITATION DATA FOR    ANKARA                TURKEY
        WAS ENTERED BY THE USER.
 NOTE:  TEMPERATURE DATA FOR    ANKARA                TURKEY
        WAS ENTERED BY THE USER.
       NORMAL MEAN MONTHLY TEMPERATURE (DEGREES CELSIUS)
JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
-------     -------     -------     -------     -------     -------
  -0.1        0.5         4.4        10.4        14.5        17.6
  20.5       20.4        16.9        11.5         5.2         1.8


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                    ANNUAL TOTALS FOR YEAR 1979
------------------------------------------------------------------------------
                                       MM          CU. METERS     PERCENT
                                   ----------      ----------     -------
 PRECIPITATION                       512.50          5125.001     100.00
 RUNOFF                               27.250          272.495       5.32
 EVAPOTRANSPIRATION                  477.655         4776.549      93.20
 PERC./LEAKAGE THROUGH LAYER  2        3.605134        36.051       0.70
 AVG. HEAD ON TOP OF LAYER  2         85.7857
 PERC./LEAKAGE THROUGH LAYER  5        0.002807         0.028       0.00
 AVG. HEAD ON TOP OF LAYER  4         13.6783
 CHANGE IN WATER STORAGE               7.593           75.928       1.48
 SOIL WATER AT START OF YEAR        3094.504        30945.043
 SOIL WATER AT END OF YEAR          3102.097        31020.971
 SNOW WATER AT START OF YEAR           0.000            0.000       0.00
 SNOW WATER AT END OF YEAR             0.000            0.000       0.00
 ANNUAL WATER BUDGET BALANCE           0.0001           0.001       0.00
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ANNUAL TOTALS FOR YEAR 1980

	MM	CU. METERS	PERCENT
PRECIPITATION	511.30	5113.001	100.00
RUNOFF	68.870	688.700	13.47
EVAPOTRANSPIRATION	416.305	4163.053	81.42
PERC./LEAKAGE THROUGH LAYER 2	3.935731	39.357	0.77
AVG. HEAD ON TOP OF LAYER 2	146.7550		
PERC./LEAKAGE THROUGH LAYER 5	0.004673	0.047	0.00
AVG. HEAD ON TOP OF LAYER 4	23.7602		
CHANGE IN WATER STORAGE	26.120	261.201	5.11
SOIL WATER AT START OF YEAR	3102.097	31020.969	
SOIL WATER AT END OF YEAR	3128.217	31282.170	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0001	0.001	0.00

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ANNUAL TOTALS FOR YEAR 1981

	MM	CU. METERS	PERCENT
PRECIPITATION	482.10	4821.001	100.00
RUNOFF	42.541	425.413	8.82
EVAPOTRANSPIRATION	447.611	4476.111	92.85
PERC./LEAKAGE THROUGH LAYER 2	4.094774	40.948	0.85
AVG. HEAD ON TOP OF LAYER 2	179.6356		
PERC./LEAKAGE THROUGH LAYER 5	0.006563	0.066	0.00
AVG. HEAD ON TOP OF LAYER 4	34.4541		
CHANGE IN WATER STORAGE	-8.059	-80.590	-1.67
SOIL WATER AT START OF YEAR	3128.217	31282.170	
SOIL WATER AT END OF YEAR	3120.158	31201.580	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0002	0.002	0.00

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ANNUAL TOTALS FOR YEAR 1982

	MM	CU. METERS	PERCENT
PRECIPITATION	324.70	3247.001	100.00
RUNOFF	34.351	343.511	10.58
EVAPOTRANSPIRATION	354.628	3546.280	109.22
PERC./LEAKAGE THROUGH LAYER 2	3.440036	34.400	1.06
AVG. HEAD ON TOP OF LAYER 2	54.5810		
PERC./LEAKAGE THROUGH LAYER 5	0.008247	0.082	0.00
AVG. HEAD ON TOP OF LAYER 4	44.1448		
CHANGE IN WATER STORAGE	-64.309	-643.087	-19.81
SOIL WATER AT START OF YEAR	3120.158	31201.580	
SOIL WATER AT END OF YEAR	3055.849	30558.492	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0214	0.214	0.01

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ANNUAL TOTALS FOR YEAR 1983

	MM	CU. METERS	PERCENT
PRECIPITATION	606.70	6067.000	100.00
RUNOFF	51.892	518.922	8.55
EVAPOTRANSPIRATION	444.747	4447.469	73.31
PERC./LEAKAGE THROUGH LAYER 2	3.273468	32.735	0.54
AVG. HEAD ON TOP OF LAYER 2	22.8429		
PERC./LEAKAGE THROUGH LAYER 5	0.009755	0.098	0.00
AVG. HEAD ON TOP OF LAYER 4	52.9613		
CHANGE IN WATER STORAGE	110.051	1100.510	18.14
SOIL WATER AT START OF YEAR	3055.849	30558.492	
SOIL WATER AT END OF YEAR	3165.900	31659.004	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00

SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0001	0.001	0.00

ANNUAL TOTALS FOR YEAR 1984

	MM	CU. METERS	PERCENT
PRECIPITATION	310.60	3106.001	100.00
RUNOFF	11.462	114.625	3.69
EVAPOTRANSPIRATION	391.084	3910.837	125.91
PERC./LEAKAGE THROUGH LAYER 2	3.935820	39.358	1.27
AVG. HEAD ON TOP OF LAYER 2	147.0829		
PERC./LEAKAGE THROUGH LAYER 5	0.011425	0.114	0.00
AVG. HEAD ON TOP OF LAYER 4	62.6627		
CHANGE IN WATER STORAGE	-91.957	-919.572	-29.61
SOIL WATER AT START OF YEAR	3165.900	31659.004	
SOIL WATER AT END OF YEAR	3073.943	30739.432	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.0003	-0.003	0.00

ANNUAL TOTALS FOR YEAR 1985

	MM	CU. METERS	PERCENT
PRECIPITATION	478.10	4781.000	100.00
RUNOFF	49.182	491.823	10.29
EVAPOTRANSPIRATION	344.993	3449.934	72.16
PERC./LEAKAGE THROUGH LAYER 2	3.432106	34.321	0.72
AVG. HEAD ON TOP OF LAYER 2	53.0743		
PERC./LEAKAGE THROUGH LAYER 5	0.012983	0.130	0.00
AVG. HEAD ON TOP OF LAYER 4	72.1496		
CHANGE IN WATER STORAGE	83.911	839.110	17.55
SOIL WATER AT START OF YEAR	3073.943	30739.432	
SOIL WATER AT END OF YEAR	3157.854	31578.541	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0004	0.004	0.00

ANNUAL TOTALS FOR YEAR 1986

	MM	CU. METERS	PERCENT
PRECIPITATION	372.50	3725.000	100.00
RUNOFF	62.992	629.920	16.91
EVAPOTRANSPIRATION	379.513	3795.126	101.88
PERC./LEAKAGE THROUGH LAYER 2	4.043622	40.436	1.09
AVG. HEAD ON TOP OF LAYER 2	170.8385		
PERC./LEAKAGE THROUGH LAYER 5	0.014656	0.147	0.00
AVG. HEAD ON TOP OF LAYER 4	82.2244		
CHANGE IN WATER STORAGE	-70.019	-700.194	-18.80
SOIL WATER AT START OF YEAR	3157.854	31578.541	
SOIL WATER AT END OF YEAR	3087.835	30878.348	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	0.000	0.00

ANNUAL TOTALS FOR YEAR 1987

	MM	CU. METERS	PERCENT
PRECIPITATION	494.60	4946.001	100.00
RUNOFF	74.210	742.104	15.00
EVAPOTRANSPIRATION	372.930	3729.296	75.40
PERC./LEAKAGE THROUGH LAYER 2	3.837657	38.377	0.78
AVG. HEAD ON TOP OF LAYER 2	130.1240		
PERC./LEAKAGE THROUGH LAYER 5	0.016329	0.163	0.00
AVG. HEAD ON TOP OF LAYER 4	92.3909		
CHANGE IN WATER STORAGE	47.444	474.436	9.59

SOIL WATER AT START OF YEAR	3087.835	30878.348	
SOIL WATER AT END OF YEAR	3135.278	31352.783	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0001	0.001	0.00

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ANNUAL TOTALS FOR YEAR 1988

	MM	CU. METERS	PERCENT
PRECIPITATION	588.30	5882.999	100.00
RUNOFF	59.920	599.199	10.19
EVAPOTRANSPIRATION	484.583	4845.830	82.37
PERC./LEAKAGE THROUGH LAYER 2	3.719018	37.190	0.63
AVG. HEAD ON TOP OF LAYER 2	105.7208		
PERC./LEAKAGE THROUGH LAYER 5	0.017993	0.180	0.00
AVG. HEAD ON TOP OF LAYER 4	102.2743		
CHANGE IN WATER STORAGE	43.779	437.791	7.44
SOIL WATER AT START OF YEAR	3135.278	31352.783	
SOIL WATER AT END OF YEAR	3179.057	31790.574	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.0001	-0.001	0.00

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ANNUAL TOTALS FOR YEAR 1989

	MM	CU. METERS	PERCENT
PRECIPITATION	467.00	4670.000	100.00
RUNOFF	19.480	194.803	4.17
EVAPOTRANSPIRATION	443.206	4432.062	94.90
PERC./LEAKAGE THROUGH LAYER 2	3.808194	38.082	0.82
AVG. HEAD ON TOP OF LAYER 2	124.9249		
PERC./LEAKAGE THROUGH LAYER 5	0.019565	0.196	0.00
AVG. HEAD ON TOP OF LAYER 4	112.2293		
CHANGE IN WATER STORAGE	4.294	42.936	0.92
SOIL WATER AT START OF YEAR	3179.057	31790.574	
SOIL WATER AT END OF YEAR	3156.351	31563.508	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	27.000	270.004	5.78
ANNUAL WATER BUDGET BALANCE	0.0002	0.002	0.00

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ANNUAL TOTALS FOR YEAR 1990

	MM	CU. METERS	PERCENT
PRECIPITATION	409.70	4097.000	100.00
RUNOFF	44.365	443.654	10.83
EVAPOTRANSPIRATION	413.234	4132.343	100.86
PERC./LEAKAGE THROUGH LAYER 2	3.438027	34.380	0.84
AVG. HEAD ON TOP OF LAYER 2	54.1992		
PERC./LEAKAGE THROUGH LAYER 5	0.021088	0.211	0.01
AVG. HEAD ON TOP OF LAYER 4	121.6424		
CHANGE IN WATER STORAGE	-47.921	-479.206	-11.70
SOIL WATER AT START OF YEAR	3156.351	31563.506	
SOIL WATER AT END OF YEAR	3135.430	31354.303	
SNOW WATER AT START OF YEAR	27.000	270.004	6.59
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.0002	-0.002	0.00

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ANNUAL TOTALS FOR YEAR 1991

	MM	CU. METERS	PERCENT
PRECIPITATION	412.80	4128.000	100.00
RUNOFF	32.111	321.115	7.78
EVAPOTRANSPIRATION	372.759	3727.587	90.30
PERC./LEAKAGE THROUGH LAYER 2	3.276608	32.766	0.79
AVG. HEAD ON TOP OF LAYER 2	23.4629		

PERC./LEAKAGE THROUGH LAYER 5	0.022505	0.225	0.01
AVG. HEAD ON TOP OF LAYER 4	130.4324		
CHANGE IN WATER STORAGE	7.908	79.077	1.92
SOIL WATER AT START OF YEAR	3135.430	31354.301	
SOIL WATER AT END OF YEAR	3143.338	31433.377	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.0002	-0.002	0.00

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ANNUAL TOTALS FOR YEAR 1992

	MM	CU. METERS	PERCENT
PRECIPITATION	483.40	4834.000	100.00
RUNOFF	29.334	293.336	6.07
EVAPOTRANSPIRATION	434.676	4346.761	89.92
PERC./LEAKAGE THROUGH LAYER 2	0.962567	9.626	0.20
AVG. HEAD ON TOP OF LAYER 2	1.4140		
PERC./LEAKAGE THROUGH LAYER 5	0.023597	0.236	0.00
AVG. HEAD ON TOP OF LAYER 4	136.8421		
CHANGE IN WATER STORAGE	19.366	193.665	4.01
SOIL WATER AT START OF YEAR	3143.338	31433.377	
SOIL WATER AT END OF YEAR	3162.704	31627.041	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0002	0.002	0.00

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ANNUAL TOTALS FOR YEAR 1993

	MM	CU. METERS	PERCENT
PRECIPITATION	400.40	4003.999	100.00
RUNOFF	53.993	539.925	13.48
EVAPOTRANSPIRATION	362.273	3622.732	90.48
PERC./LEAKAGE THROUGH LAYER 2	2.177639	21.776	0.54
AVG. HEAD ON TOP OF LAYER 2	21.5848		
PERC./LEAKAGE THROUGH LAYER 5	0.023891	0.239	0.01
AVG. HEAD ON TOP OF LAYER 4	139.0695		
CHANGE IN WATER STORAGE	-15.890	-158.895	-3.97
SOIL WATER AT START OF YEAR	3162.704	31627.041	
SOIL WATER AT END OF YEAR	3146.815	31468.146	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.0002	-0.002	0.00

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ANNUAL TOTALS FOR YEAR 1994

	MM	CU. METERS	PERCENT
PRECIPITATION	337.30	3373.001	100.00
RUNOFF	10.083	100.828	2.99
EVAPOTRANSPIRATION	306.004	3060.039	90.72
PERC./LEAKAGE THROUGH LAYER 2	3.451842	34.518	1.02
AVG. HEAD ON TOP OF LAYER 2	56.5893		
PERC./LEAKAGE THROUGH LAYER 5	0.025215	0.252	0.01
AVG. HEAD ON TOP OF LAYER 4	147.3275		
CHANGE IN WATER STORAGE	21.067	210.669	6.25
SOIL WATER AT START OF YEAR	3146.815	31468.146	
SOIL WATER AT END OF YEAR	3167.882	31678.816	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.1213	1.213	0.04

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ANNUAL TOTALS FOR YEAR 1995

	MM	CU. METERS	PERCENT
PRECIPITATION	425.70	4257.001	100.00
RUNOFF	7.673	76.732	1.80

EVAPOTRANSPIRATION	448.019	4480.190	105.24
PERC./LEAKAGE THROUGH LAYER 2	3.773217	37.732	0.89
AVG. HEAD ON TOP OF LAYER 2	117.8190		
PERC./LEAKAGE THROUGH LAYER 5	0.026744	0.267	0.01
AVG. HEAD ON TOP OF LAYER 4	156.9001		
CHANGE IN WATER STORAGE	-30.019	-300.189	-7.05
SOIL WATER AT START OF YEAR	3167.882	31678.816	
SOIL WATER AT END OF YEAR	3137.863	31378.627	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	0.000	0.00

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ANNUAL TOTALS FOR YEAR 1996

	MM	CU. METERS	PERCENT
PRECIPITATION	398.60	3986.002	100.00
RUNOFF	20.447	204.472	5.13
EVAPOTRANSPIRATION	345.421	3454.209	86.66
PERC./LEAKAGE THROUGH LAYER 2	3.445993	34.460	0.86
AVG. HEAD ON TOP OF LAYER 2	53.8811		
PERC./LEAKAGE THROUGH LAYER 5	0.028323	0.283	0.01
AVG. HEAD ON TOP OF LAYER 4	166.3440		
CHANGE IN WATER STORAGE	32.703	327.034	8.20
SOIL WATER AT START OF YEAR	3137.863	31378.629	
SOIL WATER AT END OF YEAR	3170.566	31705.662	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0004	0.004	0.00

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ANNUAL TOTALS FOR YEAR 1997

	MM	CU. METERS	PERCENT
PRECIPITATION	480.10	4801.000	100.00
RUNOFF	9.143	91.433	1.90
EVAPOTRANSPIRATION	434.439	4344.395	90.49
PERC./LEAKAGE THROUGH LAYER 2	3.259307	32.593	0.68
AVG. HEAD ON TOP OF LAYER 2	20.1897		
PERC./LEAKAGE THROUGH LAYER 5	0.029638	0.296	0.01
AVG. HEAD ON TOP OF LAYER 4	175.0996		
CHANGE IN WATER STORAGE	36.487	364.873	7.60
SOIL WATER AT START OF YEAR	3170.566	31705.664	
SOIL WATER AT END OF YEAR	3207.054	32070.539	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0003	0.003	0.00

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ANNUAL TOTALS FOR YEAR 1998

	MM	CU. METERS	PERCENT
PRECIPITATION	541.90	5419.001	100.00
RUNOFF	51.226	512.258	9.45
EVAPOTRANSPIRATION	533.153	5331.529	98.39
PERC./LEAKAGE THROUGH LAYER 2	4.096183	40.962	0.76
AVG. HEAD ON TOP OF LAYER 2	179.3294		
PERC./LEAKAGE THROUGH LAYER 5	0.031174	0.312	0.01
AVG. HEAD ON TOP OF LAYER 4	184.7864		
CHANGE IN WATER STORAGE	-42.510	-425.098	-7.84
SOIL WATER AT START OF YEAR	3207.054	32070.537	
SOIL WATER AT END OF YEAR	3164.544	31645.437	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	0.000	0.00

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B3. Output of Profile No.3

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******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**             HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE                **
**               HELP MODEL VERSION 3.04   (13 MARCH 1995)                  **
**                 DEVELOPED BY ENVIRONMENTAL LABORATORY                    **
**                   USAE WATERWAYS EXPERIMENT STATION                      **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************
PRECIPITATION DATA FILE:     C:\GEOLOGY\HELP3\ANKA.D4
TEMPERATURE DATA FILE:       C:\GEOLOGY\HELP3\ANKA.D7
SOLAR RADIATION DATA FILE:   C:\GEOLOGY\HELP3\ANKA.D13
EVAPOTRANSPIRATION DATA:     C:\GEOLOGY\HELP3\ANKA.D11
SOIL AND DESIGN DATA FILE:   C:\GEOLOGY\HELP3\PROFILE3.D10
OUTPUT DATA FILE:            C:\GEOLOGY\HELP3\anka3.OUT
TIME:  23:32     DATE:   6/15/1999
******************************************************************************
     TITLE:  Profile No.3
******************************************************************************
     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.
                                   LAYER  1
                                   --------
                      TYPE 1 - VERTICAL PERCOLATION LAYER
                          MATERIAL TEXTURE NUMBER  15
           THICKNESS                     =    100.00    CM
           POROSITY                      =      0.4750 VOL/VOL
           FIELD CAPACITY                =      0.3780 VOL/VOL
           WILTING POINT                 =      0.2650 VOL/VOL
           INITIAL SOIL WATER CONTENT    =      0.3467 VOL/VOL
           EFFECTIVE SAT. HYD. COND.     =  0.170000003000E-04 CM/SEC
       NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  3.00
                FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.
                                   LAYER  2
                                   --------
                          TYPE 3 - BARRIER SOIL LINER
                          MATERIAL TEXTURE NUMBER  45
           THICKNESS                     =     60.00    CM
           POROSITY                      =      0.4620 VOL/VOL
           FIELD CAPACITY                =      0.2450 VOL/VOL
           WILTING POINT                 =      0.0590 VOL/VOL
           INITIAL SOIL WATER CONTENT    =      0.4620 VOL/VOL
           EFFECTIVE SAT. HYD. COND.     =  0.999999994000E-08 CM/SEC
                                   LAYER  3
                                   --------
                      TYPE 1 - VERTICAL PERCOLATION LAYER
                          MATERIAL TEXTURE NUMBER  18
           THICKNESS                     =    750.00    CM
           POROSITY                      =      0.6710 VOL/VOL
           FIELD CAPACITY                =      0.2920 VOL/VOL
           WILTING POINT                 =      0.0770 VOL/VOL
           INITIAL SOIL WATER CONTENT    =      0.2920 VOL/VOL
           EFFECTIVE SAT. HYD. COND.     =  0.100000005000E-02 CM/SEC
                                   LAYER  4
                                   --------
                        TYPE 2 - LATERAL DRAINAGE LAYER
                          MATERIAL TEXTURE NUMBER   5
           THICKNESS                     =     30.00    CM
           POROSITY                      =      0.4570 VOL/VOL
           FIELD CAPACITY                =      0.1310 VOL/VOL
           WILTING POINT                 =      0.0580 VOL/VOL
           INITIAL SOIL WATER CONTENT    =      0.1422 VOL/VOL
           EFFECTIVE SAT. HYD. COND.     =  0.100000005000E-02 CM/SEC
                                   LAYER  5
                                   --------
                        TYPE 2 - LATERAL DRAINAGE LAYER
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                    MATERIAL TEXTURE NUMBER  20
      THICKNESS                      =       0.50   CM
      POROSITY                       =       0.8500 VOL/VOL
      FIELD CAPACITY                 =       0.0100 VOL/VOL
      WILTING POINT                  =       0.0050 VOL/VOL
      INITIAL SOIL WATER CONTENT     =       0.0100 VOL/VOL
      EFFECTIVE SAT. HYD. COND.      =   10.0000000000      CM/SEC
      SLOPE                          =       3.00   PERCENT
      DRAINAGE LENGTH                =      50.0    METERS
                              LAYER  6
                              --------
                  TYPE 4 - FLEXIBLE MEMBRANE LINER
                    MATERIAL TEXTURE NUMBER  35
      THICKNESS                      =       0.20   CM
      POROSITY                       =       0.0000 VOL/VOL
      FIELD CAPACITY                 =       0.0000 VOL/VOL
      WILTING POINT                  =       0.0000 VOL/VOL
      INITIAL SOIL WATER CONTENT     =       0.0000 VOL/VOL
      EFFECTIVE SAT. HYD. COND.      =  0.199999996000E-12 CM/SEC
      FML PINHOLE DENSITY            =       1.00   HOLES/HECTARE
      FML INSTALLATION DEFECTS       =      10.00   HOLES/HECTARE
      FML PLACEMENT QUALITY          =  3 - GOOD
                              LAYER  7
                              --------
                    TYPE 3 - BARRIER SOIL LINER
                    MATERIAL TEXTURE NUMBER  45
      THICKNESS                      =      60.00   CM
      POROSITY                       =       0.4620 VOL/VOL
      FIELD CAPACITY                 =       0.2450 VOL/VOL
      WILTING POINT                  =       0.0590 VOL/VOL
      INITIAL SOIL WATER CONTENT     =       0.4620 VOL/VOL
      EFFECTIVE SAT. HYD. COND.      =  0.999999994000E-08 CM/SEC
GENERAL DESIGN AND EVAPORATIVE ZONE DATA
                    ----------------------------------------
          NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
                 SOIL DATA BASE USING SOIL TEXTURE #15 WITH A
                 FAIR STAND OF GRASS, A SURFACE SLOPE OF  3.%
                 AND A SLOPE LENGTH OF  100. METERS.
         SCS RUNOFF CURVE NUMBER              =     90.00
         FRACTION OF AREA ALLOWING RUNOFF     =    100.0     PERCENT
         AREA PROJECTED ON HORIZONTAL PLANE   =      1.0000 HECTARES
         EVAPORATIVE ZONE DEPTH               =     91.0     CM
         INITIAL WATER IN EVAPORATIVE ZONE    =     30.628   CM
         UPPER LIMIT OF EVAPORATIVE STORAGE   =     43.225   CM
         LOWER LIMIT OF EVAPORATIVE STORAGE   =     24.115   CM
         INITIAL SNOW WATER                   =      0.000   CM
         INITIAL WATER IN LAYER MATERIALS     =    313.382   CM
         TOTAL INITIAL WATER                  =    313.382   CM
         TOTAL SUBSURFACE INFLOW              =      0.00    MM/YR
EVAPOTRANSPIRATION AND WEATHER DATA
                    ------------------------------------
          NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
                 ANKARA                      TURKEY
            STATION LATITUDE                         =  39.77 DEGREES
            MAXIMUM LEAF AREA INDEX                  =   2.00
            START OF GROWING SEASON (JULIAN DATE)    =     85
            END OF GROWING SEASON (JULIAN DATE)      =    301
            EVAPORATIVE ZONE DEPTH                   =  91.0  CM
            AVERAGE ANNUAL WIND SPEED                =   7.20 KPH
            AVERAGE 1ST QUARTER RELATIVE HUMIDITY    =  73.00 %
            AVERAGE 2ND QUARTER RELATIVE HUMIDITY    =  60.67 %
            AVERAGE 3RD QUARTER RELATIVE HUMIDITY    =  55.33 %
            AVERAGE 4TH QUARTER RELATIVE HUMIDITY    =  70.67 %
NOTE:  PRECIPITATION DATA FOR     ANKARA              TURKEY
                 WAS ENTERED BY THE USER.
NOTE:  TEMPERATURE DATA FOR     ANKARA              TURKEY
                 WAS ENTERED BY THE USER.
              NORMAL MEAN MONTHLY TEMPERATURE (DEGREES CELSIUS)
     JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
     -------     -------     -------     -------     -------     -------
       -0.1         0.5         4.4        10.4        14.5        17.6
       20.5        20.4        16.9        11.5         5.2         1.8
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ANNUAL TOTALS FOR YEAR 1979

	MM	CU. METERS	PERCENT
PRECIPITATION	512.50	5125.001	100.00
RUNOFF	27.250	272.495	5.32
EVAPOTRANSPIRATION	477.655	4776.549	93.20
PERC./LEAKAGE THROUGH LAYER 2	3.605134	36.051	0.70
AVG. HEAD ON TOP OF LAYER 2	85.7857		
DRAINAGE COLLECTED FROM LAYER 5	1.4926	14.926	0.29
PERC./LEAKAGE THROUGH LAYER 7	0.000021	0.000	0.00
AVG. HEAD ON TOP OF LAYER 6	0.0006		
CHANGE IN WATER STORAGE	6.103	61.025	1.19
SOIL WATER AT START OF YEAR	3133.817	31338.174	
SOIL WATER AT END OF YEAR	3139.920	31399.199	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0006	0.006	0.00

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ANNUAL TOTALS FOR YEAR 1980

	MM	CU. METERS	PERCENT
PRECIPITATION	511.30	5113.001	100.00
RUNOFF	68.870	688.700	13.47
EVAPOTRANSPIRATION	416.305	4163.053	81.42
PERC./LEAKAGE THROUGH LAYER 2	3.935731	39.357	0.77
AVG. HEAD ON TOP OF LAYER 2	146.7550		
DRAINAGE COLLECTED FROM LAYER 5	3.2553	32.553	0.64
PERC./LEAKAGE THROUGH LAYER 7	0.000021	0.000	0.00
AVG. HEAD ON TOP OF LAYER 6	0.0013		
CHANGE IN WATER STORAGE	22.870	228.695	4.47
SOIL WATER AT START OF YEAR	3139.920	31399.199	
SOIL WATER AT END OF YEAR	3162.790	31627.895	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	0.000	0.00

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ANNUAL TOTALS FOR YEAR 1981

	MM	CU. METERS	PERCENT
PRECIPITATION	482.10	4821.001	100.00
RUNOFF	42.541	425.413	8.82
EVAPOTRANSPIRATION	447.611	4476.111	92.85
PERC./LEAKAGE THROUGH LAYER 2	4.094774	40.948	0.85
AVG. HEAD ON TOP OF LAYER 2	179.6356		
DRAINAGE COLLECTED FROM LAYER 5	3.9128	39.128	0.81
PERC./LEAKAGE THROUGH LAYER 7	0.000021	0.000	0.00
AVG. HEAD ON TOP OF LAYER 6	0.0016		
CHANGE IN WATER STORAGE	-11.965	-119.654	-2.48
SOIL WATER AT START OF YEAR	3162.790	31627.895	
SOIL WATER AT END OF YEAR	3150.824	31508.240	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0002	0.002	0.00

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ANNUAL TOTALS FOR YEAR 1982

	MM	CU. METERS	PERCENT
PRECIPITATION	324.70	3247.001	100.00
RUNOFF	34.351	343.511	10.58
EVAPOTRANSPIRATION	354.628	3546.280	109.22
PERC./LEAKAGE THROUGH LAYER 2	3.440036	34.400	1.06
AVG. HEAD ON TOP OF LAYER 2	54.5810		
DRAINAGE COLLECTED FROM LAYER 5	3.8392	38.392	1.18
PERC./LEAKAGE THROUGH LAYER 7	0.000021	0.000	0.00

AVG. HEAD ON TOP OF LAYER 6	0.0016		
CHANGE IN WATER STORAGE	-68.140	-681.398	-20.99
SOIL WATER AT START OF YEAR	3150.824	31508.242	
SOIL WATER AT END OF YEAR	3082.685	30826.844	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0216	0.216	0.01

ANNUAL TOTALS FOR YEAR 1983

	MM	CU. METERS	PERCENT
PRECIPITATION	606.70	6067.000	100.00
RUNOFF	51.892	518.922	8.55
EVAPOTRANSPIRATION	444.747	4447.469	73.31
PERC./LEAKAGE THROUGH LAYER 2	3.273468	32.735	0.54
AVG. HEAD ON TOP OF LAYER 2	22.8429		
DRAINAGE COLLECTED FROM LAYER 5	3.4889	34.889	0.58
PERC./LEAKAGE THROUGH LAYER 7	0.000021	0.000	0.00
AVG. HEAD ON TOP OF LAYER 6	0.0014		
CHANGE IN WATER STORAGE	106.572	1065.720	17.57
SOIL WATER AT START OF YEAR	3082.685	30826.846	
SOIL WATER AT END OF YEAR	3189.257	31892.566	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	0.000	0.00

ANNUAL TOTALS FOR YEAR 1984

	MM	CU. METERS	PERCENT
PRECIPITATION	310.60	3106.001	100.00
RUNOFF	11.462	114.625	3.69
EVAPOTRANSPIRATION	391.084	3910.837	125.91
PERC./LEAKAGE THROUGH LAYER 2	3.935820	39.358	1.27
AVG. HEAD ON TOP OF LAYER 2	147.0829		
DRAINAGE COLLECTED FROM LAYER 5	3.4918	34.918	1.12
PERC./LEAKAGE THROUGH LAYER 7	0.000021	0.000	0.00
AVG. HEAD ON TOP OF LAYER 6	0.0014		
CHANGE IN WATER STORAGE	-95.438	-954.378	-30.73
SOIL WATER AT START OF YEAR	3189.257	31892.566	
SOIL WATER AT END OF YEAR	3093.819	30938.189	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	0.000	0.00

ANNUAL TOTALS FOR YEAR 1985

	MM	CU. METERS	PERCENT
PRECIPITATION	478.10	4781.000	100.00
RUNOFF	49.182	491.823	10.29
EVAPOTRANSPIRATION	344.993	3449.934	72.16
PERC./LEAKAGE THROUGH LAYER 2	3.432106	34.321	0.72
AVG. HEAD ON TOP OF LAYER 2	53.0743		
DRAINAGE COLLECTED FROM LAYER 5	3.6972	36.972	0.77
PERC./LEAKAGE THROUGH LAYER 7	0.000021	0.000	0.00
AVG. HEAD ON TOP OF LAYER 6	0.0015		
CHANGE IN WATER STORAGE	80.227	802.269	16.78
SOIL WATER AT START OF YEAR	3093.819	30938.189	
SOIL WATER AT END OF YEAR	3174.046	31740.457	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0002	0.002	0.00

ANNUAL TOTALS FOR YEAR 1986

	MM	CU. METERS	PERCENT

PRECIPITATION	372.50	3725.000	100.00
RUNOFF	62.992	629.920	16.91
EVAPOTRANSPIRATION	379.513	3795.126	101.88
PERC./LEAKAGE THROUGH LAYER 2	4.043622	40.436	1.09
AVG. HEAD ON TOP OF LAYER 2	170.8385		
DRAINAGE COLLECTED FROM LAYER 5	3.6876	36.876	0.99
PERC./LEAKAGE THROUGH LAYER 7	0.000021	0.000	0.00
AVG. HEAD ON TOP OF LAYER 6	0.0015		
CHANGE IN WATER STORAGE	-73.692	-736.924	-19.78
SOIL WATER AT START OF YEAR	3174.046	31740.457	
SOIL WATER AT END OF YEAR	3100.353	31003.533	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	0.000	0.00

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ANNUAL TOTALS FOR YEAR 1987

	MM	CU. METERS	PERCENT
PRECIPITATION	494.60	4946.001	100.00
RUNOFF	74.210	742.104	15.00
EVAPOTRANSPIRATION	372.930	3729.296	75.40
PERC./LEAKAGE THROUGH LAYER 2	3.837657	38.377	0.78
AVG. HEAD ON TOP OF LAYER 2	130.1240		
DRAINAGE COLLECTED FROM LAYER 5	3.8638	38.638	0.78
PERC./LEAKAGE THROUGH LAYER 7	0.000021	0.000	0.00
AVG. HEAD ON TOP OF LAYER 6	0.0016		
CHANGE IN WATER STORAGE	43.596	435.962	8.81
SOIL WATER AT START OF YEAR	3100.353	31003.533	
SOIL WATER AT END OF YEAR	3143.949	31439.496	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0001	0.001	0.00

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ANNUAL TOTALS FOR YEAR 1988

	MM	CU. METERS	PERCENT
PRECIPITATION	588.30	5882.999	100.00
RUNOFF	59.920	599.199	10.19
EVAPOTRANSPIRATION	484.583	4845.830	82.37
PERC./LEAKAGE THROUGH LAYER 2	3.719018	37.190	0.63
AVG. HEAD ON TOP OF LAYER 2	105.7208		
DRAINAGE COLLECTED FROM LAYER 5	3.7991	37.991	0.65
PERC./LEAKAGE THROUGH LAYER 7	0.000021	0.000	0.00
AVG. HEAD ON TOP OF LAYER 6	0.0015		
CHANGE IN WATER STORAGE	39.998	399.979	6.80
SOIL WATER AT START OF YEAR	3143.949	31439.496	
SOIL WATER AT END OF YEAR	3183.948	31839.475	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	0.000	0.00

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ANNUAL TOTALS FOR YEAR 1989

	MM	CU. METERS	PERCENT
PRECIPITATION	467.00	4670.000	100.00
RUNOFF	19.480	194.803	4.17
EVAPOTRANSPIRATION	443.206	4432.062	94.90
PERC./LEAKAGE THROUGH LAYER 2	3.808194	38.082	0.82
AVG. HEAD ON TOP OF LAYER 2	124.9249		
DRAINAGE COLLECTED FROM LAYER 5	3.7779	37.779	0.81
PERC./LEAKAGE THROUGH LAYER 7	0.000021	0.000	0.00
AVG. HEAD ON TOP OF LAYER 6	0.0015		
CHANGE IN WATER STORAGE	0.535	5.353	0.11
SOIL WATER AT START OF YEAR	3183.948	31839.475	
SOIL WATER AT END OF YEAR	3157.482	31574.824	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	27.000	270.004	5.78

ANNUAL WATER BUDGET BALANCE	0.0002	0.002	0.00

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ANNUAL TOTALS FOR YEAR 1990

	MM	CU. METERS	PERCENT
PRECIPITATION	409.70	4097.000	100.00
RUNOFF	44.365	443.654	10.83
EVAPOTRANSPIRATION	413.234	4132.343	100.86
PERC./LEAKAGE THROUGH LAYER 2	3.438027	34.380	0.84
AVG. HEAD ON TOP OF LAYER 2	54.1992		
DRAINAGE COLLECTED FROM LAYER 5	3.7096	37.096	0.91
PERC./LEAKAGE THROUGH LAYER 7	0.000021	0.000	0.00
AVG. HEAD ON TOP OF LAYER 6	0.0015		
CHANGE IN WATER STORAGE	-51.609	-516.094	-12.60
SOIL WATER AT START OF YEAR	3157.482	31574.824	
SOIL WATER AT END OF YEAR	3132.874	31328.734	
SNOW WATER AT START OF YEAR	27.000	270.004	6.59
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0001	0.001	0.00

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ANNUAL TOTALS FOR YEAR 1991

	MM	CU. METERS	PERCENT
PRECIPITATION	412.80	4128.000	100.00
RUNOFF	32.111	321.115	7.78
EVAPOTRANSPIRATION	372.759	3727.587	90.30
PERC./LEAKAGE THROUGH LAYER 2	3.276608	32.766	0.79
AVG. HEAD ON TOP OF LAYER 2	23.4629		
DRAINAGE COLLECTED FROM LAYER 5	3.4729	34.729	0.84
PERC./LEAKAGE THROUGH LAYER 7	0.000021	0.000	0.00
AVG. HEAD ON TOP OF LAYER 6	0.0014		
CHANGE IN WATER STORAGE	4.457	44.571	1.08
SOIL WATER AT START OF YEAR	3132.874	31328.734	
SOIL WATER AT END OF YEAR	3137.331	31373.305	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	0.000	0.00

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ANNUAL TOTALS FOR YEAR 1992

	MM	CU. METERS	PERCENT
PRECIPITATION	483.40	4834.000	100.00
RUNOFF	29.334	293.336	6.07
EVAPOTRANSPIRATION	434.676	4346.761	89.92
PERC./LEAKAGE THROUGH LAYER 2	0.962567	9.626	0.20
AVG. HEAD ON TOP OF LAYER 2	1.4140		
DRAINAGE COLLECTED FROM LAYER 5	4.0294	40.294	0.83
PERC./LEAKAGE THROUGH LAYER 7	0.000021	0.000	0.00
AVG. HEAD ON TOP OF LAYER 6	0.0016		
CHANGE IN WATER STORAGE	15.361	153.607	3.18
SOIL WATER AT START OF YEAR	3137.331	31373.305	
SOIL WATER AT END OF YEAR	3152.691	31526.912	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0002	0.002	0.00

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ANNUAL TOTALS FOR YEAR 1993

	MM	CU. METERS	PERCENT
PRECIPITATION	400.40	4003.999	100.00
RUNOFF	53.993	539.925	13.48
EVAPOTRANSPIRATION	362.273	3622.732	90.48
PERC./LEAKAGE THROUGH LAYER 2	2.177639	21.776	0.54
AVG. HEAD ON TOP OF LAYER 2	21.5848		
DRAINAGE COLLECTED FROM LAYER 5	0.9998	9.998	0.25

	MM	CU. METERS	PERCENT
PERC./LEAKAGE THROUGH LAYER 7	0.000013	0.000	0.00
AVG. HEAD ON TOP OF LAYER 6	0.0004		
CHANGE IN WATER STORAGE	-16.865	-168.654	-4.21
SOIL WATER AT START OF YEAR	3152.691	31526.912	
SOIL WATER AT END OF YEAR	3135.826	31358.258	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.0002	-0.002	0.00

ANNUAL TOTALS FOR YEAR 1994

	MM	CU. METERS	PERCENT
PRECIPITATION	337.30	3373.001	100.00
RUNOFF	10.083	100.828	2.99
EVAPOTRANSPIRATION	306.004	3060.039	90.72
PERC./LEAKAGE THROUGH LAYER 2	3.451842	34.518	1.02
AVG. HEAD ON TOP OF LAYER 2	56.5893		
DRAINAGE COLLECTED FROM LAYER 5	1.8073	18.073	0.54
PERC./LEAKAGE THROUGH LAYER 7	0.000021	0.000	0.00
AVG. HEAD ON TOP OF LAYER 6	0.0007		
CHANGE IN WATER STORAGE	19.285	192.851	5.72
SOIL WATER AT START OF YEAR	3135.826	31358.256	
SOIL WATER AT END OF YEAR	3155.111	31551.107	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.1211	1.211	0.04

ANNUAL TOTALS FOR YEAR 1995

	MM	CU. METERS	PERCENT
PRECIPITATION	425.70	4257.001	100.00
RUNOFF	7.673	76.732	1.80
EVAPOTRANSPIRATION	448.019	4480.190	105.24
PERC./LEAKAGE THROUGH LAYER 2	3.773217	37.732	0.89
AVG. HEAD ON TOP OF LAYER 2	117.8190		
DRAINAGE COLLECTED FROM LAYER 5	3.1722	31.722	0.75
PERC./LEAKAGE THROUGH LAYER 7	0.000021	0.000	0.00
AVG. HEAD ON TOP OF LAYER 6	0.0013		
CHANGE IN WATER STORAGE	-33.164	-331.644	-7.79
SOIL WATER AT START OF YEAR	3155.111	31551.107	
SOIL WATER AT END OF YEAR	3121.946	31219.463	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0001	0.001	0.00

ANNUAL TOTALS FOR YEAR 1996

	MM	CU. METERS	PERCENT
PRECIPITATION	398.60	3986.002	100.00
RUNOFF	20.447	204.472	5.13
EVAPOTRANSPIRATION	345.421	3454.209	86.66
PERC./LEAKAGE THROUGH LAYER 2	3.445993	34.460	0.86
AVG. HEAD ON TOP OF LAYER 2	53.8811		
DRAINAGE COLLECTED FROM LAYER 5	3.6256	36.256	0.91
PERC./LEAKAGE THROUGH LAYER 7	0.000021	0.000	0.00
AVG. HEAD ON TOP OF LAYER 6	0.0015		
CHANGE IN WATER STORAGE	29.107	291.066	7.30
SOIL WATER AT START OF YEAR	3121.946	31219.463	
SOIL WATER AT END OF YEAR	3151.053	31510.527	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	0.000	0.00

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ANNUAL TOTALS FOR YEAR 1997

	MM	CU. METERS	PERCENT
PRECIPITATION	480.10	4801.000	100.00
RUNOFF	9.143	91.433	1.90
EVAPOTRANSPIRATION	434.439	4344.395	90.49
PERC./LEAKAGE THROUGH LAYER 2	3.259307	32.593	0.68
AVG. HEAD ON TOP OF LAYER 2	20.1897		
DRAINAGE COLLECTED FROM LAYER 5	3.4601	34.601	0.72
PERC./LEAKAGE THROUGH LAYER 7	0.000021	0.000	0.00
AVG. HEAD ON TOP OF LAYER 6	0.0014		
CHANGE IN WATER STORAGE	33.057	330.569	6.89
SOIL WATER AT START OF YEAR	3151.053	31510.527	
SOIL WATER AT END OF YEAR	3184.110	31841.096	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0002	0.002	0.00

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ANNUAL TOTALS FOR YEAR 1998

	MM	CU. METERS	PERCENT
PRECIPITATION	541.90	5419.001	100.00
RUNOFF	51.226	512.258	9.45
EVAPOTRANSPIRATION	533.153	5331.529	98.39
PERC./LEAKAGE THROUGH LAYER 2	4.096183	40.962	0.76
AVG. HEAD ON TOP OF LAYER 2	179.3294		
DRAINAGE COLLECTED FROM LAYER 5	3.4542	34.542	0.64
PERC./LEAKAGE THROUGH LAYER 7	0.000021	0.000	0.00
AVG. HEAD ON TOP OF LAYER 6	0.0014		
CHANGE IN WATER STORAGE	-45.933	-459.330	-8.48
SOIL WATER AT START OF YEAR	3184.110	31841.096	
SOIL WATER AT END OF YEAR	3138.177	31381.766	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0002	0.002	0.00

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B4. Output of Water Balance Method

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******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.04    (13 MARCH 1995)                **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************
PRECIPITATION DATA FILE:     C:\GEOLOGY\HELP3\ankara\DENE4.D4
TEMPERATURE DATA FILE:       C:\GEOLOGY\HELP3\ankara\DENE7.D7
SOLAR RADIATION DATA FILE:   C:\GEOLOGY\HELP3\ankara\DENE13.D13
EVAPOTRANSPIRATION DATA:     C:\GEOLOGY\HELP3\ankara\DENE11.D11
SOIL AND DESIGN DATA FILE:   C:\GEOLOGY\HELP3\ankara\DENE10.D10
OUTPUT DATA FILE:            C:\GEOLOGY\HELP3\WBM3.OUT
TIME:  17:47     DATE:   6/13/1999
******************************************************************************
     TITLE:  Check by Water Balance Method
******************************************************************************
     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
            COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.
                                  LAYER  1
                                  --------
                    TYPE 1 - VERTICAL PERCOLATION LAYER
                        MATERIAL TEXTURE NUMBER  15
          THICKNESS                     =    100.00    CM
          POROSITY                      =      0.4750 VOL/VOL
          FIELD CAPACITY                =      0.3780 VOL/VOL
          WILTING POINT                 =      0.2650 VOL/VOL
          INITIAL SOIL WATER CONTENT    =???????????? VOL/VOL
          EFFECTIVE SAT. HYD. COND.     =  0.170000003000E-04 CM/SEC

        NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  3.00
                 FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.

                    GENERAL DESIGN AND EVAPORATIVE ZONE DATA
                    ----------------------------------------

        NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
                 SOIL DATA BASE USING SOIL TEXTURE #15 WITH A
                 FAIR STAND OF GRASS, A SURFACE SLOPE OF  3.%
                 AND A SLOPE LENGTH OF  100. METERS.

       SCS RUNOFF CURVE NUMBER            =     90.00
       FRACTION OF AREA ALLOWING RUNOFF   =    100.0     PERCENT
       AREA PROJECTED ON HORIZONTAL PLANE =      1.0000 HECTARES
       EVAPORATIVE ZONE DEPTH             =    91.0     CM
       INITIAL WATER IN EVAPORATIVE ZONE  =    34.064   CM
       UPPER LIMIT OF EVAPORATIVE STORAGE =    43.225   CM
       LOWER LIMIT OF EVAPORATIVE STORAGE =    24.115   CM
       INITIAL SNOW WATER                 =     0.000   CM
       INITIAL WATER IN LAYER MATERIALS   =         -   CM
       TOTAL INITIAL WATER                =         -   CM
       TOTAL SUBSURFACE INFLOW            =      0.00   MM/YR


                     EVAPOTRANSPIRATION AND WEATHER DATA
                     -----------------------------------
        NOTE:  EVAPOTRANSPIRATION DATA FOR     PHILADELPHIA           PENNSYLVANIA
                 WAS ENTERED FROM THE DEFAULT DATA FILE.
            STATION LATITUDE                        =  33.00 DEGREES
            MAXIMUM LEAF AREA INDEX                 =   2.00
            START OF GROWING SEASON (JULIAN DATE)   =     90
            END OF GROWING SEASON (JULIAN DATE)     =    300
            EVAPORATIVE ZONE DEPTH                  =  91.0  CM
            AVERAGE ANNUAL WIND SPEED               =   7.65 KPH
            AVERAGE 1ST QUARTER RELATIVE HUMIDITY   =  73.00 %
            AVERAGE 2ND QUARTER RELATIVE HUMIDITY   =  60.67 %
```

AVERAGE 3RD QUARTER RELATIVE HUMIDITY = 55.33 %
AVERAGE 4TH QUARTER RELATIVE HUMIDITY = 70.67 %

NOTE: PRECIPITATION DATA FOR PHILADELPHIA PENNSYLVANIA
WAS ENTERED FROM THE DEFAULT DATA FILE.

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR PHILADELPHIA PENNSYLVAN

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES CELSIUS)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
-0.4	0.0	5.8	12.2	17.0	22.1
24.9	23.9	19.7	13.2	8.5	1.3

****

ANNUAL TOTALS FOR YEAR 1

	MM	CU. METERS	PERCENT
PRECIPITATION	959.61	143941.844	100.00
RUNOFF	72.977	10946.487	7.60
EVAPOTRANSPIRATION	739.442	110916.328	77.06
PERC./LEAKAGE THROUGH LAYER 1	143.100220	21465.033	14.91
CHANGE IN WATER STORAGE	4.093	613.960	0.43
SOIL WATER AT START OF YEAR	370.682	55602.352	
SOIL WATER AT END OF YEAR	374.775	56216.309	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0002	0.025	0.00

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APPENDIX C

SENSITIVITY OF PROFILE NO.3

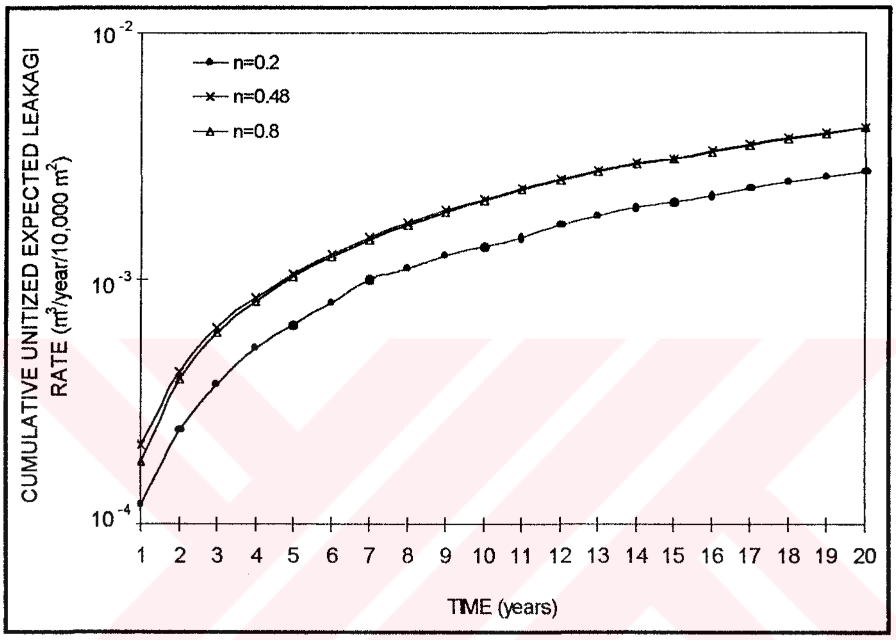

Figure C1. Sensitivity of the unitized expected leakage rate to the porosity of the topsoil in Profile No.3.

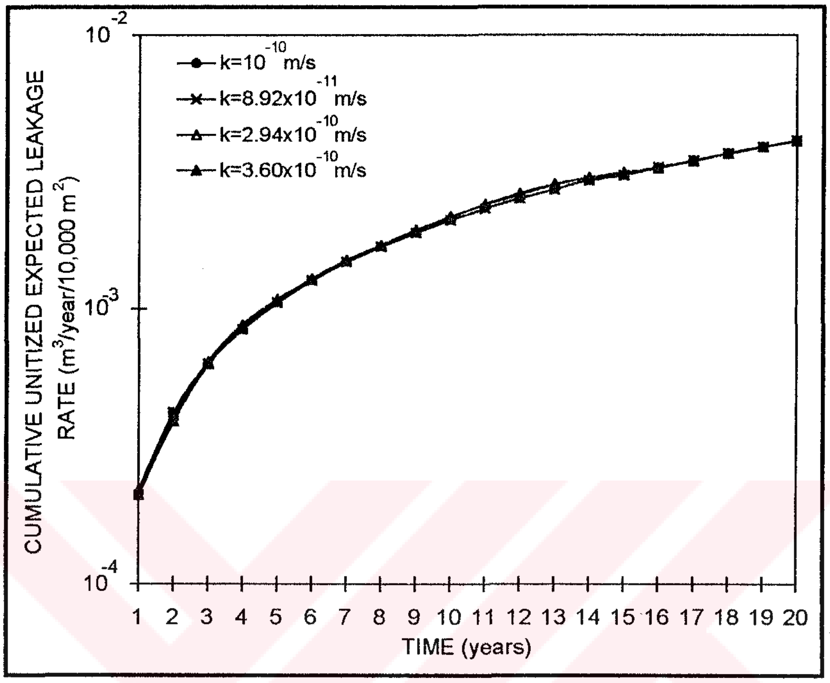

Figure C2. Sensitivity of the unitized expected leakage rate to the hydraulic conductivity of compacted clay liner in Profile No.3.