UNIVERSITY OF NAIROBI

# ANALYSIS OF THE YATTA-CANAL INTAKE VALLEY ALONG THIKA RIVER IN KENYA FOR A STORAGE RESERVOIR BASED ON GEOPHYSICAL AND GEOTECHNICAL SURVEY DATA

This dissertation is
submitted in partial fulfillment of
the requirements for the award of a Master of Science degree in
Engineering Geology

by

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December, 2010

## DECLARATION

I Jeremiah L. MUIA declare that this is my original work and had not been presented for a degree elsewhere. All sources of information have been specifically acknowledged by means of references.

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## ABSTRACT

The aim of this work was to carry out an assessment on the suitability of the surface and subsurface geological conditions of a valley occurring within the precincts of the Yatta-canal intake area along River Thika for a storage reservoir. The Yatta District is one of the arid and semi-arid Districts in Kenya. Over 70% of the population in Yatta depends on agriculture for their livelihoods. Because rains are locally erratic and unevenly distributed, the poverty levels are high in the area at 67.5%.The reservoir will ensure an hitherto perennial flow of water in the canal. The Yatta area is situated within the Mozambique Belt, a major structural/metamorphic unit which extends along the African east coast from Mozambique and Malagasy into the Sudan and possibly as far north as Egypt and Arabia; it represents one of the fundamental geological features of Africa.The old geological map of the region depicts that the study area consist only of boitite gneiss but the facts on the ground reveal the existence of more than one geological formation though biotite gneiss is predominant. Both Geophysical and Geotechnical techniques were employed in this work. The logging of the trial pits revealed that there exists three soil types within the study area. Geological profiles inferred from the interpreted geophysical data, indicate that the subsurface conditions at the study area mainly consists of two geologic formations namely soil overburden overlying either weathered biotite gneiss or fresh basement rock consisting of banded migmatites and granitoid gneisses occasionally containing quartzo -feldspathic veins. All the soils samples tested fall within the semi-permeable category. Although the calculated Optimum Moisture Content (OMC) for the trial pits is within recommended percentage according to the US Classification and identification of soils for general engineering purposes for fine grained Soils, it should always be less than the shrinkage limit. There are no faults or significant fractures observed at the area near HEP 1, which is recommended for the dam axis area. Subject to confirmation of the subsurface foundation conditions by core drilling and testing of the bedrock geotechnical characteristics, geophysical and geotechnical investigations done imply that the study area is feasible for dam site and is founded on a sound rock foundation. The valley has an approximate water holding capacity of 24 million cubic litres.

**ACKNOWLEDGEMENTS**

Am grateful to God for the ability to work on and write this dissertation. This work would not have been complete without the scholarship awarded to me by the University of Nairobi to undertake my Masters training. Am really obliged to thank my supervisors Dr. Eliud Mathu and Prof. Justus Barongo for their technical guidance, moral support and patience through out my entire research period.

I cannot forget to appreciate the Mawa Geological Consultants and the CAS Consulting Engineers for the fieldwork support and provisions in terms of office facilitation, survey equipment and software back up.

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All this time my family has stood with me and I would not have made it without their moral and financial support. My heartfelt gratitude goes to all my parents. To my wife, I say thank you for walking with me every stride all along in this work.

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# CHAPTER ONE

## 1.0 INTRODUCTION

### 1.1 STATEMENT OF THE PROBLEM

The Yatta District is one of the arid and semi-arid Districts in Kenya. Over 70% of the population in Yatta depends on agriculture for their livelihoods. Because rains are locally erratic and unevenly distributed, the poverty levels are high in the area at 67.5%, according to the results of the most recent economic survey of the district. This is mainly due to water scarcity for irrigated agriculture that forces local farmers to grow low value crops. The Yatta farrow whose source is the Thika River is an artificial canal and the only source of surface water for irrigation and domestic use in Yatta. Currently, only 800 ha are supplied with irrigation water against a potential acreage of 2512 ha. The water shortage in the Yatta canal is so acute at certain times of the year that major water works such as the Matuu Water Supply has been experiencing total lack of this resource at its storage facilities.

In the lower sections where the treatment works are located, the furrow dries up for about 5 months every year. In 2009 when Kenya was going through a spell of drought, the lower reaches of the Thika River dried up completely including intake point where the Yatta canal draws water from.

A sustainable solution to this situation would be a water storage reservoir possibly in the vast Thika River valley possibly within the precincts of the Yatta canal intake.This imperative idea would ensure the following in the arid Yatta District, whose economic lifeline is the Yatta Canal; Sufficient water in Yatta Canal and Ndalani sub-canal throughout the year, even during the driest months.

Crops yields and supply of domestic water are expected to increase significantly. This is expected to have the positive effect of improving food security and reducing the still escalating poverty levels in Yatta.

Despite this need of a water storage reservoir in the vicinity, the existing geological map that captures the area along Thika River valley done by Fairburn in 1961 has very limited information for surface and subsurface analysis the study area's suitability for a storage reservoir. His work by then was done to outline the regional geology at a very small scale of 1:250, 000.The latter has very little and inaccurate geotechnical information for engineering purposes hence a more refined geological mapping at a large scale of not more that 1: 10,000 was imperative. Good dam site are rare to find especially a naturally occurring valley that is backed up by favorable foundation characteristics i.e. a competent rock. The study area is well endowed with a suitable topography on both sides of the Thika River that could make a nice storage reservoir. It is narrower and steeper near the Yatta canal intake area and gentle and expansive upstream (*Fig.1.10)*.The intake area could thus, based on physical attributes, be a good site for the embankment. However despite this favourable relief, the underlying geology and soil characteristics needs to be mapped at a scale big enough to asses the site's suitability for a storage reservoir. With a possible length of 1.5KM, 0.8KM in breadth and an embankment height of at least 40M.This valley, contingent upon a favouarble geologic conditions has an approximate capacity of 24 million cubic metres.

## 1.2 AIM AND OBJECTIVES.

### 1.2.1 Aim

The aim of this work was to carry out an assessment on the suitability of the surface and Subsurface geological conditions of a valley occurring within the precincts of the Yatta-canal intake area along River Thika that would form a basis for future references with regard to the construction of a much needed water storage reservoir.

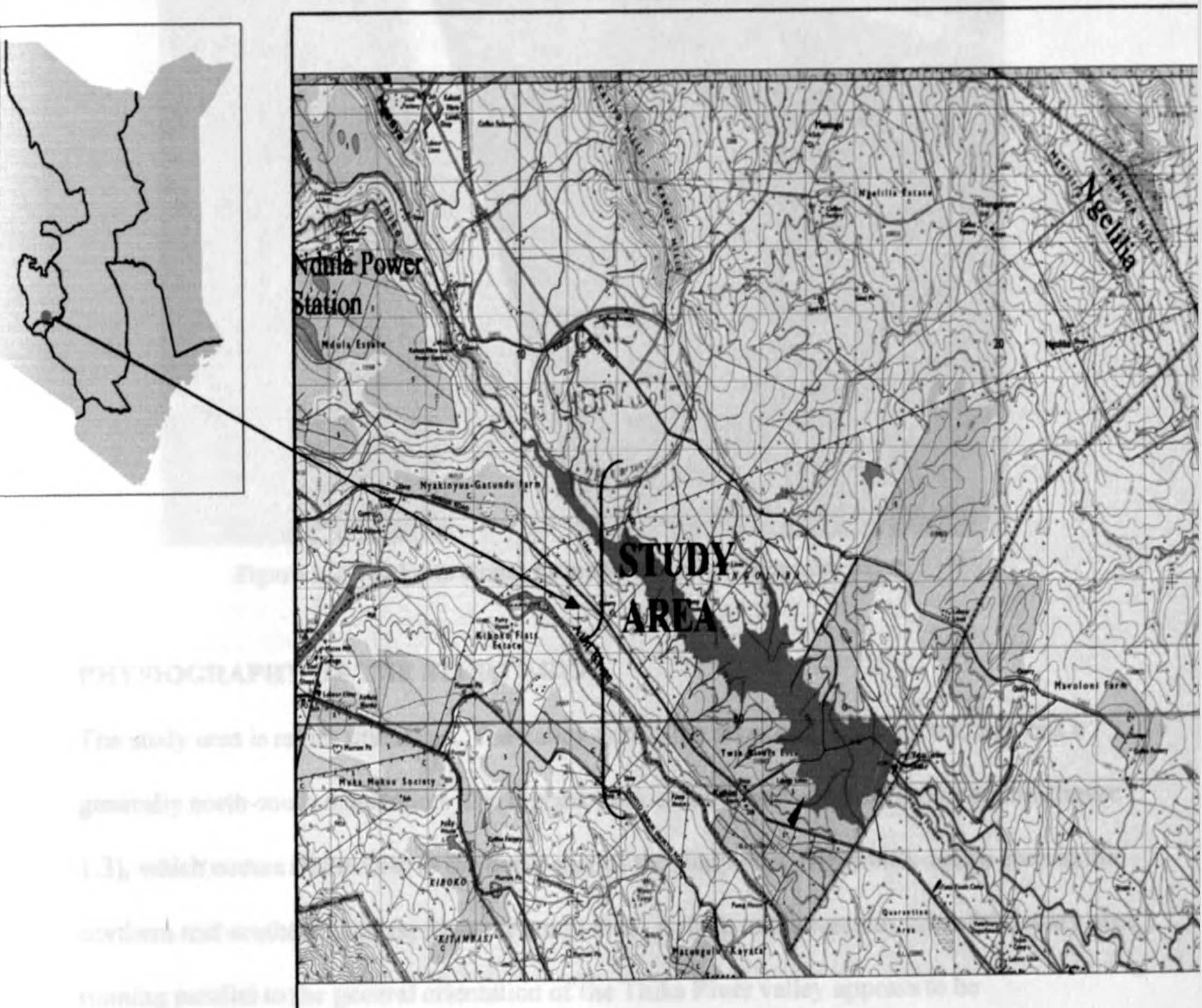
### 1.22 Specific Objectives.

1. To apply geophysical resistivity and geotechnical methods to give an insight into the subsurface geologic properties and nature of the site foundation, which included inference of the subsurface geological bodies and thickness of soil overburden to be encountered within the site area.
2. To use the processed and interpreted geophysical resistivity data to plan the locations of trial

pits and core drilling to obtain the actual soil and rock samples for testing to determine various geotechnical characteristics for use in the dam design.

## 1.3 LOCATION OF THE STUDY AREA

The Yatta canal intake valley herein referred to as the "study area" is located in the geographical boundary of the Yatta and Thika Districts, an area normally known as Kathini (Yatta ) and Ngoliba (Thika).It draws its water from the Thika river. The latter is deeply incised in the centre of a wide, expansive and long valley that runs almost parallel Thika Garissa road. It's Located about a kilometer from this highway to the East of Ngoliba market. The intake point is precisely as shown in *Figure 1.1*.The Yatta canal immediately after the intake is as shown in *Figure 1.2*. The overflow space at the background empties excess water back to Thika River. Its approximately 1.5km long by 1.0km wide.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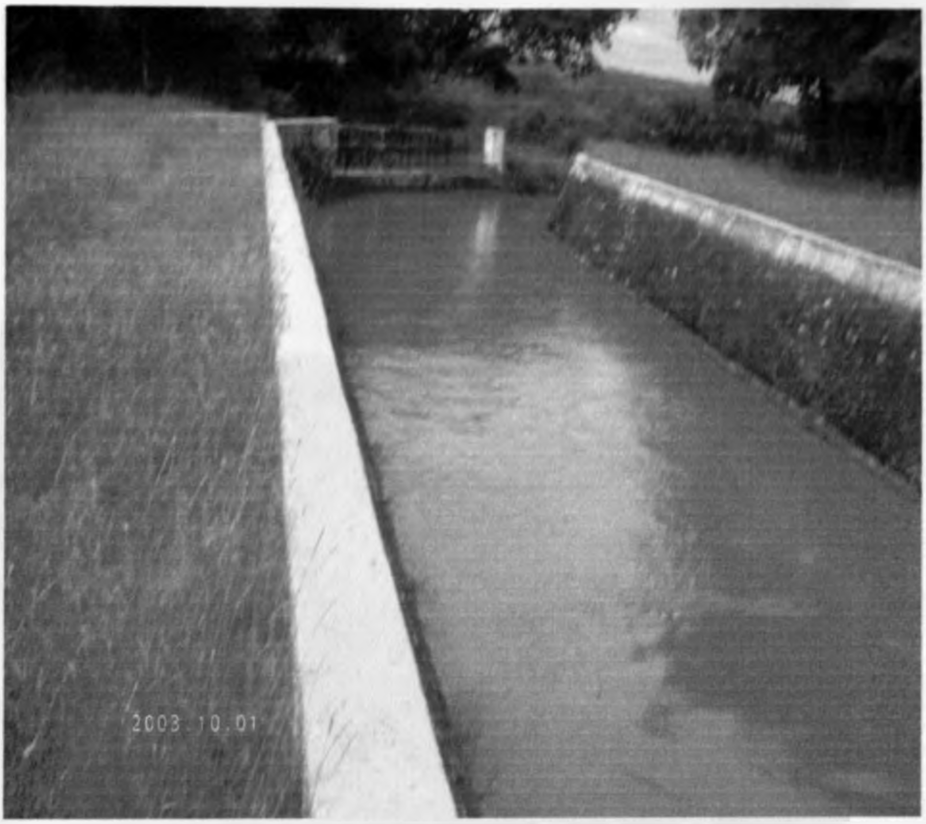



**Figure 1.2 The Yatta Canal Immediately after the intake point.**

## 1.4 PHYSIOGRAPHY OF THE STUDY AREA

The study area is rather undulated. The valley within the proposed reservoir area exhibits a generally north-south orientation. The highest peak in the area is the Kilimambogo hill (figure 1.3), which occurs about 5km to the north east of the study area. Other hills can be seen in the northern and southern horizon from the study area .A ridge to the western side of the study area running parallel to the general orientation of the Thika River valley appears to be the hydrogeological divide between the Athi and the Thika River drainage basin. The average altitude at the valley within the study area is about 1200m above sea level.


**Figure 1.3 A view of the western slope of the valley about a kilometre to the East of Ngoliba market. At the background is the Kilimambogo hill.**

## 1.5 CLIMATE

The climate of the study area (Ngoliba, Kathini) ranges from semi-arid to tropical lowland type due to the fact that it lies at the border between Central and Eastern Provinces. The average annual rainfall in the area is approximately 900mm (Sombroek, 1982).

The rainfall pattern exhibits a bi-modal distribution with wet seasons in March to May and October to December corresponding to "long" and "short" rains, respectively. About 0%-85% of the precipitation falls during these seasons. *Figure 1.6* shows a make-shift bridge in Mavoloni located about 400m upstream from the intake point. The previous concrete bridge was swept when Thika River had flooded and inundated most of the slope area during the 1998 Elnino rains.

The average annual temperature ranges from 15 $o^C$-32 $o^C$ with average minima and maxima of 12 $o^C$ -15 $o^C$ and 27 $o^C$ -32 $o^C$, respectively. The warmest period occurs from January to March. Average potential evaporation is between 550-750 mm per year.

## 6 SOILS, VEGETATION AND DRAINAGE

The soil overburden at the dam axis area consists of black cotton soil (*figure 1.4*), on the right side of the river bank and whitish loam clay soil on the left side of the river bank. The black cotton soil is inferred to have originated from the erosion of the phonolitic volcanic rocks which rested unconformably on the uneven surface of the Precambrian basement rock (Saggerson, 1991). The white clay soils are products of weathering of feldspathic biotite gneisses and directly overlie the Precambrian rocks. The study area is covered by a thick vegetation (*figure 1.5*), comprising shrubs on area that are not developed. It occupies part of the coffee estate owned by the Mavoloni farmers

Association. The Thika River is the main drainage feature in the study area. Various tributaries drain in it, both upstream and downstream of the site. The Thika river source is the Abadares ranges.The Sasumua river that feeds the Sasumua dam/reservoir eventually also drains into Thika River.


**Figure 1.4 The Western valley (from Thika River) of the study area comprising predominantly black cotton soil.**


**igure 1.5. A view of the thicket on both sides of the river banks around the Yatta Canal Intake area**

**Figure 1.6 A small make shift Bridge connecting residents of Ngoliba on the western flank of the valley to those of east.**

## 7 PREVIOUS WORKS

Various workers have executed research in both Machakos and Thika areas. They include Fairburn who wrote the report entitled; "Geology of North Machakos and Thika area". Dr Eliud Mathu and Dr. C. Nyamai of the University of Nairobi, Geology Department have been working in the Ukambani Metamorphic basement rocks, where they have described the complexity of the geology, structures and tectonics in the region (Mathu et al, 2000). The United States Geological Survey in conjunction with Professor J. Barongo of the Seismology section of the Nairobi University geology Department have established a seismic station and have been able to document regional seismic data (Pers.com.).

## 8 GEOLOGY AND STRUCTURES

The Yatta area is situated within the Mozambique Belt, a major structural/metamorphic unit which extends along the African east coast from Mozambique and Malagasy into the Sudan and possibly as far north as Egypt and Arabia; it represents one of the fundamental geological features of Africa (Homes, 1951; Clifford, 1970; Kroner, 1977, and 1979). The belt consists typically of high-grade metamorphic rocks, characterized by K/Ar-ages of 400-600 m.y. (Cahen, 1961). The Yatta Phonolite forms an unconformable capping, some 20 m thick, on a Miocene erosion surface above Mozambiquian gneisses. The phonolite lava presumably flowed along an old river bed incised in an older surface. Subsequent erosion of the adjacent gneisses resulted in the present reversed morphological feature of the Yatta Plateau (Fujita, 1977). According to Fairburn, 1961, the regional geology mainly consists of Precambrian basement rock system composed of biotite gneisses alternating with migmatites and granitoid gneisses. The most abundant rock in the area is biotite gneisses although foliated migmatites with distinct dipping planes and occasional quartzo-feldspathic veins are aligned parallel to the foliation. The general strike of the rock system is north west – south east.

There is a very dense rock outcrop of migmatite with elongated quartzite veins cutting across the riverbed near the Yatta canal intake, which can be arguably a suitable area for the dam axis. It exhibits quartzite veins that are resistance to weathering. The old geological map of the area (*Figure 1.7* ) area depicts the study area as only comprising biotite gneiss. However geological facts on the site at a much larger scale reveal that the site consists of several other formations although biotite gneiss seems to be predominant (*figure 1.8).* The geologic profiles of the study area along the area recommended for dam axis and reservoir area are as shown in *Figures 1.11 and 1.12* respectively.

Some basement rocks exhibiting bouldinage (pinch and swell) structures were encountered along the riverbed about 250 metres upstream of the Yatta Canal intake as shown in (*figure 1.13).* This bouldinage shows the direction of maximum extensional and compressional tectonic forces. The quartzite mineral are seen here having resisted squashing by the tectonic forces. The direction of maximum tectonic compressional forces is perpendicular to the orientation of the lineated minerals in the Study Area. The compresssional forces stretched the biotite gneiss in the area into some limited degree of foliation. The foliated formation dips up stream, a phenomenon that makes the site favourable as an embankment area to avoid leakage of water downstream. *Figure 1.14* shows a granitic outcrop that was weathered by exfoliation. The soil overburden at the area of study consists of black cotton soil on the right side of the river bank and whitish loam clayey soil on the left side of the river bank. The black cotton soil is inferred to have originated from the erosion of the phonolitic volcanic rocks that rested unconformably on the uneven surface of the Precambrian basement rock (Saggerson, 1991).

The white clay soils are inferred to be the products of weathering of feldspathic biotite gneisses and directly overlie the Precambrian rocks. The soils in the area upstream from the Yatta canal, presumably a suitable site for the dam abutments and reservoir area are red coffee soils derived from eroded volcanic tuffs which overlie the basement rocks.

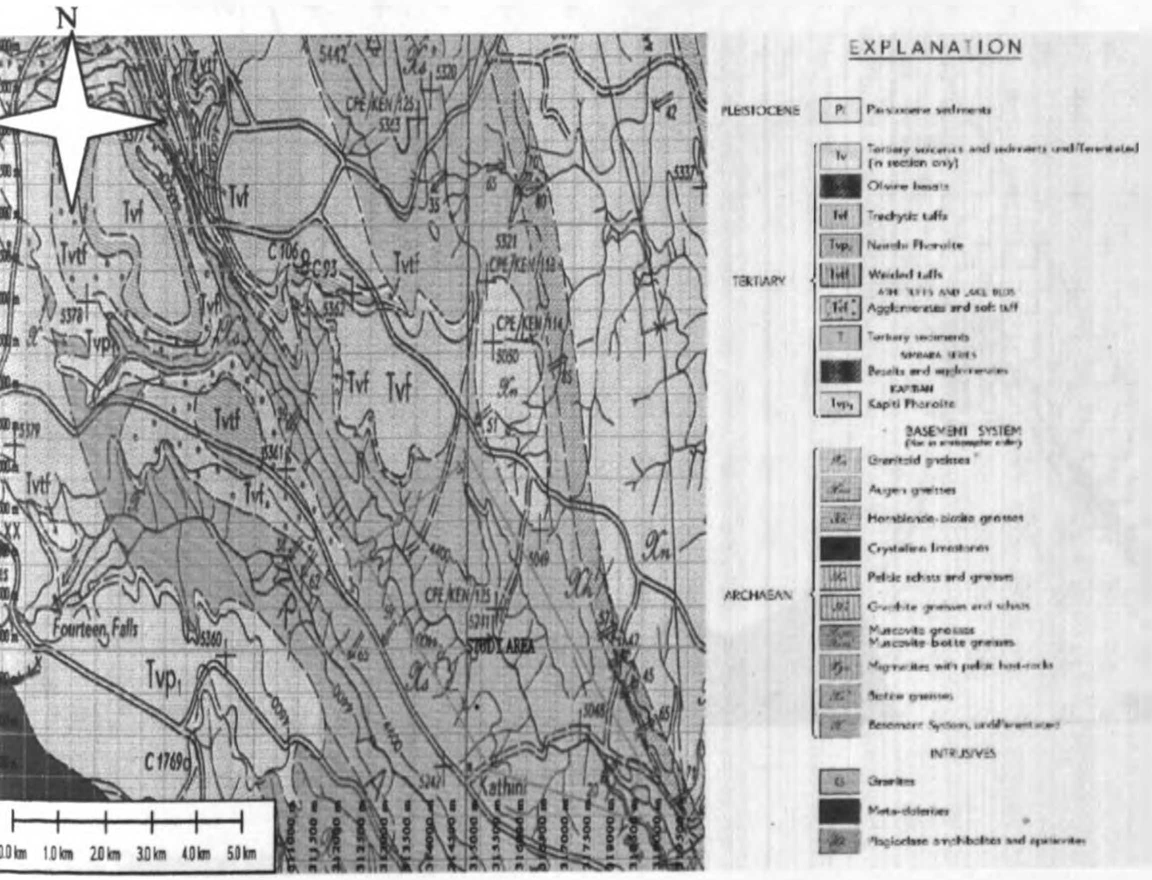



**Figure 1.7: Old Geological Map of the study area and the neighbouring region (Source Fairburn, 1961)**

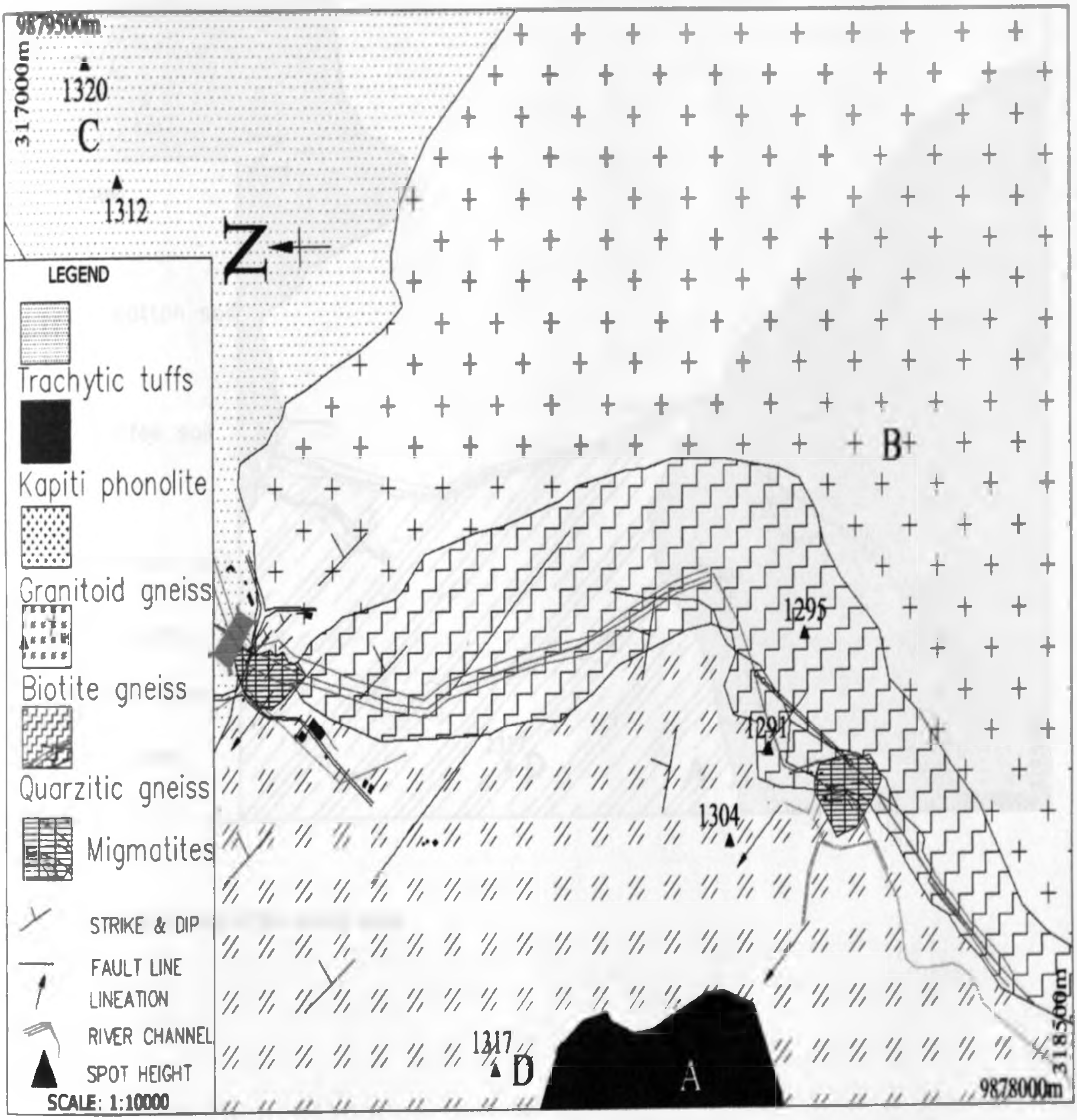



**Figure 1.8. Geological map of the study area**

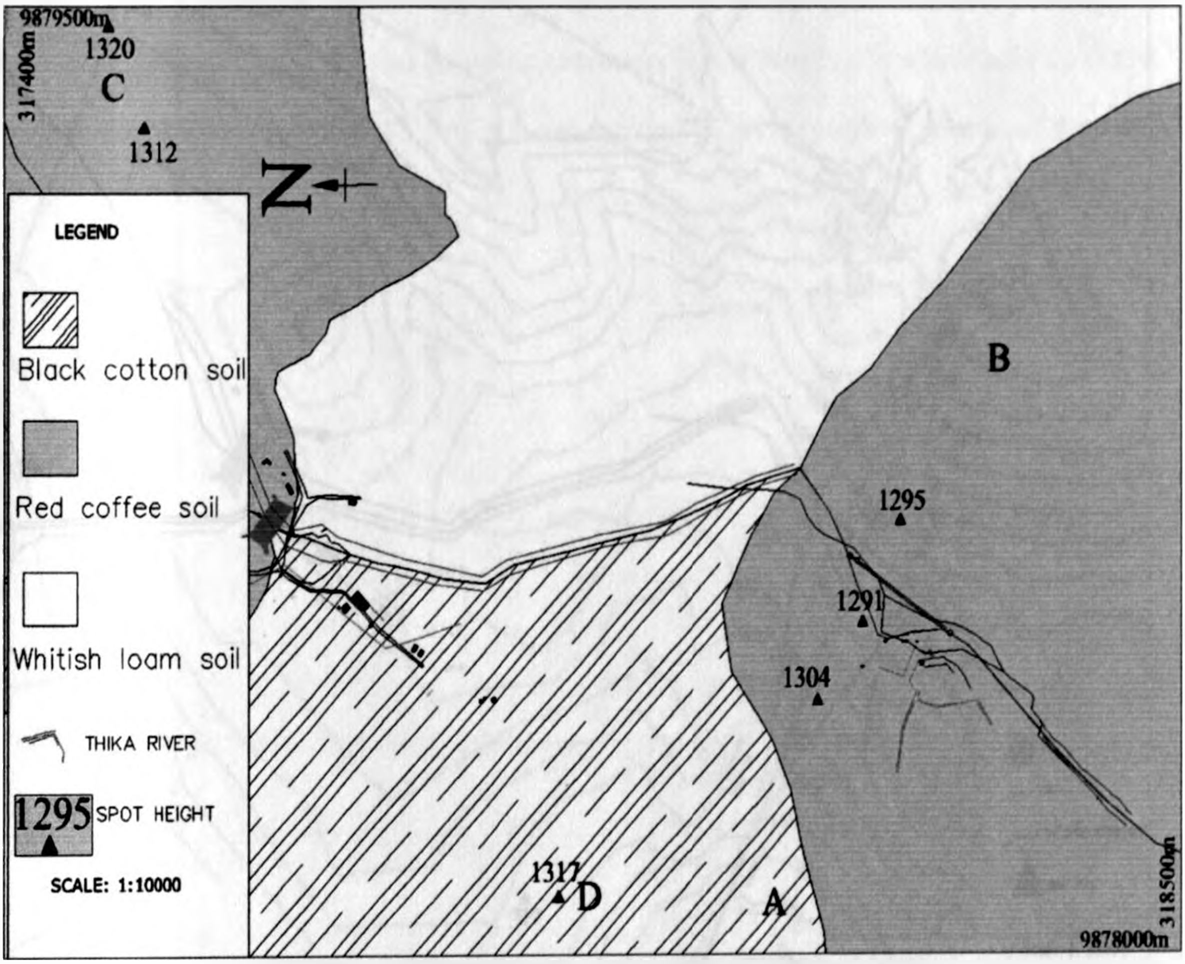



**Figure 1.9 Soil Map of the study area.**

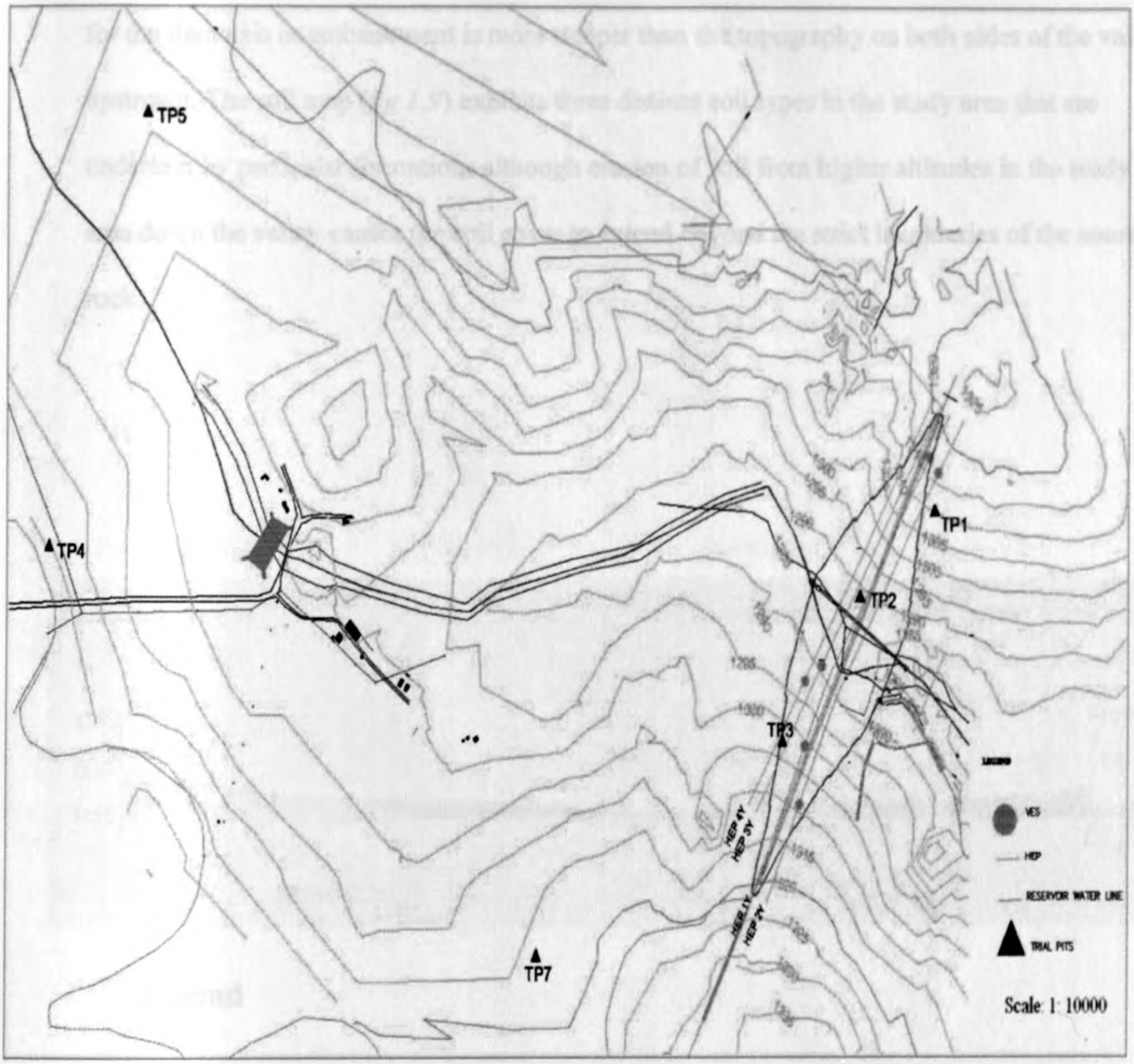



**Figure 1.10 .Contour map of the Study Area showing the Traverse HEP line and VES Points as well as Trail Pits Points in recommended dam embankment area. It also indicates AB and CD along which two geologic cross sections have been drawn.**

The contour map (*fig. 1.10*) above, of the study area shows the valley at the recommended area for the dam axis or embankment is more steeper than the topography on both sides of the valley upstream. The soil map (*fig 1.9*) exhibits three distinct soil types in the study area that are underlain by particular formations although erosion of soil from higher altitudes in the study area down the valley causes the soil cover to extend beyond the strict boundaries of the source rock.

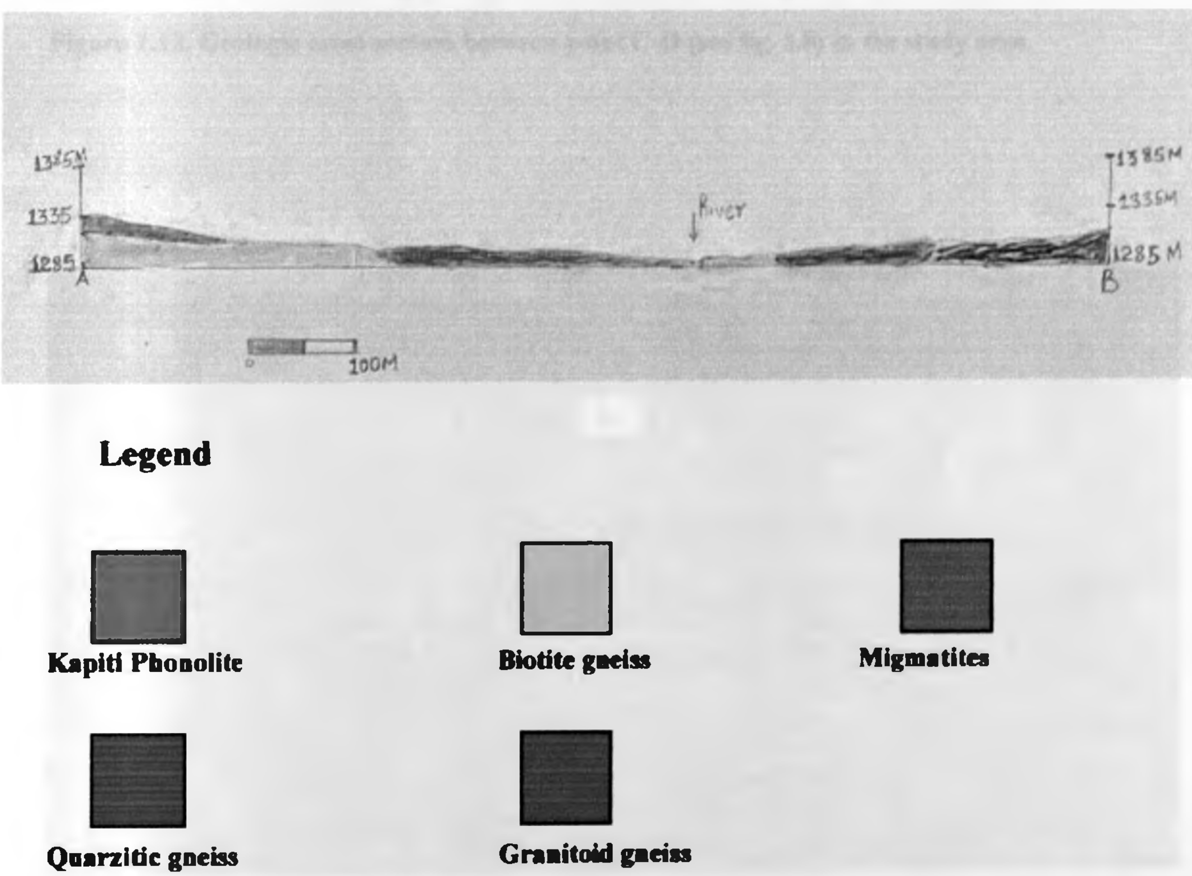
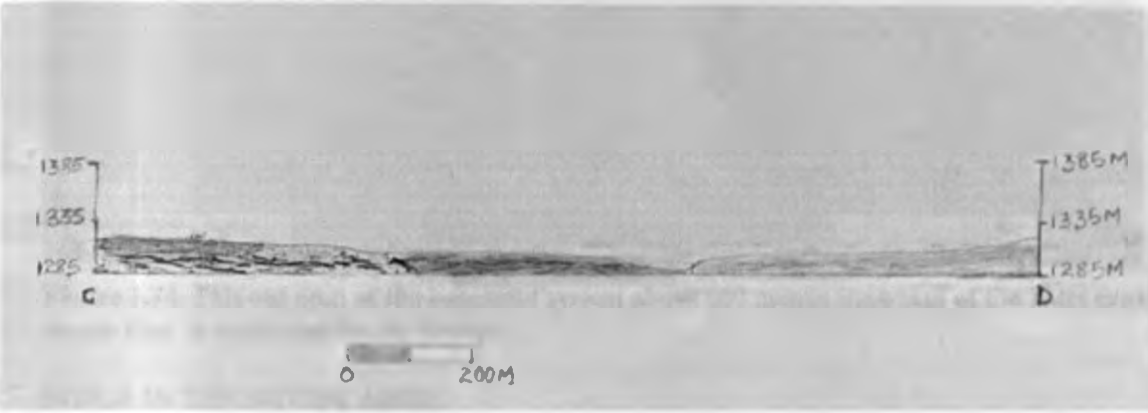



**Figure 1.11. Geologic cross section along point A-B (see fig 1.8) in the study area**




**Legend**

**Trachytic tuffs** **Migmatites** **Biotite gneiss**

**Figure 1.12. Geologic cross section between point C-D (see fig. 1.8) in the study area.**

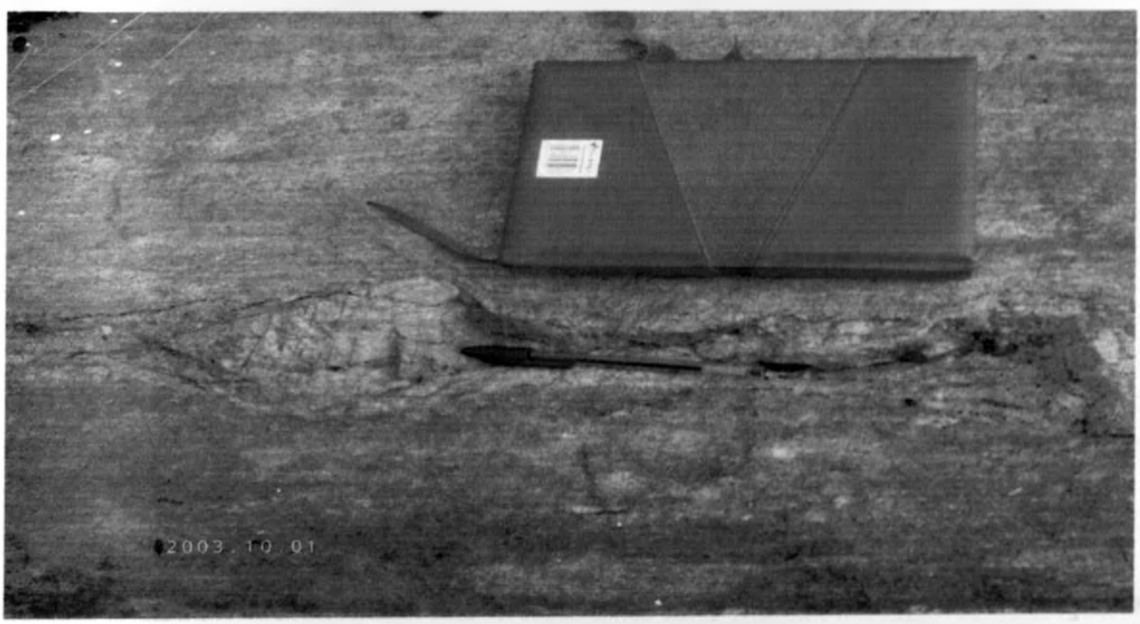



**Figure 1.13 Boudin structures are shown by this rock outcrop around 250 metres upstream from the Yatta Canal Intake.**

**Figure 1.14. This out crop of the basement system about 600 metres upstream of the Yatta canal intake that is weathered by exfoliation.**

## 1.9 SOILS IN THE STUDY AREA

Besides the underlying geology, soil characteristics are also very important candidates with regard to the investigations of a site's suitability for a storage reservoir. Geotechnical aspects of these soils including their optimum moisture content and maximum dry densities should be favourable and within the recommended range for a site to be deemed suitable for the construction of a water storage reservoir. Three distinct types of soils occur in the study area as shown in *figure 1.9*.

### 1.91 Red coffee soil

It si usually weighty to lift and difficult to work. Drainage is usually bad. They are found in the northern portion of the study area underlain by Trachytic tuffs.

### 1.92 Whitish loam soil

It contains sand, silt and clay, in such well-balanced proportions that none produces a dominating influence. It overlies the granitic basement rock in the eastern lower half of the study area.

### 1.93 Black cotton soil

It's a highly sensitive to seasonal moisture content variations is responsible for substantial distress to the structures that are built over these soils. They occur in the western central part of the study area and are inferred to have originated from wehered nephiline from the nearby Kapiti phonolites.

# CHAPTER TWO

## 2.0 METHODOLOGY

### 2.1 INTRODUCTION

Besides geotechnical methods, geo-electrical resistivity surveying methods are nowadays commonly used for geotechnical investigation and environmental survey (Loke, 1999).Both geophysical and geotechnical methods were employed in this work.

### 2.2 GEOPHYSICAL (ELECTRICAL RESISTIVITY) METHOD

#### 2.2.1 Basic Principles of Resistivity measurements

The resistivity of the ground is measured by injecting current with two electrodes and measuring the resulting potential difference with two other electrodes. The readings are usually converted to an apparent resistivity, corresponding to the resistivity of a homogeneous half-space that would give the same result. The investigated volume can be changed by moving the electrodes. Large separations give larger investigation depths. Moderm data acquisition systems have made it feasible to measure resistivity along profiles with several electrode separations. The data are usually inverted to a vertical resistivity section, assuming 2D geometry perpendicular to the profile. The inversion process is generally underdetermined, which means constraints have to be applied to the model. Most commonly local variability is minimized, resulting in smooth models that are compatible with measured data.

This means that sharp resistivity borders like e.g. the ground water surface is visualized as a smooth transition in such an inverted section.

For instance, If an electric current I (A) is flowing through a linear conductor of uniform cross-section A(m$^2$) and a length L (m). Ohm's law states that

$$dV = IR$$

Where dV is the potential difference (volt, V) between the ends of the conductor and R (ohm,) is the resistance of the conductor. The resistivity ( $P$) that is the physical property of the conductor that can be defined by ;

$$P = RA/L$$

The basis of the electrical resistivity method is to introduce a known current into the ground and measure potential differences on the surface to estimate the resistivity of the subsurface. In a homogeneous and isotropic half-space, electrical equipotentials are hemispherical, when the current electrodes are located at the surface *(figure 2.1)*. The current density $J(A/m^2)$ has t hen to be calculated for all the radial directions with:

$$J=I/2Hr^2$$

Where $J=I/2Hr^2$ is the area of a hemispherical sphere of radius r. The potential V can then be expressed as follows:

$$V=P/I/2Hr$$

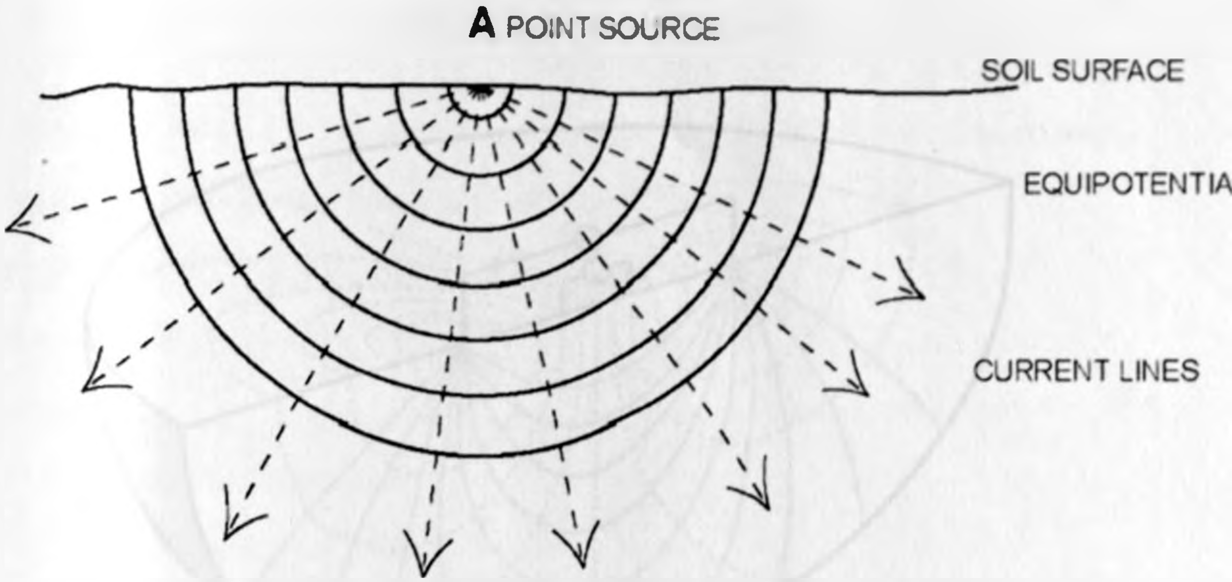



**Figure 2.1. Distribution of the current flow in a homogeneous ground.**

The resistivity measurements are made by introducing a DC or low-frequency alternating current into the ground by means of two electrodes (A, B in *Figure 2.2*) connected to a portable power source. The resulting potential difference is measured on the ground with two potential electrodes (M, N). The potential field produced in the underground is dependent on the dispersion of the specific electrical resistance.

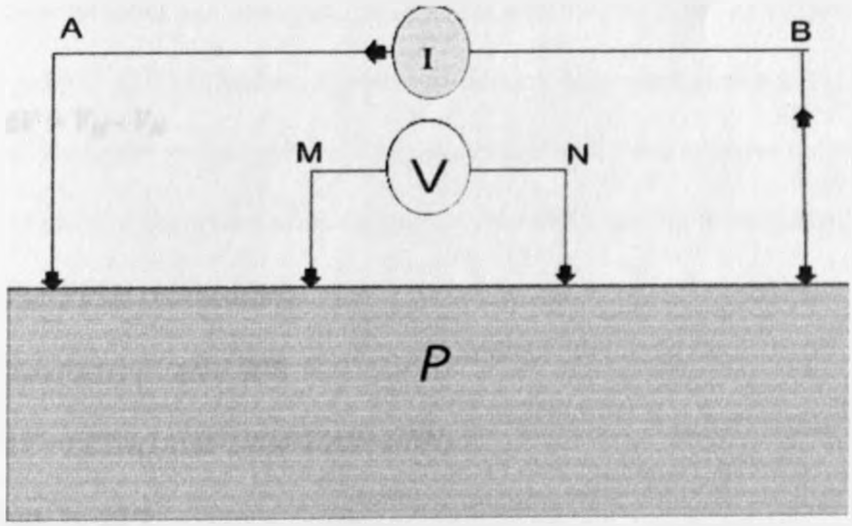



**Figure 2.2 . Outline of four electrodes array for resistivity measurement on the surface**

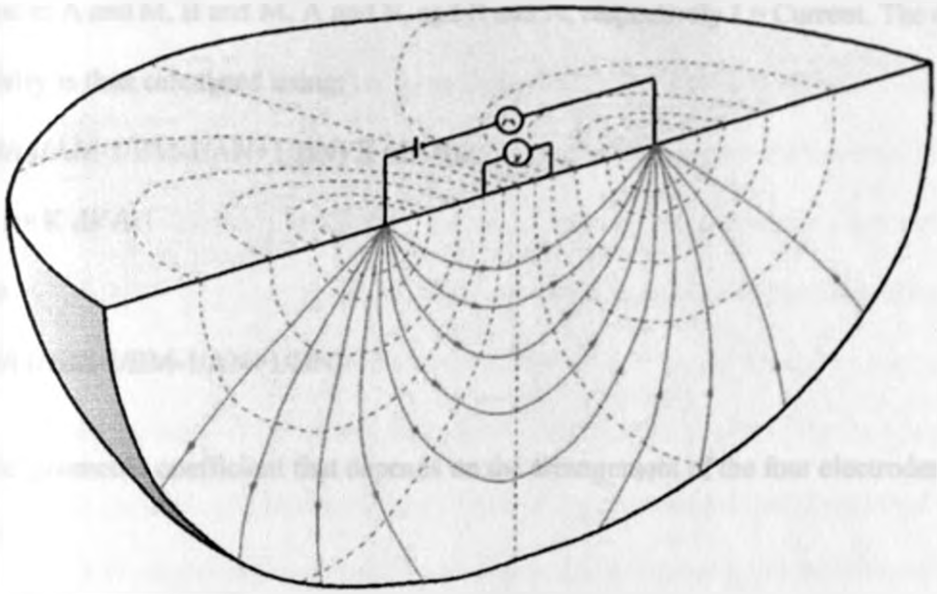


**Figure 2.3. Current dipole (solid lines) and potential field (dashed lines) showed in the situation of homogenous dispersion resistance.**

If the resistance is a homogenous, the electric current- and potential-field lines are produced as illustrated in *Figure 2.3*.

The Potential difference ( dV) measured between the electrodes M and N is given by equations

$$dV = V_M - V_N$$

Where

$$V_M = PI/2H\ (1/AM - 1/BN)$$

$$V_N = PI/2H\ (1/AN - 1/BN)$$

*Thus* $dV = PI/2H(1/AM - 1/BM - 1/AN + 1/BN)$

NB: H=22/7

Where H=22/7 while AM, BM, AN and BN represent the geometrical distance between the electrodes A and M, B and M, A and N, and B and N, respectively.I = Current. The electrical resistivity is then calculated using:

P= 2H/(1/AM-1/BM-1/AN+1/BN) X (d*V*/I)

OR, P= K d*V*/I

Where

K=2H/(1/AM-1/BM-1/AN+1/BN)

K is the geometric coefficient that depends on the arrangement of the four electrodes A, B, M and N.

**2.2.2. Apparent resistivity**

This Equation K= d*V*/I can be used to calculate the true resistivity of the underground if the Medium is homogenous. The resistivity so obtained will be constant and independent of both electrode configuration on and surface location. If the ground is inhomogeneous, the resistivity *(P* ), as calculated from Equation K= D*v/I*), will vary on altering the geometrical arrangement of the electrodes. The resistivity that is then calculated is termed the apparent resistivity, *Pa* and it should be considered as some sort of average resistivities encountered in the heterogeneous underground. In general, all field data are apparent resistivity. They are interpreted to obtain the true resistivities of the layers in the ground. The apparent resistivity will be close to the true resistivity in the vicinity of electrodes when the relative electrode spacing is very small.

There are different methods involved to get the apparent resistivity of the subsurface. Resistivity profiling is one, in which the spacing of electrodes is kept constant along the survey line. This provides a lateral resistivity distribution at a constant depth. Vertical electrical sounding (VES) method gives the apparent resistivity variation with depth for a horizontal layered earth. This is achieved by taking number of measurements at a common midpoint with successive larger electrode separation. The calculated resistivity is plotted as a function of electrode separation to produce a sounding curve.

Therefore it can be said that Electrical Resistivity is an active geophysical prospecting technique which detects subsurface features in terms of the resistance they present to the passage of an artificially induced electric current. In the dry state, most soils and rocks are insulators but, when they become moist, electrical currents are able to flow through the movement of ions which are always dissolved in the pore water. As the soil or rock absorbs more water the conductivity increases since more ions become available for the conduction and their mobility is enhanced. Hence electrical resistivity surveying primarily maps the volume concentration of ground moisture, which varies according to lithology, porosity and time of year.

Temperature fluctuations can also be important, although in mid-latitudes this effect is insignificant.

As mentioned before, current is sent into the ground through a pair of electrodes, called current electrodes as shown in analogy to *figure 2.2* and the resulting potential difference across the ground is measured with the help of another pair of electrodes, called potential electrodes.The ratio between the potential difference (change in V) and the current (I) gives the apparent resistance, which depends on the electrodes arrangement and on the resistivities of the subsurface formations. There are several types of electrode arrangements (configurations) of which Wenner and Schlumberger configurations are more popular.

**2.2.3 Wenner configuration.**

In Wenner configuration, all the four electrodes are kept along a line at equal distance.The electrodes are moved simultaneously keeping the inter electrode spacing same. The current is sent normally through the outer electrodes and the potential difference is measured across the inner electrodes. The resistance is multiplied by the configuration factor , to get the value of apparent resistivity.

### 2.2.4 Schlumberger configuration

In Schlumberger configuration, all the four electrodes are kept in a line similar to that of Wenner but the outer electrode spacing is kept large compared to the inner electrode spacing, usually more than five times. For each measurement, only the current electrodes are moved keeping the potential electrodes at the same location. The potential electrodes are moved only when the signal becomes too weak to be measured.

### 2.2.5 Resistivity observation procedures

The two types of procedures for making resistivity observations namely resistivity sounding (also called Vertical Electrical Sounding,VES) and resistivity profiling (Horizontal Electrical Profiling,

HEP). Resistivity profiling is employed to determine the lateral variation in the resistivities thereby establishing the existence of vertical bodies like dykes, fracture zones, geological contacts of dipping strata etc. The Vertical Electrical Sounding is used to estimate the resistivities and thickness of various subsurface layers at a given location and is mainly used in groundwater exploration to determine the disposition of the aquifers.

In the VES approach, the center of the configuration is kept fixed and the measurements are made by successively increasing electrodes spacing. The apparent resistivity values obtained with increasing values of electrode separations are used to estimate the thickness and resistivity of the subsurface formation.

## 2.3 GEOTECHNICAL METHODS

There are various geotechnical investigation techniques that are normally used to probe the suitability of a site (especially its soil) for a proposed project. According to Krynine et al, 1957, the following soil tests are recommended; Optimum Moisture Content and Maximum Dry Density, Atterberg Limits, Particle Size Distribution, Triaxial and Permeability Tests.

Due to a financial constraint, only Compaction (to determine Optimum Moisture Content or level and Maximum Dry Density of the soils) and permeability tests were undertaken for the study area.

### 2.3.1 Soil Compaction Test.

A compaction test is a soil quality test used to assess the level of compaction which can occur in the soil on a site. Compaction tests are commonly performed as part of a geotechnical profile of a building site. They may also be performed to learn more about a soil in a particular area, whether or not the area is slated for development. A geotechnical engineer, geologist, or a soil scientist may conduct a compaction test .In some cases, the test may be performed in situ, in which case the testing options may be more limited, and the profile will not be as complete. Compaction tests can also be performed in a lab environment with soil samples taken from a site. The lab allows for more controls and more finesse of the test. Soil often needs to be taken back to the lab anyway for the performance of additional soil quality tests which are designed to provide more information about the characteristics and composition of the soil.

The goal of a soil compaction test is to find the maximum practical density of the soil. For the test, a sample of soil is packed into a mold and subjected to pressure to force the soil to compact. The test is repeated several times, with the moisture level of the soil being adjusted to achieve a range of values.

The test results can be used to determine how much the soil can compact, what the optimum moisture level on the site is, and what the maximum dry density of the soil is.

The more moisture in the soil, the more it can be compacted. Compaction tests provide important information about the soil quality at a site which can be used to determine where the best building sites are, how much weight the soil can withstand, and whether or not the site is even appropriate for building. These tests are one among many assessments performed when evaluating sites to create a complete picture.

The development of the soil compaction test is credited to Ralph R. Proctor, and it is sometimes known as the Procter Test. Proctor developed the test in the 1930s, and the mechanism of the test has not changed much since; for testing, a mold of standardized size is used, with a mallet of standardized weight dropped from a standard height to achieve the desired level of pressure. Like other scientific tests, the compaction test is designed to be repeatable by anyone with a knowledge of the procedure and the standard equipment.

### 2.3.2 Falling Head Permeability.

The falling head permeability test is a common laboratory testing method used to determine the permeability of fine grained soils with intermediate and low permeability such as silts and clays. This testing method can be applied to both an undisturbed and disturbed sample .

This test involves flow of water through a relatively short soil sample connected to standpipe a which provides the water head and also allows measuring the volume of water passing through the sample. The diameter of the standpipe depends on the permeability of the tested soil. The test can be carried out in a Falling Head permeability cell or in an oedometer cell.

Before starting the flow measurements, the soil sample is saturated and the standpipes are filled with de-aired water to a given level. The test then starts by allowing water to flow through the sample until the water in the standpipe reaches a given lower limit. The time required for the water in the standpipe to drop from the upper to the lower level is recorded. Often, the standpipe is refilled and the test is repeated for a couple of times. The recorded time should be the same for each test within an allowable variation of about 10%, otherwise the test is failed (Head, 1982).

On the basis of the test results, the permeability of the sample can be calculated as

$K=[a.L / (A.\Delta t)].Log(hU / hL)$

in which we have

L: the height of the soil sample column

A: the sample cross section

a: the cross section of the standpipe

$\Delta t$: the recorded time for the water column to flow though the sample

hU and hL : the upper and lower water level in the standpipe measured using the same water head reference.

# CHAPTER THREE

## 3.0 DATA ACQUISITION

### 3.1 RELIMINARY/DESKTOP STUDIES.

Prior to the actual fieldwork, desktop studies were done to give a general geological feel of what is expected in the light of the aim and objectives of the study. A topographical map of the area (scale 1 ; 100,000) was examined. A satellite image and the geological map of Thika and north Machakos was also reviewed.

This stage of the study also involved utilization of existing geological reports of previous workers in the area that are available at the Geology and Mines Department as well as the Ministry of Water and Irrigation as well as the Department of Geology Department, University of Nairobi. Hydrological maps available at the Department of Geography and Environmental Studies, University of Nairobi, were also resourceful at this level.

### 3.2 FIELDWORK

The fieldwork started in earnest in July 27, 2008.The study area is about 100km from Nairobi along Thika Garissa road. From Ngoliba market, the site is only a kilometer to the east. The two week's exercise involved both the geophysical survey and collection of soil representative samples for the seemingly three soil types in the study area for geotechnical investigations. Additional investigations were also done in the neighbouring area in a bid to assess the availability of dam embankment material.

#### 3.2.1 Instrumentation

The geophysical investigation were done using the ABEM Signal Averaging System (SAS) 300B .The image a some technical specifications for this instrument is as shown in *Figure 3.1* and *table 3.1,* respectively.

**Figure 3.1 Photograph of Terameter SAS-300**

| | |
|---|---|
| Receiver: | |
| Number of input channels | 1- automatic ranging |
| Input impedance | 10 Megaohm |
| Resolution | 30 nV |
| IP chargeability | Up to 10 time windows, user selectable |
| Maximum input voltage | 400 volts |
| IP integration interval | 20 ms /16.66 ms depending on power line frequency |
| Dynamic range | up to 140 dB, plus 64 dB automatic gain |
| Maximum integration interval | 8 seconds |
| Transmitter | |
| Output current | 1, 2, 5, 10, 20, 50, 100, 200, 500, 1000ma |
| Maximum output voltage | 400 V |
| Output current accuracy | Better than 0.5% (at 100 ma) |
| Maximum output power | 100 W |
| General: | |
| Computer | PC compatible |
| Mass storage | More than 30 thousand readings |
| Display | LCD 200x64 pixels (8 lines of 64 char.) |
| Serial interface | RS 232 |
| Power | external 12v through SAS-EBA |

**Table 3.1: Technical Specifications for Terameter – SAS 300**

### 3.2.2 Field Survey and Data

In order to cover the expected dam foundation (embankment) area, Horizontal Electrical Profiling (HEP) were undertaken along four traverse lines across the river at a separation distance of 20metres. *Figure 3.2* shows the area of the traverse lines. Seven vertical electrical soundings (VESs) were carried out at the points where anomalous low resistivity values were observed on the HEPs. The electrical resistivity values for all the Horizontal Profiling and Vertical Electrical Soundings obtained are shown in tables *A3.1* to *A3.17*, in the appendices. Numerous ground elevation data were obtained at the embankment area along the traverse lines as well as within the reservoir or abutment area in *UTM* system using a Global Positioning System (GPS).A computer software known as *AUTOCAD* was used to interpolate and generate the contour Map shown in *figure 3.3*.The GPS readings at the site showed a slight shift compared to the contour lines in the topographical map of the area.

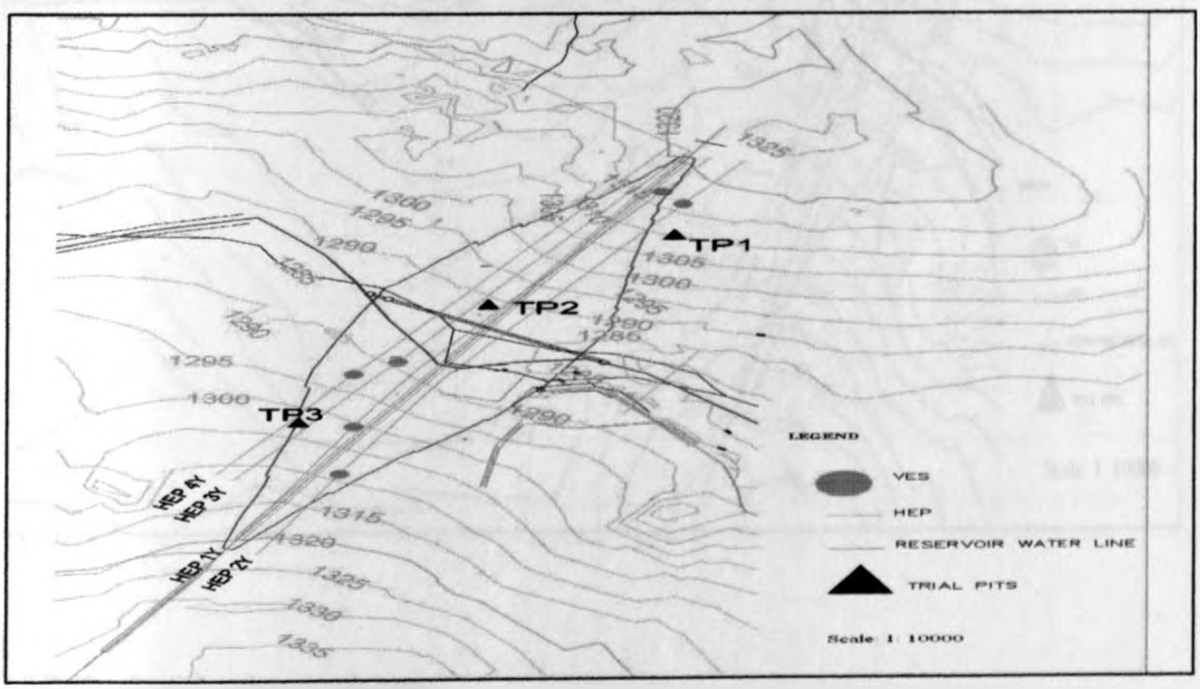



**Figure 3.2: Map of the study area showing the four traverse lines and VES points within the area recommended for the embankment.**

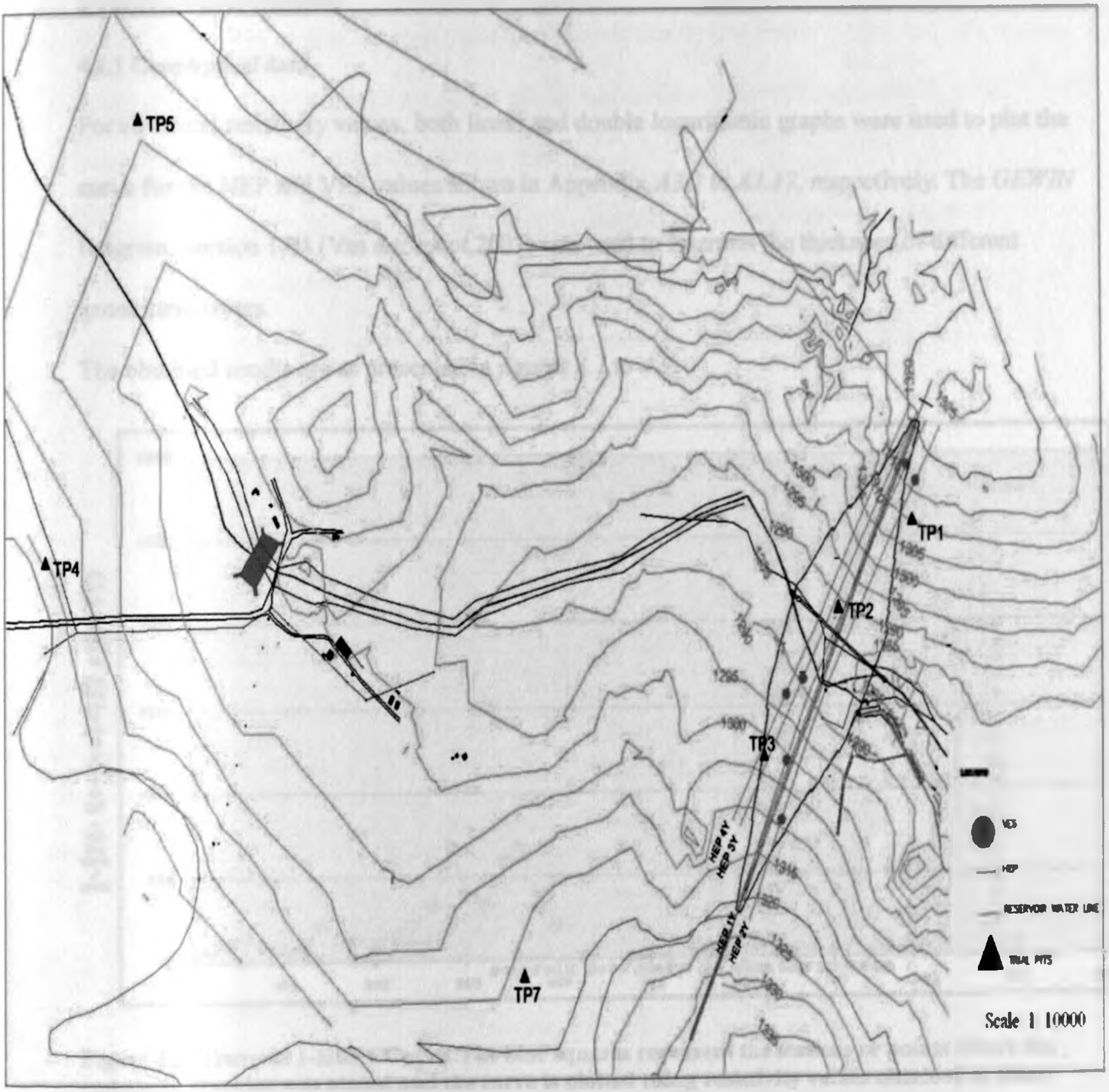



**Figure 3.3 Embankment and reservoir area**

# CHAPTER FOUR

## 4.0 DATA PROCESSING AND INTERPRETATION

### 4.1 DATA PROCESSING

#### 4.1.1 Geophysical data

For electrical resistivity values, both linear and double logarithmic graphs were used to plot the curve for the HEP and VES values shown in Appendix *A3.1* to *A3.17*, respectively. The *GEWIN* Program version 1.04 (Van der moot,2001) was used to interpret the thickness of different geoelectric layers.

The obtained results are as presented in *figures 4.1* to *4.7*.

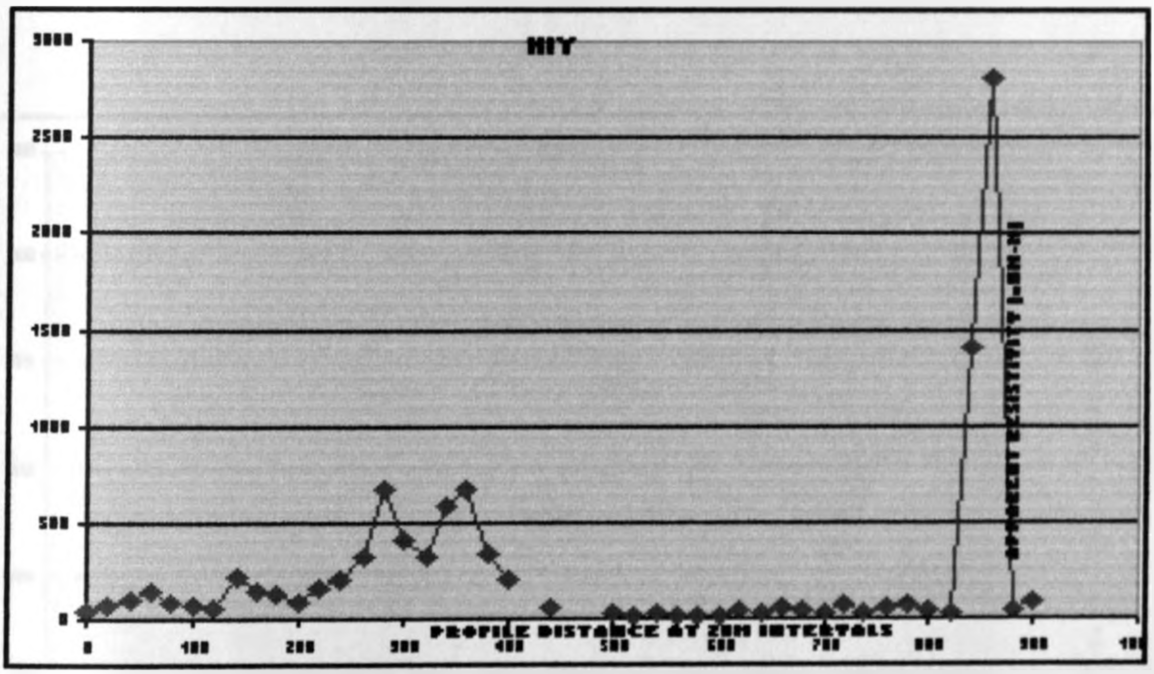


**Figure 4.1: Traverse 1-HEP1 Curve. The blue squares represent the stations or points where the resistivity machine was placed and the curve is plotted using resistivity values obtained at these points along the traverse.**

This traverse was executed along the line shown as HEP Y1 in *figure 3.2*. Its azimuth is E-W. depicts a sharp anomaly comprising a very high resistivity value between station 40 and 45.The other anomalies reading of relatively higher resistivity values is shown between station 20 and

30. A vertical Electrical Sounding was conducted at station 43 to give more insight as to what geological feature could have given this harp rise in resistivity values at this point of traverse HEP Y1.The host rock to the western half of this traverse line is biotite gneiss while the eastern half including the area showing high resistivity is underlain by granitic gneiss with some migmatites and quartz vein near the river channel.

The second traverse line *(Figure 4.2)*, designed in *figure 3.2* as HEP Y2 was done 20m downstream and parallel to traverse HEP 1Y with the same azimuth (E-W).It also showed an anomalous high resitivity at more less the same position but with a slight shift to the west.

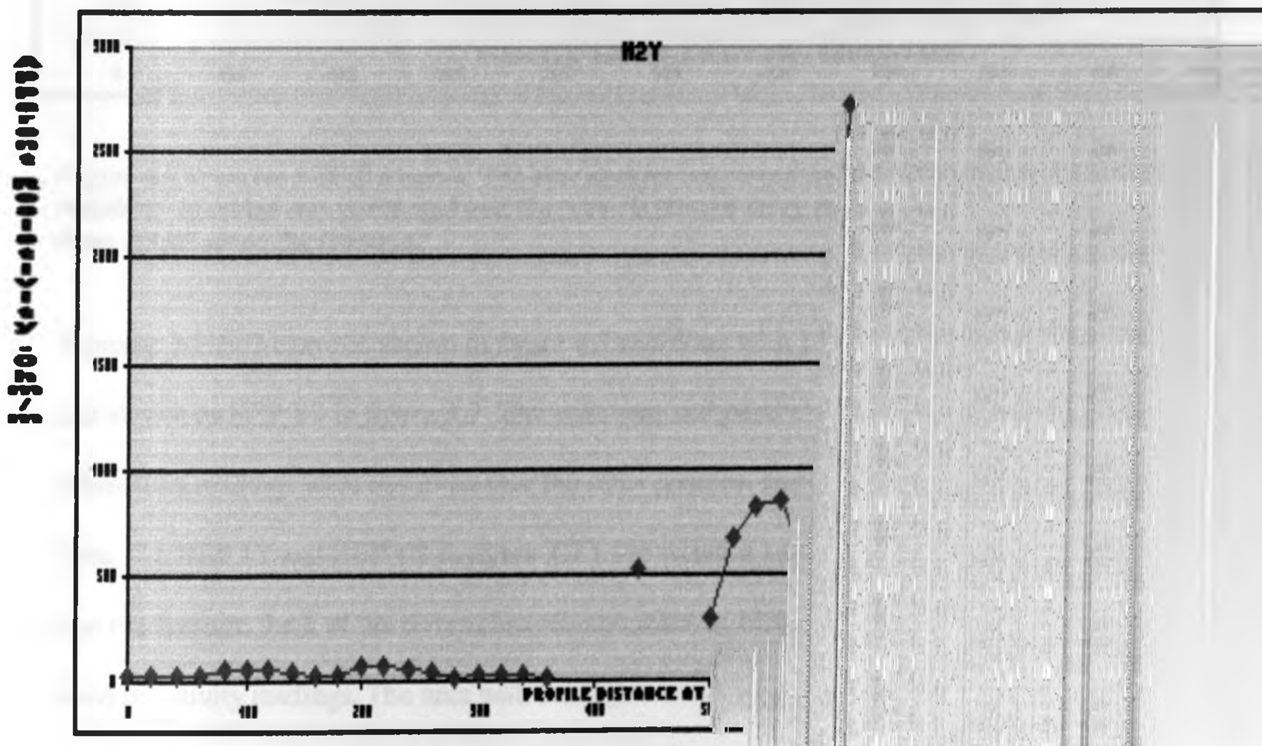



**Figure 4.2 Traverse 2-HEP2 curve. The blue squares represent the stations or points where the resistivity machine was positioned and the curve is plotted using resistivity values obtained at these points along the traverse**

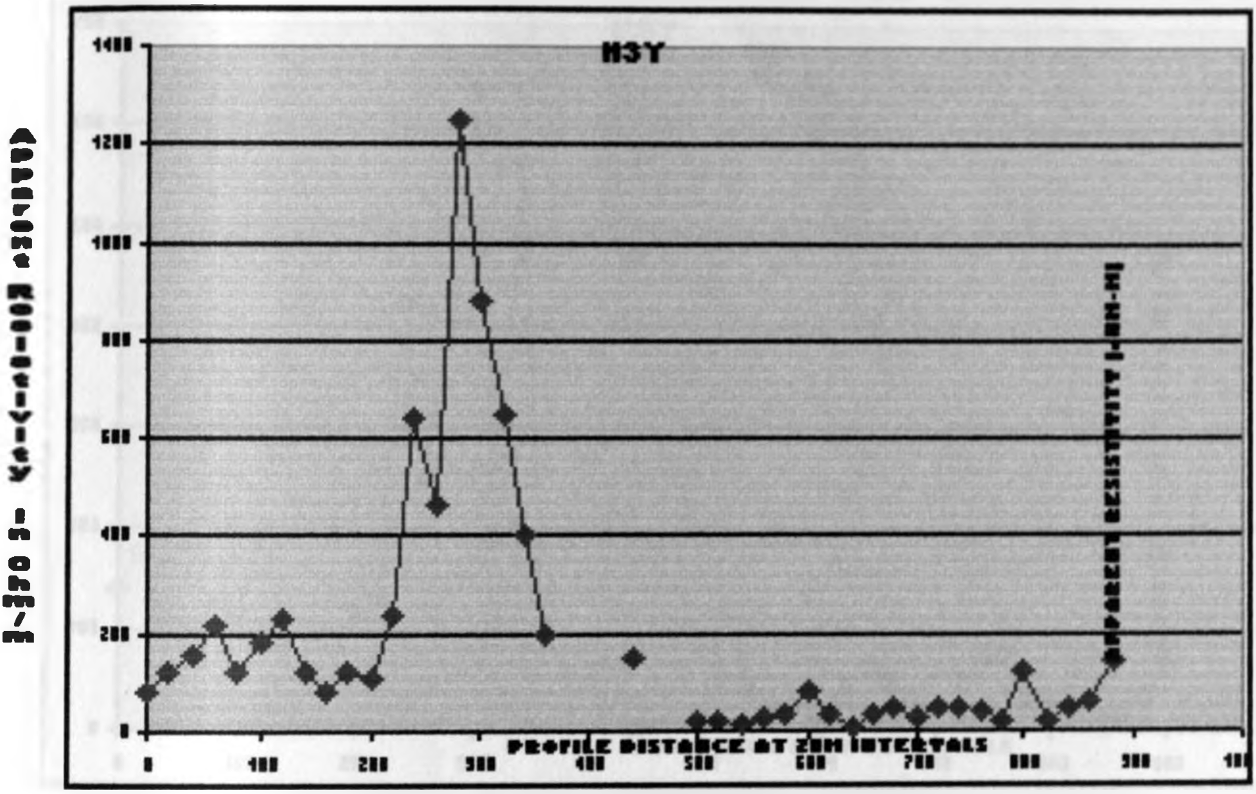



**Figure 4.3 Traverse 3-HEP 3 curve. The blue squares represent the stations or points where the resistivity machine was positioned and the curve is plotted using resistivity values obtained at these points along the traverse.**

Traverse 3-HEP3 curve as shown in *figure 4.3* was done with a W-E azimuth 20m along the line shown as HEP Y3 in *figure 3.2* 20m upstream and parallel to traverse1- HEP1. The same anomalous readings were observed near the same position and the two previous traverse lines. (i.e HEP 1Y and HEP Y2 *in figure 3.2* ).The western half along this traverse line which is also the western flank of the rivers channel comprises of biotite gneiss that depicts a generally same resistivity readings. The area with the high anomalous resistivity values along thos traverse line is again underlain by granitoid gneiss towards the east end and migmatites and quartz veins near the river channel.

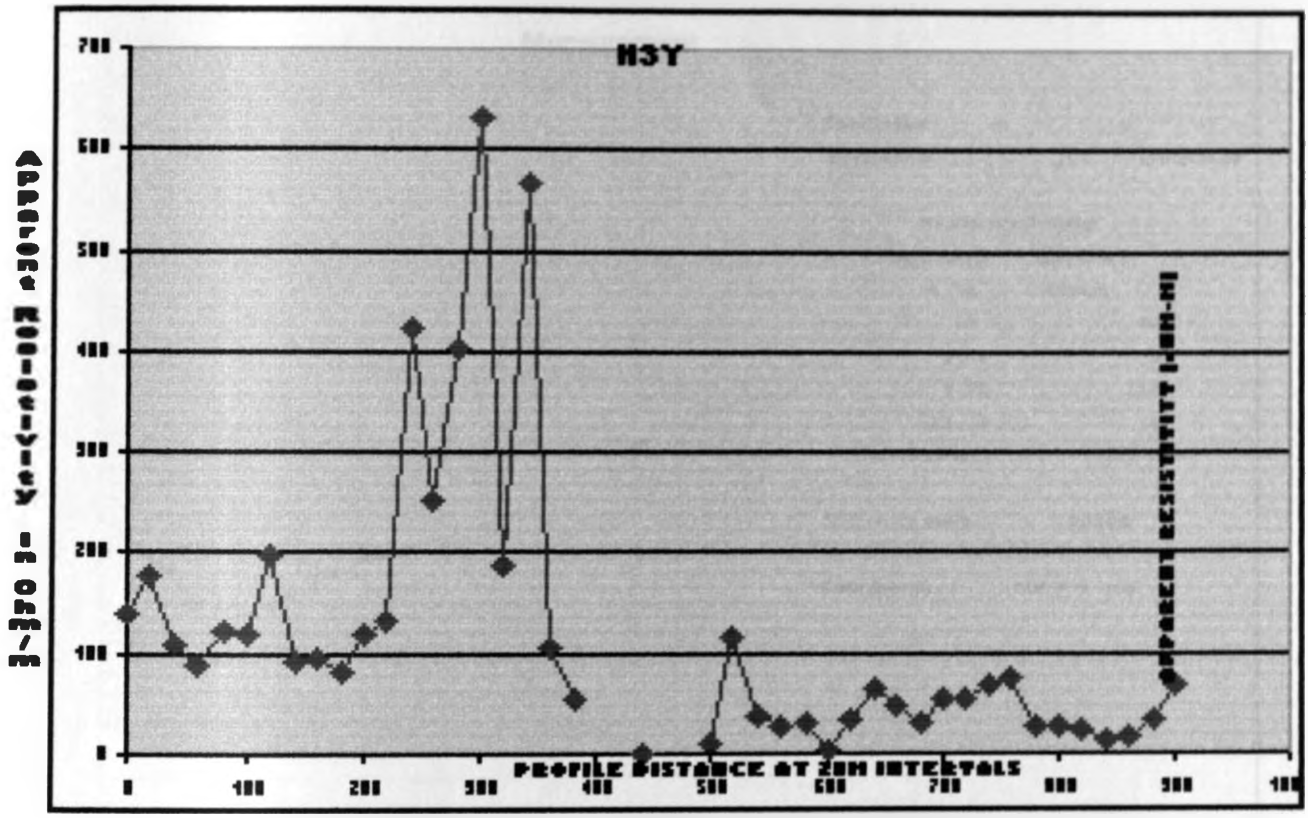



**Figure 4.4 Traverse 4 –HEP 4 curve. The blue squares represent the stations or points where the resistivity machine was positioned and the curve is plotted using resistivity values obtained at these points along the traverse.**

Traverse 4-HEP 4 curve *(figure 4.4)* represents the graph of the resistivity values in ohm (y-axis) against the distance along the line shown as HEP Y4 in *figure 3.2.*

The reading were taken at a E-W azimuth, which means station 1 was located at the eastern side of the river bank. Its is precisely 40m upstream of the first traverse line shown as HEP 1Y in *figure 3.2.* The area with the anomalously high resistivity values lies to the north of the same anomalous signals in traverse line 1,2 and three. However the anomalous readings the are slightly lower than the other peak in previous 3 traverse HEP lines and covers a wider area across. These anomalous readings occur within area covered by quartzofeldspathic gneiss and migmatites.

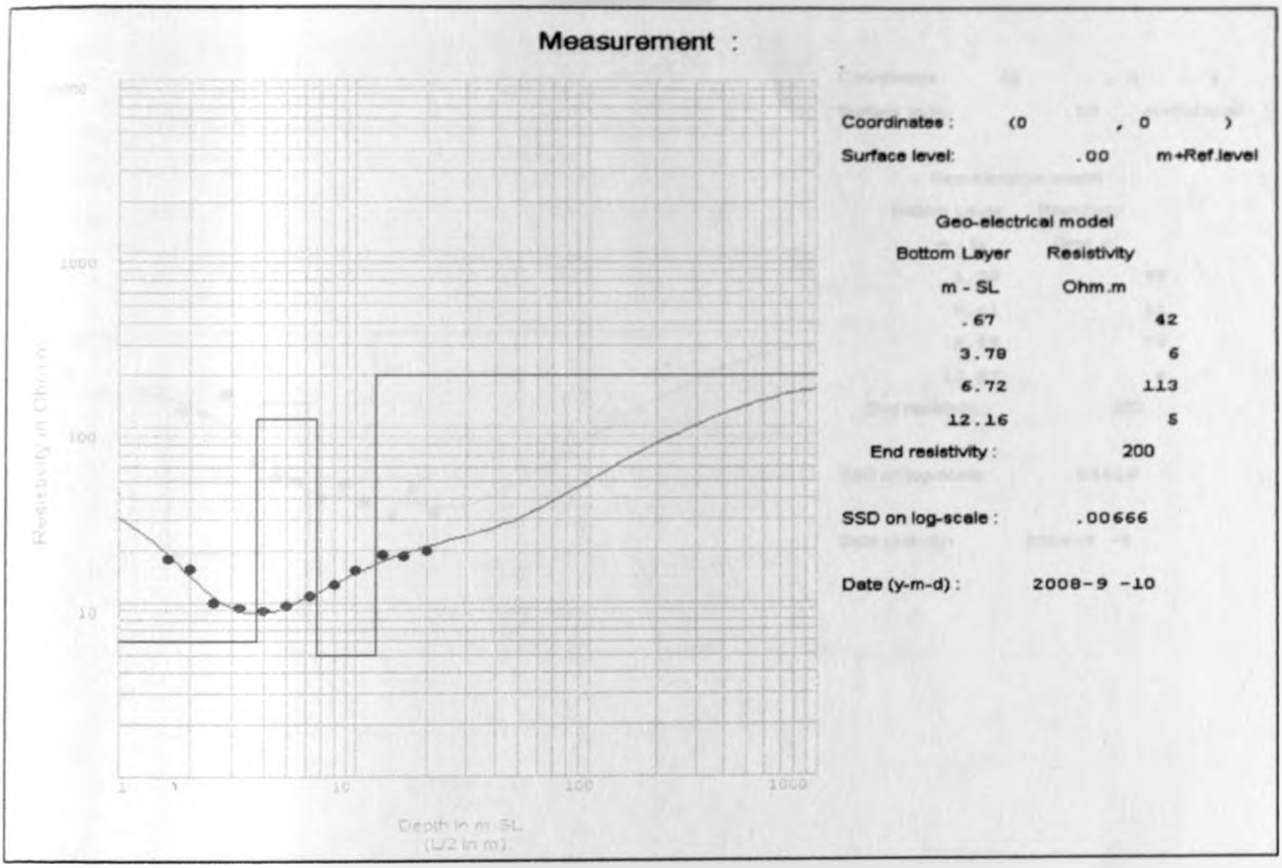



**Figure 4.5 Traverse 1-VES 1 curve. The green and red lines represent model curve while the blue dots represent the physical data curve.**

Traverse 1-VES 1 curve (figure 4.5) shows a four geo-electric layers model with low resistivities at a depth of 3.78m and 12.16m .This point is represented by the green circle along HEP 1Y near TP1 in *figure 3.2.*The thickness of the overlying soil cover is hereby inferred to e 0.67m.This layer is underlain gravelly subsoil of about 3.12m. A partially weathered gneiss comprises the third geo-electric layer that overlies the fresh basement from 20m.

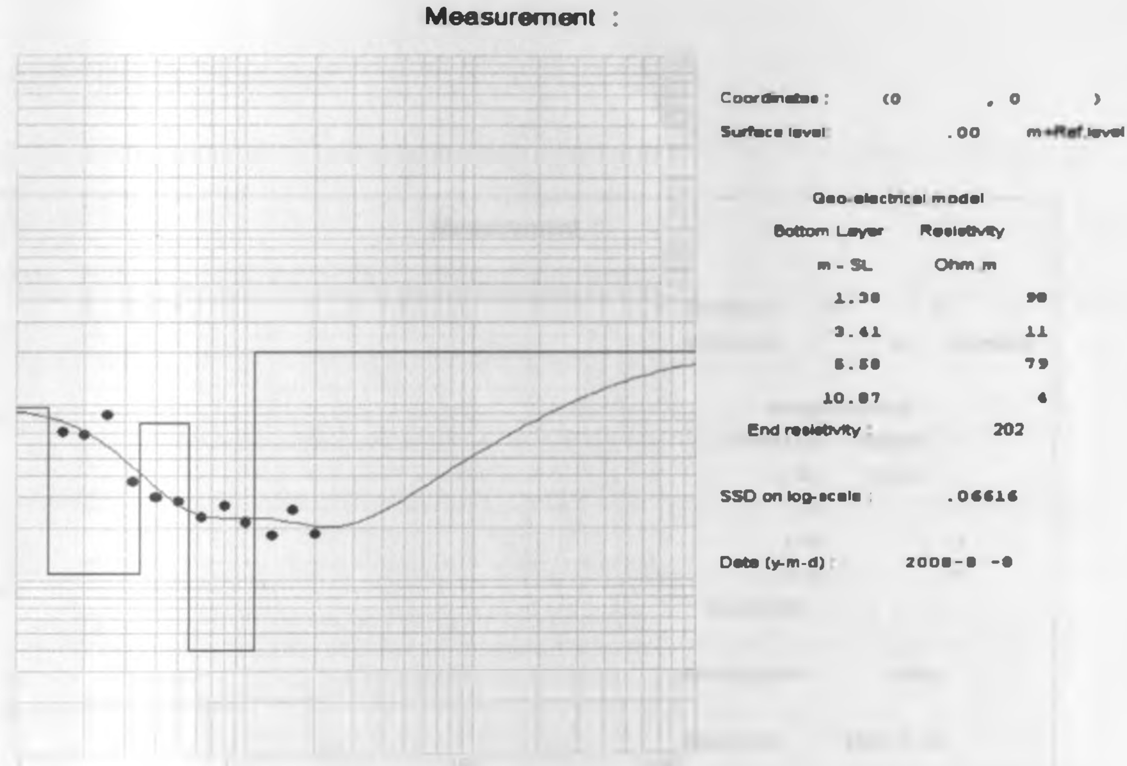



**Figure 4.6 Traverse 2-VES1 curve. The green and red lines represent model curve while the blue dots represent the physical data curve.**

Traverse 2-VES1 curve is a plot of the a soundings done along Traverse 2 at the point of anomalously high resistivity values precisely at the point indicated y the green circle along HEP 2Y near TP1 in *figure 3.2.* Just like in Traverse 1-VES this curve depicts a four layer model with a low resistivity of 4 ohm-m at a depth of 10m inferred to somewhat wet weathered thin layer of gneiss overlain dry thin weathered gneiss and gravely subsoil. The top soil is whitish loamy and is about 1.38m thick. A fresh gneissic is occurring from a depth of 20m.

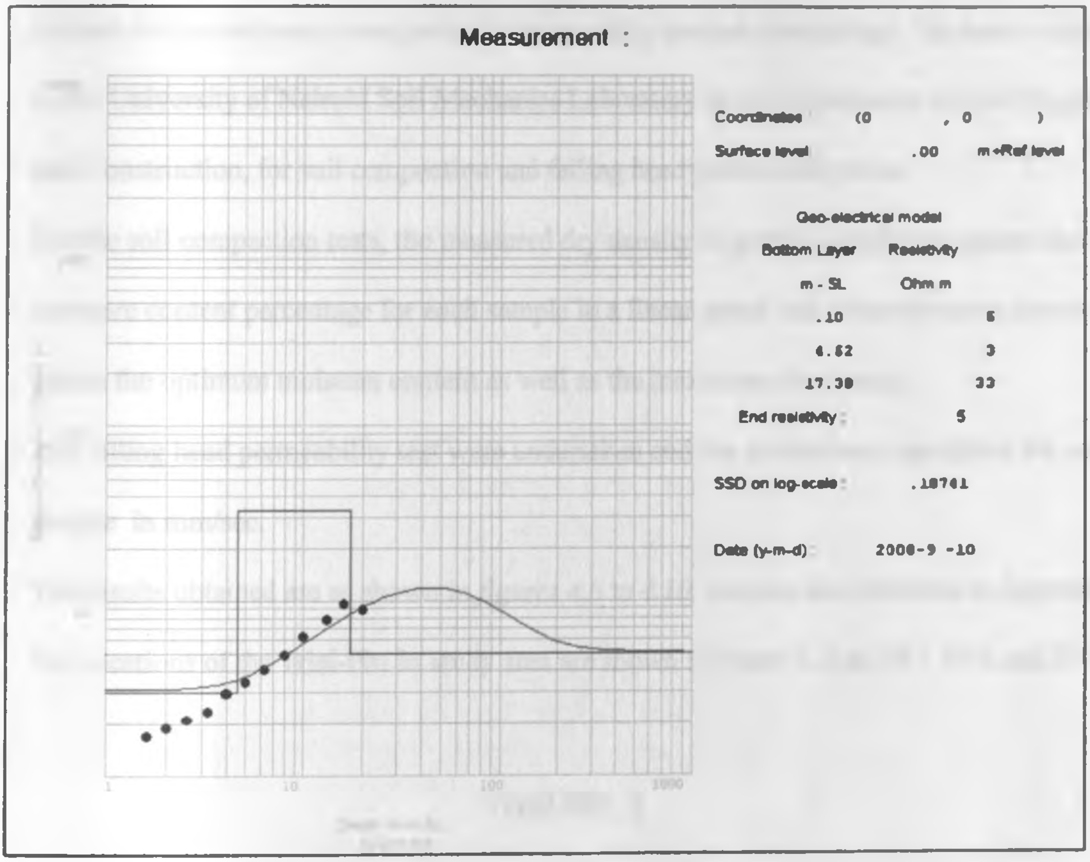



**Figure 4.7 Traverse 3-VES 1 curve. The green and red lines represent model curve while the blue dots represent the physical data curve.**

Traverse 3-VES 1 curve *(figure 4.6)* represents the interpretation of the reading of a sounding conducted along traverse 3-HEP3 indicated by a green circle along HEP 3Y in *figure 3.2* near TP3. It depicts a three layer model comprising a 0.1m organic material, and 4.5m thick black cotton coffee topsoil. This layer is underlain by partially weathered biotite gneiss.

### 4.1.2 Geotechnical data

Six kilograms, each for three representative samples were collected at points of geotechnical interest in the study area were packed into carefully labeled sample bags. The latter were taken to the University of Nairobi Soil Mechanics Laboratory in the Department of Civil Engineering and Construction, for soil compaction and falling head permeability tests.

For the soil compaction tests, the measured dry density in g/cm3 was plotted against the moisture content percentage for each sample in a linear graph and a best-fit curve drawn to obtain the optimum moisture content as well as the maximum dry density.

The falling head permeability test were undertaken and the results were calculated for each sample in mm/sec.

The results obtained are as shown in *figures 4.8* to *4.10*, and are also available in Appendix 1.

The locations of the Trial-Pits in study area are shown in *figure 3.2, as TP1, TP2 and TP3*

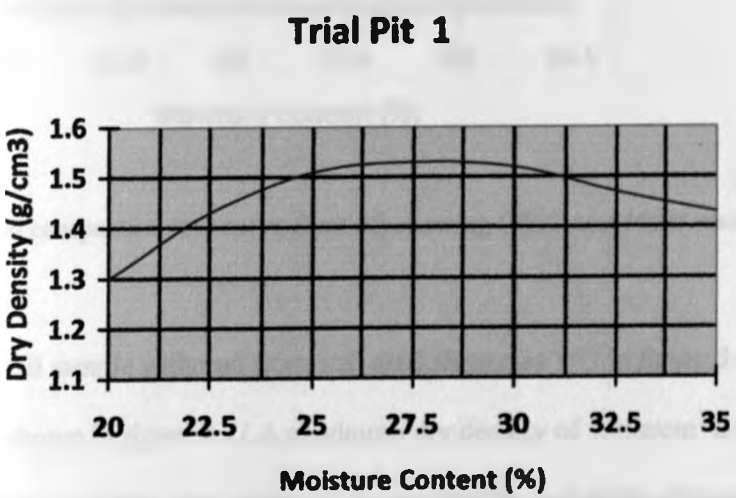



**Figure 4.8 Soil compaction test curve (best fit) showing OMC and MDD results for Trial-Pit 1**

This soil compaction curve (figure 4.9) for trail pit 1 represents the processed results of the disturbed sample obtained from the point labeled TP1 figure 3.4.The soil type at this point is red coffee soil. It depicts an optimum moisture content of 27.5% and corresponding maximum dry density of 1.53g/cm$^3$.Trial Pit 2 soil sample was obtained from the point marked as TP2 in *figure 3.4* within the embankment area. The result of the compaction test are shown by the curve in *figure 4.10.*The soil cover at this point is whitish loamy inferred to have originated from the weathering of feldspars from the underlying quartzofeldspathic gneiss. It shows optimum moisture content of 17.0% and maximum dry density of 1.83g/cm$^3$

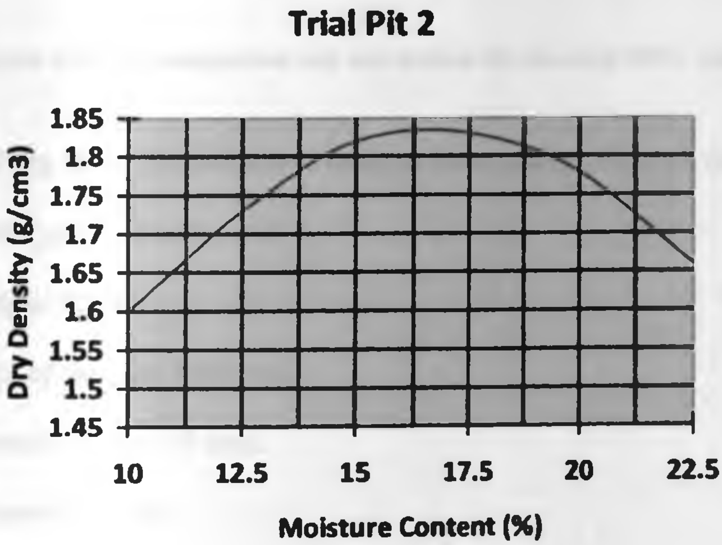



**Figure 4.10 Soil compaction test curve (best fit) showing OMC and MDD results for Trial-Pit 2**

Black cotton soil sample gathered from trail pit 3 shown as TP3 in *figure 3.4* has its compaction test results as shown in *figure 4.11*.A maximum dry density of 1.45g/cm$^3$ and an optimum moisture content of 25.9% were obtained. An account the suitability of these results in light of the aim and objectives of this study is discussed in the next chapter.

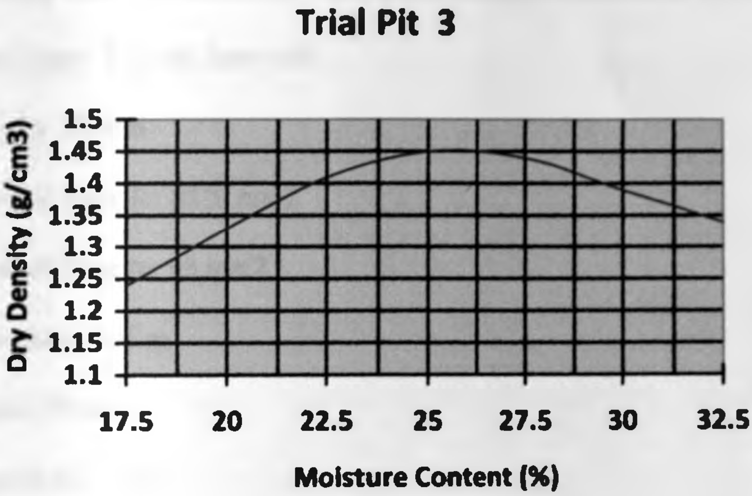



**Figure 4.11 Soil compaction test curve (best fit) showing OMC and MDD results for Trial-Pit 3**

**Falling Head Permeability results soil sample obtained at Trial-Pit 1**

Soil Type: Red coffee soil

Height: 85 mm

Area of Sample: 8820 mm2

Area of Burette: 95 mm2

Diameter: 106 m

Time: 20 min.

Log10 H1: 1.989

Log10 H2: 1.893

Thus k= $\frac{2.3 \times 85 \times 95 \quad x \quad 0.096}{8820 \quad x \quad 20 \times 60}$

= 1.685x 10 $-^{4}$ mm/sec

**Falling Head Permeability results soil sample obtained at Trial-Pit 2**

Soil Type: Whitish loam soil

Height: 92 mm

Area of Sample: 8820 mm2

Area of Burette: 95 mm2

Diameter: 106 m

Time: 20 min.

Log10 H1: 1.986

Log10 H2: 1.942

Thus k= $\dfrac{2.3 \times 92 \times 95 \quad x \quad 0.044}{8820 \quad x \quad 20 \times 60}$

= $8.357 \times 10^{-5}$ mm/sec

**Falling Head Permeability results soil sample obtained at Trial-Pit 3:**

Soil Type: Red Coffee soil

Height: 84 mm

Area of Sample: 9156 mm2

Area of Burette: 95 mm2

Diameter: 108 m

Time: 53 min.

Log10 H1: 1.978

Log10 H2: 1.708

Thus k= $\dfrac{2.3 \times 84 \times 95 \quad x \quad 0.270}{9156 \quad x \quad 53 \times 60}$

= $1.702 \times 10^{-4}$ mm/sec

K represents the permeability of the different types of soil which can also be expressed as the hydraulic conductivity. The permeability results of all the three soil types in the study area fall within the semi-permeable category according to the US Classification of hydraulic conductivity of soils for engineering. This rate is arguably satisfactory for the borrow reservoir area but for the sake of the embankment, it needs to be reduced to by other engineering methods to ensure that no considerable amount of water is seeping through it incase of an earth dam.

# CHAPTER FIVE

## 5.0 DISCUSSION OF RESULTS

The old geological map of the area (*Figure 1.7* ) area depicts the study area as only comprising biotite gneiss. However geological facts on the site at a much larger scale reveal that the site consists of several other formations although biotite gneiss seems to be predominant (*figure1.8)*.

### 5.1 GEOPHYSICAL DATA RESULTS

At the left (eastern) river bank along HEP 1, the thickness of the soil overburden varies from 1m at Traverse HEP1-VES1 to 3.41 m at Traverse HEP2-VES1 .Traverse HEP 3-VES1 depicts either a rather thick soil overburden or a highly weathered gneissic rock subject to drilling logs. This point is recommended for core drilling. The maximum depth to fresh basement rock in all the surveyed area appears to be 20 m.

On the left bank at the area of Traverse HEP1, near the river course, a weathered rock there outcrops. The anomalously high resisitivity values in station 15-20, for Traverse HEP1 & Traverse HEP2 and station 40-45 for Traverse HEP3 and Traverse HEP4 may be depicting a long quartz vein cross cutting the gneissic basement oriented north-south. This is subject to confirmation by actual drilling of the area recommended for such exercises although there exists numerous thin quart veins within the gneissic outcrops near the river course. A summary of the VES surveys and their corresponding geological inferences are as shown in table 5.1 below.

| VES No. | VES Location (UTM) | Elevation (m) | Depth Interval (m) | Resistivity (Ohm–m) | Inferred Geological formation |
|---|---|---|---|---|---|
| Traverse 1-VES1 | 317497 9879220 | 1329 (stn46) | 0.67<br>3.78<br>6.72<br>12.16<br>>12.16 | 42<br>6<br>113<br>5<br>200 | Whitish loam soil<br>Gravelly subsoil<br>Partially weathered gneiss<br>Wet weathered gneiss<br>Fresh gneiss |
| Traverse 2-VES1 | 317806 9879635 | (stn45)<br><br>1324m | 1.38<br>3.41<br>5.58<br>10.87<br>>10.87 | 98<br>11<br>79<br>4<br>202.59 | Whitish clay soil<br>Clayey gravel<br>Weathered gneiss<br>Wet weathered gneiss<br>Fresh gneiss |
| Traverse 3-HEP3-VES1 | 317358 9879048 | 1316 (stn39) | 0.10<br>4.5<br>17.38 | 5<br>3<br>33 | Black cotton soil<br>Weathered gneiss<br>Partially Weathered gneiss. |

**Table 5.1 Summary of the VES surveys and their Geological inferences.**

## 5.2 GEOTECHNICAL DATA RESULTS

The logging of the trial pits revealed that there exists three soil types: namely, brown loam top soil, black cotton soil, and red coffee soil at various locations within the study area. In shallow trial pit 3, weathered rock zones were encountered consisting of cobbles and quartz gravels at depths ranging from 0.7 m to more than 2 m underlain by highly weathered basement rock system. Occasionally, whitish steaky clay resulting from weathering of feldspars in biotite gneisses was encountered on the left river bank close to the Traverse HEP 1 at very shallow depth. Soil compaction refers to the process of obtaining increased density of soil in a fill by reduction of its pore space by the expulsion of air. The bearing capacity of any soil usually increases with increasing dry density and decreasing moisture content. High density assures high shear strength and greater imperviousness. When a soil is submerged, its effective density is reduced and with this its bearing capacity.

The moisture content of a soil is defined as the ratio of the weight of water present in the soil to the dry weight of solid soil particles. The moisture content at which the weight of soil grains obtained in a unit volume of the compacted soil mass is maximum is called the "optimum moisture content" and the dry density so obtained is called "Maximum Dry Density" (MDD). As coarse-grained soils do not absorb the water and are not appreciably amenable to lubrication, they do not display distinct Optimum moisture content. For coarse and fine-grained soils, average values are 8 to 15 and 17 to 36, respectively. At Optimum Moisture Content, the soil is broadly 90% saturated depending upon the type of soil, meaning that about 10% of the void space is occupied by air.

The Optimum Moisture Content for soil sample obtained at Trial-Pit 1, 2 and 3 are 27.5%, 17.0% and 25.9% respectively. This falls within the recommended US classification and identification of soils for general engineering purposes for fine grained Soils as mentioned above. However, The Optimum Moisture Content (OMC) should always be less than the shrinkage limit (Hanns et al, 1975).The rate of movement of gravitational water through soil pores is termed the permeability of soil. Permeability of disturbed/undisturbed soil samples should be measured in the laboratory. Permeability of foundation and embankment soils should also be measured in situ. The soils are categorised as permeable, semi permeable or impermeable as per the following limits.

Impermeable : with permeability less than 1 x 10-6 cm/sec

Semi permeable: with permeability 1x 10-6 to 1x 10-4 cm/sec.

Permeable : With permeability more than 1x 10-4 cm/sec.

The dam embankments should be impermeable. The permeability of the down stream section of embankment should not be less than that upstream. The falling head permeability for the soils samples collected at trial/test pit 1, 2 and 3 are $1.685\times 10^{-4}$ mm/sec, $8.35\times10^{-5}$ and $1.702\times10^{-4}$, respectively. Thus, according to the above US classification of soils for dam engineering purposes, all the soil samples tested fall within the semi-permeable category.

# CHAPTER SIX

## 6.0 CONSLUSION AND RECOMMENDATIONS.

The study area near the Yatta Canal intake is located directly on the basement rock outcrop of foliated biotite gneisses alternating with banded migmatites and granitoid gneisses.

The soil overburden consists of the coffee red soil mostly on the high ground and a narrow strip of black cotton soil along the right river bank. The results of geophysical exploration indicate shallow soil overburden within the precincts of the Yatta canal intake, ranging between 0.5 m and 2.0 m.

Geological profiles inferred from the interpreted geophysical data, indicate that the subsurface conditions at the study area mainly consist of two geologic formations. These are; soil overburden overlying either weathered biotite gneiss or fresh basement rock consisting of banded migmatites and granitoid gneisses occasionally containing quartzo - feldspathic veins. Subject to confirmation of the subsurface foundation conditions by core drilling and testing of the bedrock geotechnical characteristics, geophysical investigations imply that the study area is feasible and is founded on a sound rock foundation .

Geophysical investigations have established the nature of the subsurface materials and the depth to the bedrock. The detailed resistivity values obtained at the profiles are consistent in all the HEPS while the vertical electrical soundings display several formation layers identified by the degree of weathering of the bedrock.

There are no faults or significant fractures observed at the area near HEP 1, which is recommended for the dam axis area. It is therefore recommended that a minimum of three boreholes be core drilled along the area recommended for the dam axis (about 80m upstream of the Yatta Canal Intake) to confirm the geophysical findings and the bearing capacity of the bedrock. Other two boreholes should be drilled in the reservoir area including the digging of trial pits to establish the soil characteristics at the bore areas within the dam reservoir where thick soil overburden was identified. In view of the shallow depth to fresh bedrock inferred from the geophysical investigations, the expected depths of the boreholes should be between 15 to 20 metres subject to continuous fresh compact rock being encountered. Although the calculated Optimum Moisture Content (OMC) for the trial pits falls within recommended percentage according to the US classification and identification of soils for general engineering purposes for fine grained soils, the OMC should always be less than the shrinkage limit. Otherwise on exposure to sun, cracks will develop in such soil. If such soil has to be used in embankments, then it should be covered with good suitable soil, so that moisture reduction in such soils is avoided.

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APPENDICES

Raw geophysical data for the four traverse lines for and VES points.

Raw data for soil compaction and permeability test and their raw curves (disturbed samples) for the three trail pits.

US Soil Classification for Dam Engineering purposes.

Recommended ionic concentrations for both ground and surface water.

**Appendix 1**

## Geophysical data

### Table A3.1: HEP 1

| STATION NO | dv/I | DISTANCE(meters) | RESISTIVITY |
|---|---|---|---|
| 1 | 0.038 | 0 | 48.258 |
| 2 | 0.063 | 20 | 79.38 |
| 3 | 0.085 | 40 | 107.1 |
| 4 | 0.115 | 60 | 144.522 |
| 5 | 0.075 | 80 | 95.004 |
| 6 | 0.058 | 100 | 125.044 |
| 7 | 0.043 | 120 | 54.054 |
| 8 | 0.177 | 140 | 222.39 |
| 9 | 0.111 | 160 | 140.364 |
| 10 | 0.099 | 180 | 125.244 |
| 11 | 0.072 | 200 | 91.244 |
| 12 | 0.126 | 220 | 158.76 |
| 13 | 0.126 | 240 | 204.246 |
| 14 | 0.26 | 260 | 327.6 |
| 15 | 0.538 | 280 | 677.88 |
| 16 | 0.324 | 300 | 408.24 |
| 17 | 0.258 | 320 | 324.08 |
| 18 | 0.459 | 340 | 578.34 |
| 19 | 0.535 | 360 | 674.1 |
| 20 | 0.262 | 380 | 330.12 |
| 21 | 0.161 | 400 | 202.23 |
| 22 | | 420 | |
| 23 | 0.051 | 440 | 64.638 |
| 24 | | 460 | |
| 25 | | 480 | |
| 26 | 0.018 | 500 | 32.058 |
| 27 | 0.011 | 520 | 13.734 |
| 28 | 0.02 | 540 | 25.704 |
| 29 | 0.016 | 560 | 19.782 |
| 30 | 0.015 | 580 | 18.522 |
| 31 | 0.016 | 600 | 19.53 |
| 32 | 0.037 | 620 | 46.494 |
| 33 | 0.026 | 640 | 32.886 |
| 34 | 0.046 | 660 | 57.96 |
| 35 | 0.038 | 680 | 48.384 |
| 36 | 0.018 | 700 | 22.806 |
| 37 | 0.057 | 720 | 72.072 |
| 38 | 0.027 | 740 | 34.272 |
| 39 | 0.047 | 760 | 59.598 |
| 40 | 0.053 | 780 | 366.402 |
| 41 | 0.036 | 800 | 2945.846 |
| 42 | 0.018 | 820 | 225.932 |

Table A3.2: HEP 1-VES 1

| MN/2 | AB/2 (meters) | K | dv/I | RESISTIVITY |
|---|---|---|---|---|
| 0.5 | 1.6 | 7.26 | 2.46 | 17.85 |
| 0.5 | 2 | 11.78 | 1.32 | 15.62 |
| 0.5 | 2.5 | 18.85 | 0.52 | 9.93 |
| 0.5 | 3.2 | 31.38 | 0.29 | 9.32 |
| 0.5 | 4 | 49.48 | 0.18 | 8.98 |
| 0.5 | 5 | 77.75 | 0.12 | 9.59 |
| 0.5 | 6.3 | 123.9 | 0.08 | 10.97 |
| 0.5 | 8 | 200.05 | 0.06 | 12.66 |
| 0.5 | 10 | 313.36 | 0.04 | 15.17 |
| 0.5 | 13 | 530.13 | 0.03 | 18.77 |
| 0.5 | 16 | 803.44 | 0.02 | 18.48 |
| 0.5 | 20 | 125.58 | 0.01 | 19.72 |

Table A3.3: HEP1-VES 2

| MN/2 | AB/2(meters) | K | dv/ I | RESISTIVITY |
|---|---|---|---|---|
| 0.5 | 1.6 | 7.2 | 0.0807 | 0.59 |
| 0.5 | 2 | 11.78 | 0.0801 | 0.94 |
| 0.5 | 2.5 | 18.85 | 0.0793 | 1.49 |
| 0.5 | 3.2 | 31.38 | 0.0789 | 2.48 |
| 0.5 | 4 | 49.48 | 0.0783 | 3.87 |
| 0.5 | 5 | 77.75 | 0.0779 | 6.06 |
| 0.5 | 6.3 | 123.9 | 0.0772 | 9.57 |
| 0.5 | 8 | 200.27 | 0.0763 | 15.28 |
| 0.5 | 10 | 313.36 | 0.0742 | 23.25 |
| 0.5 | 13 | 530.13 | 0.0729 | 38.65 |
| 0.5 | 16 | 803.44 | 0.0699 | 56.16 |
| 0.5 | 20 | 1255.81 | 0.0429 | 53.87 |

**Table A3.4: HEP 2**

| STATION NO. | dV/I | DISTANCE(meters) | RESISTIVITY (ohm-m) |
|---|---|---|---|
| 1 | 0.23 | 0 | |
| 2 | 0.024 | 20 | 30.744 |
| 3 | 0.026 | 40 | 32.76 |
| 4 | 0.026 | 60 | 32.634 |
| 5 | 0.051 | 80 | 63.882 |
| 6 | 0.052 | 100 | 62.52 |
| 7 | 0.046 | 120 | 57.708 |
| 8 | 0.031 | 140 | 38.43 |
| 9 | 0.027 | 160 | 34.524 |
| 10 | 0.022 | 180 | 27.846 |
| 11 | 0.053 | 200 | 66.654 |
| 12 | 0.058 | 220 | 72.954 |
| 13 | 0.046 | 240 | 57.582 |
| 14 | 0.038 | 260 | 47.25 |
| 15 | 0.015 | 280 | 18.648 |
| 16 | 0.026 | 300 | 33.012 |
| 17 | 0.028 | 320 | 35,28 |
| 18 | 0.018 | 340 | 23.184 |
| 19 | 0.01 | 360 | 12.978 |
| 20 | | 380 | |
| 21 | | 400 | |
| 22 | | 420 | |
| 23 | 0.422 | 440 | 531.72 |
| 24 | 0.261 | 460 | |
| 25 | 0.233 | 480 | |
| 26 | 0.232 | 500 | 292.32 |
| 27 | 0.537 | 520 | 676.32 |
| 28 | 0.646 | 540 | 813.96 |
| 29 | 0.677 | 560 | 853.02 |
| 30 | 0.464 | 580 | 584.64 |
| 31 | 0.521 | 600 | 656.46 |
| 32 | 2.16 | 620 | 272.16 |
| 33 | 0.274 | 640 | 345.24 |
| 34 | 0.135 | 660 | 170.478 |
| 35 | 0.15 | 680 | 189.0 |
| 36 | 0.06 | 700 | 75.6 |
| 37 | 0.087 | 720 | 109.62 |
| 38 | 0.139 | 740 | 175.14 |
| 39 | 0.194 | 760 | 244.44 |
| 40 | 0.149 | 800 | 187.74 |
| 41 | 0.11 | 820 | 138.6 |
| 42 | 0.204 | 840 | 257.04 |
| 43 | 0.055 | 860 | 69.3 |

**Table A3.5: HEP 2-VES 1**

| MN/2 | AB/2 | K | Dv/I | RESISTIVITY |
|---|---|---|---|---|
| 0.5 | 1.6 | 7.26 | 9.8 | 71.12 |
| 0.5 | 2 | 11.78 | 5.82 | 68.56 |
| 0.5 | 2.5 | 18.85 | 4.69 | 88.4 |
| 0.5 | 3.2 | 31.38 | 1.175 | 36.88 |
| 0.5 | 4 | 49.48 | 0.607 | 30.03 |
| 0.5 | 5 | 77.75 | 0.367 | 28.54 |
| 0.5 | 6.3 | 123.9 | 0.1857 | 23.01 |
| 0.5 | 8 | 200.05 | 0.1328 | 26.6 |
| 0.5 | 10 | 313.36 | 0.0682 | 21.37 |
| 0.5 | 13 | 530.13 | 0.0341 | 18.08 |
| 0.5 | 16 | 803.44 | 0.0314 | 25.23 |
| 0.5 | 20 | 125.581 | 0.0148 | 18.59 |

**Table A3.6: HEP2-VES 2**

| MN/2 | AB/2 | K | dv/I | RESISTIVITY |
|---|---|---|---|---|
| 0.5 | 1.6 | 7.26 | 7.45 | 54.06 |
| 0.5 | 2 | 11.78 | 4.17 | 49.13 |
| 0.5 | 2.5 | 18.85 | 2.3 | 43.35 |
| 0.5 | 3.2 | 31.38 | 2.312 | 41.18 |
| 0.5 | 4 | 49.48 | 0.913 | 45.18 |
| 0.5 | 5 | 77.75 | 0.645 | 50.15 |
| 0.5 | 6.3 | 123.9 | 0.511 | 63.31 |
| 0.5 | 8 | 200.05 | 0.867 | 173.63 |
| 0.5 | 10 | 313.36 | 0.186 | 58.29 |
| 0.5 | 13 | 530.13 | 0.118 | 62.56 |
| 0.5 | 16 | 803.44 | 0.79 | 63.47 |
| 0.5 | 20 | 125.581 | 0.06 | 75.35 |

**Table A3.7: HEP 3**

| STATION NO. | dV/I | DISTANCE(meters) | RESISTIVITY (ohm-m) |
|---|---|---|---|
| 1 | 0.066 | 0 | 82.908 |
| 2 | 0.1 | 20 | 126.126 |
| 3 | 0.126 | 40 | 158.76 |
| 4 | 0.174 | 60 | 219.24 |
| 5 | 0.097 | 80 | 122.22 |
| 6 | 0.144 | 100 | 181.44 |
| 7 | 0.183 | 120 | 230.58 |
| 8 | 0.1 | 140 | 126.00 |
| 9 | 0.065 | 160 | 81.774 |
| 10 | 0.085 | 180 | 107.1 |
| 11 | 0.192 | 200 | 241.92 |
| 12 | 0.51 | 220 | 642.62 |
| 13 | 0.37 | 240 | 466.2 |
| 14 | 0.99 | 260 | 124.74 |
| 15 | 0.7 | 280 | 882.00 |
| 16 | 0.514 | 300 | 674.64 |
| 17 | 0.318 | 320 | 400.68 |
| 18 | 0.156 | 340 | 196.938 |
| 29 | | 360 | |
| 20 | | 380 | |
| 21 | | 400 | |
| 22 | 0.117 | 420 | 147.42 |
| 23 | 0.071 | 440 | |
| 24 | | 460 | |
| 25 | 0.015 | 480 | 18.396 |
| 26 | | 500 | |
| 27 | 0.017 | 520 | 21.042 |
| 28 | 0.1 | 540 | 13.104 |
| 29 | 0.023 | 560 | 28.35 |
| 30 | 0.027 | 580 | 34.272 |
| 31 | 0.067 | 600 | 84.042 |
| 32 | 0.03 | 620 | 37.17 |
| 33 | 0.004 | 640 | 51.66 |
| 34 | 0.026 | 660 | 32.76 |
| 35 | 0.037 | 680 | 46.116 |
| 36 | 0.024 | 700 | 30.24 |
| 37 | 0.38 | 720 | 48.384 |
| 38 | 0.035 | 740 | 44.604 |
| 49 | 0.033 | 760 | 42.084 |
| 40 | 0.018 | 780 | 22.176 |
| 41 | 0.099 | 800 | 124.74 |
| 42 | 0.018 | 820 | 22.68 |

**Table A3.8: HEP 3 VES 1**

| MN/2 | AB/2 | K | dv/I | RESISTIVITY |
|---|---|---|---|---|
| 0.5 | 1.6 | 7.26 | 0.234 | 1.7 |
| 0.5 | 2 | 11.78 | 0.1598 | 1.88 |
| 0.5 | 2.5 | 18.85 | 0.1107 | 2.09 |
| 0.5 | 3.2 | 31.38 | 0.037 | 1.16 |
| 0.5 | 4 | 49.48 | 0.0595 | 2.94 |
| 0.5 | 5 | 77.75 | 0.0444 | 3.45 |
| 0.5 | 6.3 | 123.9 | 0.0326 | 4.04 |
| 0.5 | 8 | 200.27 | 0.0244 | 4.89 |
| 0.5 | 10 | 313.36 | 0.0199 | 6.24 |
| 0.5 | 13 | 530.13 | 0.0148 | 7.85 |
| 0.5 | 16 | 803.44 | 0.0119 | 9.56 |

**TableA3.9: HEP 3-VES 2**

| MN/2 | AB/2 | K | dV/I | RESISTIVITY |
|---|---|---|---|---|
| 0.5 | 1.6 | 7.26 | 8.6 | 62.92 |
| 0.5 | 2 | 11.78 | 6.05 | 71.27 |
| 0.5 | 2.5 | 18.85 | 4.06 | 763.53 |
| 0.5 | 3.2 | 31.38 | 3.58 | 112.35 |
| 0.5 | 4 | 49.48 | 1.447 | 71.6 |
| 0.5 | 5 | 77.75 | 0.766 | 59.56 |
| 0.5 | 6.3 | 123.9 | 0.359 | 44.48 |
| 0.5 | 8 | 200.27 | 0.1693 | 33.91 |
| 0.5 | 10 | 313.36 | 0.981 | 30.74 |
| 0.5 | 13 | 530.13 | 0.0533 | 28.26 |
| 0.5 | 16 | 803.44 | 0.0334 | 32.7 |

**Table A3.10: HEP 4**

| STATION NO. | dV/I | DISTANCE(meters) | RESISTIVITY (ohm-m) |
|---|---|---|---|
| | | | |
| 1 | 0.11 | 0 | 138.6 |
| 2 | 0.141 | 20 | 177.66 |
| 3 | 0.086 | 40 | 108.36 |
| 4 | 0.071 | 60 | 89.46 |
| 5 | 0.099 | 80 | 124.236 |
| 6 | 0.096 | 100 | 120.96 |
| 7 | 0.157 | 120 | 197.19 |
| 8 | 0.072 | 140 | 90.72 |
| 9 | 0.078 | 160 | 95.76 |
| 10 | 0.065 | 180 | 81.90 |
| 11 | 0.095 | 200 | 119.07 |
| 12 | 0.106 | 220 | 133.812 |
| 13 | 0.336 | 240 | 423.36 |
| 14 | 0.200 | 260 | 251.748 |
| 15 | 0.319 | 280 | 401.94 |
| 16 | 0.502 | 300 | 632.52 |
| 17 | 0.148 | 320 | 186.48 |
| 18 | 0.451 | 340 | 568.26 |
| 19 | 0.085 | 360 | 107.352 |
| 20 | 0.043 | 380 | 54.18 |
| 21 | 0.161 | 400 | 202.23 |
| 22 | | 420 | |
| 23 | 0.051 | 440 | |
| 24 | 0.012 | 460 | |
| 25 | 0.012 | 480 | |
| 26 | 0.008 | 500 | 23.058 |
| 27 | 0.091 | 520 | 114.66 |
| 28 | 0.031 | 540 | 39.06 |
| 29 | 0.023 | 560 | 28.854 |
| 30 | 0.024 | 580 | 30.366 |
| 31 | 0.004 | 600 | 4.788 |
| 32 | 0.028 | 620 | 35.154 |
| 33 | 0.052 | 640 | 65.268 |
| 34 | 0.038 | 660 | 48.132 |
| 35 | 0.024 | 680 | 30.618 |
| 36 | 0.044 | 700 | 55.188 |
| 37 | 0.043 | 720 | 54.684 |
| 38 | 0.053 | 740 | 66.584 |
| 39 | 0.061 | 760 | 76.356 |
| 40 | 0.022 | 800 | 27.216 |
| 41 | 0.02 | 820 | 25.704 |
| 42 | 0.019 | 840 | 23.814 |
| 43 | 0.012 | 860 | 14.49 |

**Table A3.11: HEP 4-VES 1**

| MN/2 | AB/2 | K | dv/I | RESITIVITY |
|---|---|---|---|---|
| 0.5 | 1.6 | 7.26 | 5.98 | 43.4 |
| 0.5 | 2 | 11.78 | 2.36 | 27.8 |
| 0.5 | 2.5 | 18.85 | 0.54 | 10.18 |
| 0.5 | 3.2 | 31.38 | 0.031 | 0.99 |
| 0.5 | 4 | 49.48 | 0.082 | 4.06 |
| 0.5 | 5 | 77.75 | 0.485 | 37.71 |
| 0.5 | 6.3 | 123.9 | 0.195 | 24.16 |
| 0.5 | 8 | 200.27 | 0.13 | 26.04 |
| 0.5 | 10 | 313.36 | 0.093 | 29.14 |
| 0.5 | 13 | 530.13 | 0.080 | 42.41 |
| 0.5 | 16 | 803.44 | 0.039 | 31.33 |

**Appendix 2**

**Geotechnical data**

**Table A3.12: Trial pit 1-Soil compaction test**

| TEST NUMBER | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| WATER ADDED IN C.C | 300 | 400 | 500 | 600 | 700 |
| WATER OF MOULD +SPECIMEN (w)g | 6512 | 6704 | 6882 | 6909 | 6841 |
| WATER OF MOULD (w2)g | 5026 | 5026 | 5026 | 5026 | 5026 |
| WATER OF SPECIMEN w = w1-w2)gm | 1436 | 1678 | 1856 | 1883 | 1815 |
| BULK DENSITY OF SPECIMEN (p = w/v)g/cm3 | 1.55 | 1.76 | 1.94 | 1.97 | 1.90 |
| DRYING DISH NO. | 180 | 102 | 213 | 145 | 164 |
| WT OF DRYING DISH + WET SPECIMEN (w3)g | 352.8 | 289.9 | 303.3 | 338.5 | 355.2 |
| WT OF DRYING DISH + DRY SPECIMEN (w4)g | 313.8 | 256.6 | 258.4 | 283.5 | 291.2 |
| WT OF DRYING DISH (w5)g | 110.3 | 113.1 | 92.8 | 106.5 | 108.7 |
| LOSS OF WEIGHT IN DRYI NG (w3-w4)g | 39.0 | 33.3 | 44.9 | 55.0 | 64.0 |
| WATER OF DRY SPECIMEN (w3-w4)g | 203.5 | 143.5 | 165.6 | 177.0 | 182.5 |
| MOISTURE CONTENT (M)% | *19.2* | *23.2* | *27.1* | *31.1* | *35.1* |
| DRY DENSITY OF SPECIMEN | *1.30* | *1.43* | *1.53* | *1.50* | *1.41* |

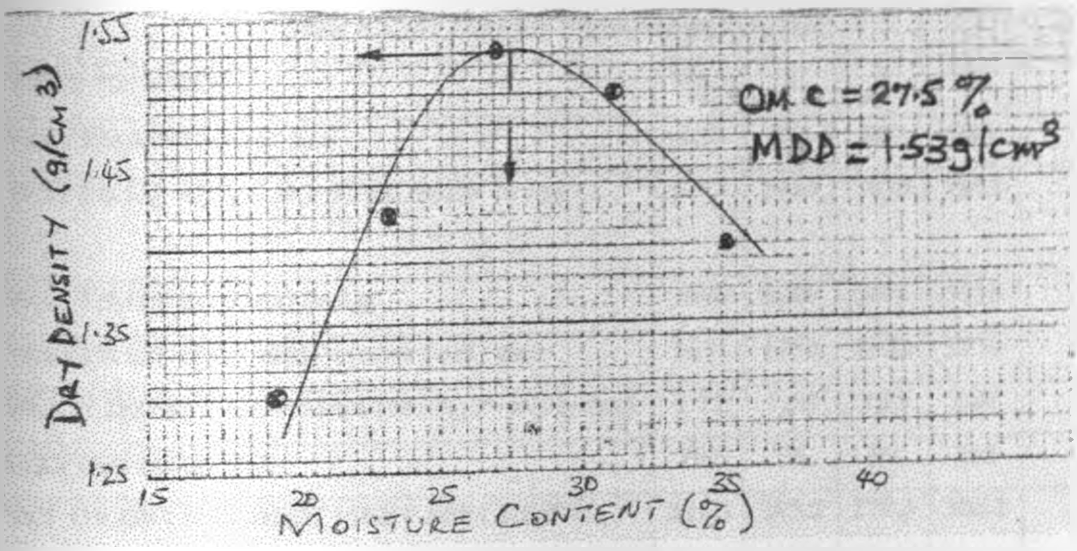



**Table A3.13: Trial pit 1-Falling Head Permeability test**

| TIME IN SEC/MIN | HEAD (CM/IN) | LOG 10 |
|---|---|---|
| 0 | 97.6 | 1.989 |
| 5 | 92.7 | 1.967 |
| 10 | 87.8 | 1.943 |
| 15 | 82.9 | 1.919 |
| 20 | 78.2 | 1.893 |

Table A3.14: Trial pit 2-Soil compaction test

| TEST NUMBER | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|
| WATER ADDED IN C.C | 200 | 300 | 400 | 500 | |
| WATER OF MOULD + SPECIMEN (w1)g | 6717 | 6918 | 7078 | 7002 | |
| WATER OF MOULD (w2)g | 5026 | 5026 | 5026 | 5026 | |
| WATER OF SPECIMEN (w=w1-w2) gms | 1691 | 1892 | 2052 | 1976 | |
| BULK DENSITY OF SPECIMEN (P=w/v)g/cm3 | 1.77 | 1.98 | 2.15 | 2.01 | |
| DRYING DISH NO. | 197 | 50 | 89 | 204 | |
| WT OF DRYING DISH +WET SPECIMEN (w3)g | 241.4 | 285.2 | 279.3 | 306.1 | |
| WT OF DRYING DISH +DRY SPECIMEN (w4g) | 227.2 | 262.5 | 264.7 | 265.9 | |
| WT OF DRYING DISH (w5)g | 78.3 | 93.0 | 94.9 | 80.0 | |
| LOSS OF WEIGHT IN DRYING (w3-w4)g | 14.2 | 22.7 | 32.6 | 40.2 | |
| WATER OF DRY SPECIMEN (w3-w4)g | 149.2 | 169.5 | 151.8 | 155.9 | |
| MOISTURE CONTENT (M)% | *9.5* | *13.4* | *17.5* | *21.6* | |
| DRY DENSITY OF SPECIMEN | *1.62* | *1.75* | *1.83* | *1.70* | |

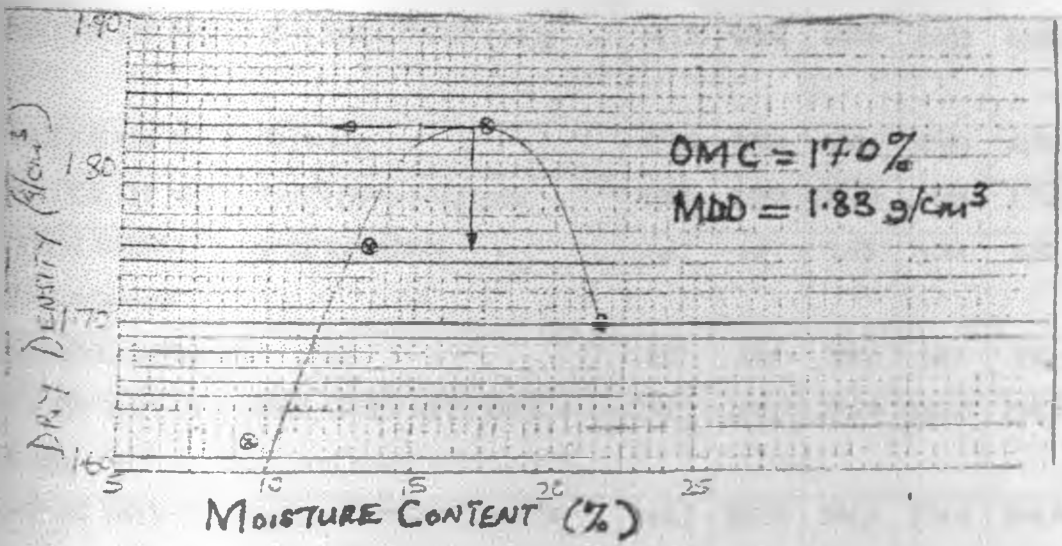



**Table A3.15: Trial pit 2-Falling Head Permeability test**

| TIME IN SEC/MIN | HEAD (CM/IN | LOG 1O |
|---|---|---|
| 0 | 96.8 | 1.986 |
| 5 | 94.5 | 1.975 |
| 10 | 92.2 | 1.965 |
| 15 | 89.9 | 1.954 |
| 20 | 87.5 | 1.942 |

**Table A3.16: Trial pit 3-Soil compaction test**

| TEST NUMBER | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| WATER ADDED IN C.C | 300 | 400 | 500 | 600 | 700 |
| WATER OF MOULD + SPECIMEN (w1)g | 5910 | 6002 | 6206 | 6252 | 6222 |
| WATER OF MOULD (w2)g | 4504 | 4504 | 4504 | 4504 | 4504 |
| WATER OF SPECIMEN (w=w1-w2)gms | 1406 | 1498 | 1702 | 1748 | 1718 |
| BULK DENSITY OF SPECIMEN (P=w/v)g/cm3 | 1.47 | 1.57 | 1.78 | 1.83 | 1.80 |
| DRYING DISH NO. | 157 | 194 | 185 | 107 | 195 |
| WT OF DRYING DISH +WET SPECIMEN (w3)g | 291.0 | 293.5 | 283.7 | 266.8 | 254.5 |
| WT OF DRYING DISH +DRY SPECIMEN (w4g) | 264.2 | 259.8 | 244.3 | 229.8 | 254.5 |
| WT OF DRYING DISH (w5)g | 108.9 | 93.6 | 79.3 | 95.0 | 78.7 |
| LOSS OF WEIGHT IN DRYING (w3-w4)g | 26.8 | 33.7 | 39.4 | 37.0 | 41.6 |
| WATER OF DRY SPECIMEN (w3-w4)g | 155.3 | 166.2 | 165.0 | 134.8 | 134.2 |
| MOISTURE CONTENT (M)% | *17.3* | *20.3* | *23.9* | *27.4* | *31.0* |
| DRY DENSITY OF SPECIMEN | *1.25* | *1.31* | *1.44* | *1.44* | *1.37* |

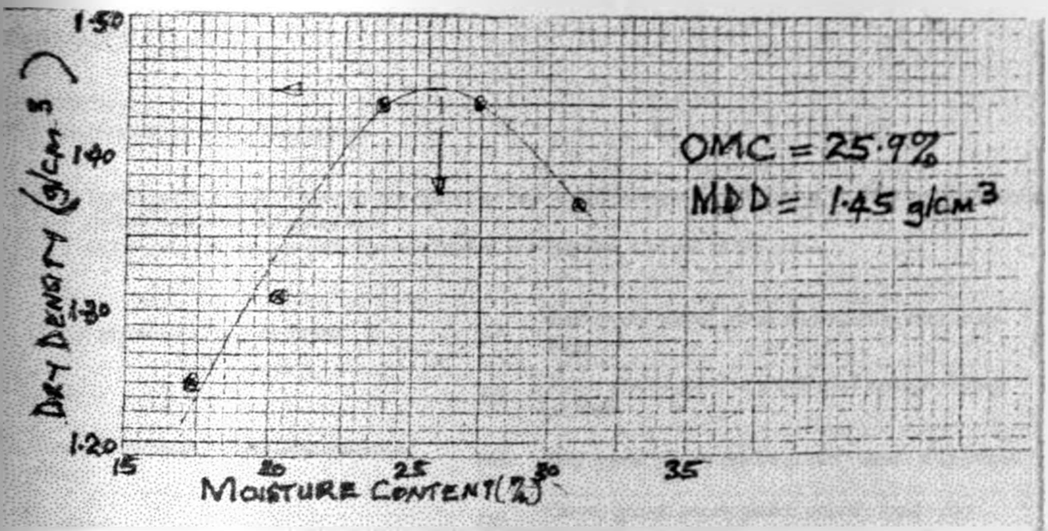



**Table A3.17: Trial pit 3-Falling Head Permeability test**

| TIME IN SEC/MIN | HEAD (CM/IN) | LOG 10 |
|---|---|---|
| 0 | 95.0 | 1.978 |
| 10.6 | 86.2 | 1.936 |
| 21.2 | 77.4 | 1.889 |
| 31.8 | 68.6 | 1.838 |
| 42.4 | 59.8 | 1.777 |

**APPENDIX 3**

**ANNEXURE-I**

Soil Classification including Description

a. Coarse grained soils: These contain more than half materials larger than 75 micron IS sieve size, the smallest particle visible to the naked eye.

(i) Gravels - More than half of coarse fraction is larger than 4.75 mm IS Sieve size.

| | | |
|---|---|---|
| Clean gravels (Little or no fines) | GW | Well graded gravel, gravel sand mixture, little or no fines |
| -- do -- | GP | Poorly graded gravel or gravel sand mixture, little or no fines |
| Gravel with fines(Appreciable amount of fines) | GM | Silty gravel, poorly graded gravel - sand - silt mixture |
| -- do -- | GC | Clayey gravel, poorly graded gravel - sand - clay mixtures |

b.

(ii) Sands - More than half of fraction is smaller than 4.75 mm IS sieve size.

| | | |
|---|---|---|
| Clean sands ( Little or no fines) | SW | Well graded sands, gravelly sands, little or no fines |
| -- do -- | SP | Poorly graded sands or gravelly sands, little or no fines |
| Sands with fines (Appreciable amount of fines) | SM | Silty sands, poorly graded sand - silt mixtures |
| -- do -- | SC | Clayey sands, poorly graded sand clay mixtures |

b. Fine grained soils: These contain more than half of materials smaller than 75 micron IS sieve size. The 75 micron IS sieve size is smallest particle size visible to the naked eye.

| | | |
|---|---|---|
| Silts and clays with low compressibility and liquid limit less than 35 | ML | Inorganic silts and very fine sands rock flour, silty or clayey fine sand or clayey silts with none to low plasticity |
| -- do -- | CL | Inorganic clays, gravelly clays, sandy clays, silty clays, lean clays of low plasticity |
| -- do -- | OL | Organic silts and organic silty clays of low plasticity |
| Silts and clays with medium compressibility and liquid limit greater than 35 and less then 50 | MI | Inorganic silts, silty or clayey fine sands or clayey silts of medium plasticity |
| -- do -- | CI | Inorganic clays, gravelly clays, sandy clays, silty clays, lean clays of medium plasticity |
| -- do -- | OI | Organic silts and organic silty clays of medium plasticity |
| Silts and clays with high compressibility and liquid limit greater than 50 | MH | Inorganic silts of high compressibility, micaceous or diatomaceous fine sandy or silty soils, elastic soils |
| -- do -- | CH | Inorganic clays of high plasticity, fat clays |
| -- do -- | OH | Organic clays of medium to high plasticity |

c. Highly organic soils:

| | |
|---|---|
| Pt | Peat and other high organic soils with very high compressibility |

d.

(Extract from Table 2 of I.S. 1498-1970

**ANNEXURE-II**
**Suitability of soils for construction of dams**

| Relative Suitability | Homogeneous Dykes | Zoned Dam | | Impervious Blanket |
|---|---|---|---|---|
| | | Impervious Core | Pervious Shell | |
| **Very Suitable** | GC | GC | SW, GW | GC |
| **Suitable** | CL, CI | CL, CI | GM | CL, CI |
| **Fairly Suitable** | SP, SM, CH | GM, GC, SM, SC, CH | SP, GP | CH, SM, SC, GC |
| **Poor** | -- | ML, MI, MH | -- | -- |
| **Not Suitable** | -- | OL, OI, OH, Pt | -- | -- |

**(Extract from Appendix A of I.S. 12169-1987)**

**ANNEXURE-III**
**Average properties for different types of soils**

| S. No. | Soil Group | Maximum Dry Density (Kg/cum) | Optimum Moisture Content (Percent) | Cohesion Kg/sqm | Degrees |
|---|---|---|---|---|---|
| 1 | GC | >1840 | <15 | NA | >31 |
| 2 | GM | >1830 | <15 | NA | >34 |
| 3 | SM | 1830±16 | 15±0.4 | 500±500 | 30±4 |
| 4 | SC | 1840±16 | 15±0.4 | 1100±600 | 31±4 |
| 5 | ML | 1650±16 | 19±0.7 | 900±NA | 32±2 |
| 6 | CL | 1730±16 | 17±0.03 | 1200±200 | 28±2 |
| 7 | CH | 1510±32 | 25±1.2 | 1300±600 | 19±5 |
| 8 | MH | 1310±64 | 36±3.2 | 2000±900 | 25±3 |

**(Extract from Table 2 of I.S. 12169-1987)**

**ANNEXURE-IV**
**Degree of Expansion of fine grain soils**

| Liquid Limit | Plasticity Index | Shrinkage Index | Free Swell (Percent) | Degree of Expansion | Degree of Severity |
|---|---|---|---|---|---|
| 20-35 | <12 | <15 | <50 | Low | Non Critical |
| 35-50 | 12-23 | 15-30 | 50-100 | Medium | MArginal |
| 50-70 | 23-32 | 30-60 | 100-200 | High | Critical |
| 70-90 | >32 | >60 | >200 | Very High | Severe |

(Extract from Table 8 of I.S. 1498-1970)

**ANNEXURE-V**
**General guidelines for embankment sections**

| S. No. | Description | Height upto 5 m. | | Height above 5 m. | | Height above 10 m. and upto 15 m. |
|---|---|---|---|---|---|---|
| 1 | Type of Section | Homogeneous/ Modified homogeneous section | | Zoned/ Modified homogeneous/ Homogeneous section | | Zoned/ Modified homogeneous/ Homogeneous section |
| 2(a) | Side slopes for coarse grained soils | U/S | D/S | | | |
| (i) | GW, GP, SW, SP | Not Suitable | | Not Suitable | | Not suitable for core, suitable for casing zone |
| (ii) | GC, GM, SC, SM | 2:1 | 2:1 | 2:1 | 2:1 | Section to be decided based upon the stability analysis |
| (b) | Fine Grained Soil | | | | | |
| (i) | CL, ML, CI, MI | 2:1 | 2:1 | 2.5:1 | 2.25:1 | —do— |
| (ii) | CH, MH | 2:1 | 2:1 | 3.75:1 | 2.5:1 | —do— |
| 3 | Hearting zone | Not required | | May be provided | | Necessary |
| (a) | Top Width | — | | 3 m. | | 3 m. |
| (b) | Top level | — | | 0.5 m above MWL | | 0.5 m above MWL |
| 4 | Rock Toe Height | Not necessary upto 3 m height. Above 3 m height, 1m height of rock toe may be provided. | | Necessary. H/5, where H is height of embankment. | | Necessary. H/5, where H is height of embankment. |
| 5 | Berms | Not necessary | | Not necessary | | The berm may be provided as per design. The minimum berm width shall be 3m. |

(Extract from Table 1 of I.S. 12169-1987)

Abbreviations:
U/S =upstream
D/S = downstream
H = Horozontal
V = Vertical

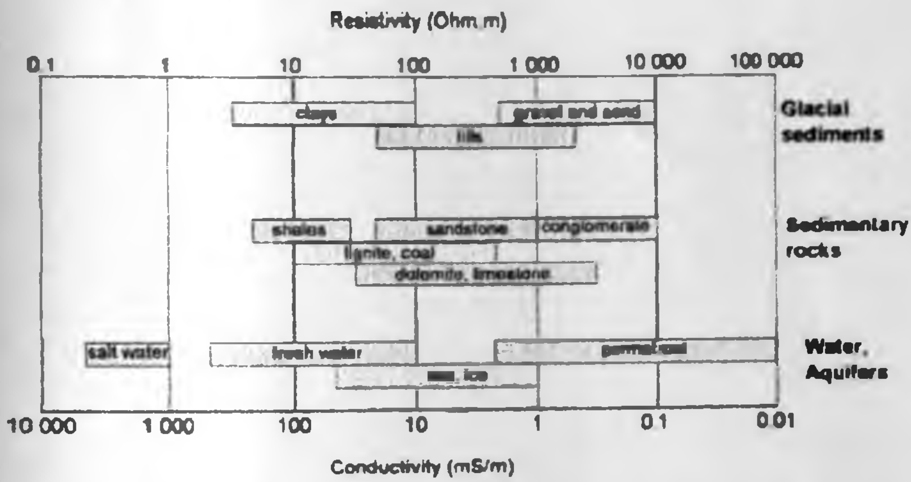
## Appendix 4

| Appendix 4 | | World Health Organisation 2003 Guidelines: | 1971 Int Standards: | EC Directive 1980 relating to the quality of water intended for human consumption: | European Community | |
|---|---|---|---|---|---|---|
| Substance or Characteristic | | Guideline Value (GV) | Upper limit (HL) (tentative) | Guide level (GL) | Max Admissible Concentration (MAC) | |
| Inorganic Constituents of health significance: | | | | | | |
| Antimony | Sb | 0.005 | | | 0.01 | |
| Arsenic | As | 0.01 | 0.05 | | 0.05 | |
| Cadmium | Cd | 0.003 | 0.01 | | 0.005 | |
| Chromium | Cr | 0.05* | 0.05 | | | |
| Cyanide | CN | 0.07 | 0.05 | | 0.05 | |
| Fluoride | F | 1.5 | 1.7 | | 1.5 | |
| Lead | Pb | 0.01 | 0.10 | | 0.05 | |
| Mercury | Hg | 0.001 | 0.001 | | 0.001 | |
| Nickel | Ni | 0.02 | | | 0.05 | |
| Nitrates | N | 50(as N) | 45 (as $NO_3$) | 25 (as $NO_3$) | 50 (as $NO_3$) | |
| Selenium | Se | 0.01 | 0.01 | | 0.01 | |
| Other Substances | MAC: | Desirable Level: | GV: Permissible Level: | Highest | Maximum | GV: |
| Aluminum | Al | 0.20* | | | 0.05 | 0.20 |
| Ammonium | $NH_4$ | | | | 0.05 | 0.50 |
| Barium | Ba | 0.7 | | | 0.10 | |
| Boron | B | 0.3 | | | 1.0 | |
| Calcium | Ca | | 75 | 50 | 100 | |
| Chloride | Cl | 250 | 200 | 600 | 25 | |
| Copper | Cu | 2 | 0.05 | | 0.10 | |
| Hydrogen | $H_2$ | | | | | |
| Sulphide | $H_2S$ | ND | | | | ND |
| Iron | Fe | 2 | 0.10 | 1.0 | 0.05 | 0.20 |
| Magnesium | Mg | 0.10 | 30 | 150 | 30 | 50 |
| Molybdenum | Md | 0.07 | | | | |
| Manganese | Mn | 0.5 | 0.05 | 0.50 | 0.02 | 0.05 |
| Nitrite | $NO_2$ | 3 | | | | 0.10 |
| Potassium | K | | | | 10 | 12 |
| Silver | Ag | 0.1* | | | | 0.01 |
| Sodium | Na | 200* | | | 20 | 175 |
| Sulphate | $SO_4$ | 400* | 200 | 400 | 25 | 250 |
| Zinc | Zn | 3* | 5.0 | 15 | 0.10 | |
| Total Dissolved Solids | | | 500 | 1500 | | 1500 |
| Total Hardness as $CaCO_3$ | | 500 | 100 | 500 | | |
| Colour | Hazen | 15 | 5 | 50 | 1 | 20 |
| Odour | | Inoffensive | Unobjectionable | | | 2 or 3 TON |
| Taste | | Inoffensive | Unobjectionable | | | 2 or 3 TON |
| Turbidity | (JTU) | 5 | 5 | 25 | 0.4 | 4 |
| pH | | 6.5 - 8.5 | 7.0 - 8.5 | 6.5 - 9.2 | 6.5 - 8.5 | 9.5 (max) |
| Temperature | °C | | | | 12 | 25 |
| EC | uS/cm | | | | 400 | |

Notes: ND - Not Detectable; IO - Inoffensive; GL - Guide Level; UO - Unobjectionable; * - Not To Be Exceeded

(Based on Table 8.1, in Twort, Law & Crowley, 1985 - Water Supply, Edward Arnold, London) and WHO Guidelines for Drinking Water 3rd Edition, 2003.
(Website: www.w[illegible]int/water_sanitation_health[illegible]guidelines2/e[illegible]

## Appendix 5




**Typical ranges of electrical resistivities of earth materials (modified from Palacky, 1987).**