GEOHYDROLOGICAL STUDY ON THE EFFECTS OF THE SAND DAMS ON GROUNDWATER STORAGE ALONG KIINDU RIVER IN MULANGO AREA.

February 2003.

1.0 INTRODUCTION.

1.1 Geographical Data.

The study area is situated in the Mulango area. This area lies between latitudes 27^o East and 28^o East and the river flows along longitude 38^o south. This area is some 13 km from Kitui Town and lies on the Kiindu river basin. Along this catchment, whose drainage is defined by several tributaries joining the river, thirty-two sand dams were developed in the whole catchment, along the main Kiindu river course and most of its tributaries, which join the river in a trachelic pattern. This may be considered to influence the ground water levels in the area between the two channels. The original aim of constructing these sand dams was to harvest the floodwaters and the run-off in these areas. All the run- off in the area usually goes to this river, which is seasonal.

1.2 Summary of Field Investigations Undertaken

The study took place from 10th-22nd February 2003.This is one of the driest periods in the region and water levels are at their lowest. Thus the geophysical study was able to get the most depressed water levels in the river.

1.3 The Kiindu River

This river runs along the Mulango–Kyangunga road and has it mouth around Wikililye market It runs all the way to Nzeeo river in a stretch of about seventeen kilometers. The main tributaries of the river that have sand dams established are Nduni and Muusya streams.These streams and the main Kiindu River has been the point of last resort for water to the local community. Usually they get water from scoop holes made in the sand for their domestic and livestock use. The locals confessed that before the establishment of the sand dams, the riverbed was made up of alluvial deposits, which mainly comprised clays and silts. Floodwaters last only a few hours after a storm. However now that the river is full of sand as a result of the dams, there is more water retained in the sand and it is available year round.

1.4 Water Abstraction Activities In The River and the Adjacent- lying Areas

Several shallow wells have been established in the area and show remarkable high levels of water. Those done before the establishment of the dams are alleged to have had more water after the establishment of the dams, suggesting the replenishment role of these dams to the groundwater table and probably the general ground water potential in the adjacent-lying areas. These dams have greatly affected the geomorphology and gradient of the river. The riverbeds slope has been greatly flattened and the banks lowered due to the annual deposition of sand in the river basin. This is coupled by raising levels of water in the sand, which significantly reduces the depths of the scoop holes for obtaining water.

1.5 Scope of Study

The study was based on about a stretch of seven sand dams. Using the nomenclature of SASOL about the naming of the dams, the dams studied are, Syonganga,Kwa Kangesa, Kwa Ndunda, Kwa Lwanga, Kwa Manja, Nzemeini, Uvatii. In the GPS they are from code 356 to 350 downstream the river. These dams are usually spaced at an average of about five hundred to seven hundred meters. So the study covers a stretch of about four kilometers of the river and between fifty and hundred meters on both sides of the riverbanks. This study, however, is guided by presumed effect to the ground water potential of the area resulting from establishment of the sand dams. The motivation for the study was the hydrological and ecological changes noticed after these establishments. It was to determine and relate the changes to the availability of more water attributed to the sand dams.

2.0 OBJECTIVE (S) FOR THE STUDY

The main objective for the study was to determine the ground water recharge effected by the establishment of the sand dams along Kiindu River Channel as depicted from the following study parameters:

a) Soil characteristics-namely, porosity, permeability, Transmissivity etc.
b) Geophysical anomalies deduced from the geoelectrical data gathered.
c) Structural geology on the country rock that forms the riverbed and the rivers adjacent lying areas.
d) River bank heights relative to the water rest level in the sands present in the river.
e) Hydrological parameters namely drainage geometry of the basin.
f) Vegetation characteristics on the river bank sides.

3.0 FIELD INVESTIGATIONS AND EQUIPMENT;

Study Methodology

This gives a brief on the activities in the study and the equipment used in the field investigations and the justifications for respective studies/activities carried out.

3.1 Reconnaissance Surveys

The study began by a two-day reconnaissance survey, which involved walking through the whole river course visiting all the dams. This was for familiarization and sampling of study sites. The sampling of the dams was based on several parameters, which involved a portion of the river with dams showing most diverse hydro-geological characteristics. This is because one of the mail targets of the study was to determine the relationship between the effects of the sand dams for dams in a series. It was the portion of the river that was most representative that was suitable for the study.

Sites for geophysical studies were selected on this earmarked portion of the river, which comprised a stretch of seven dams in a series. This was mainly on the banks some fifty to hundred meters away from the river course. These sites were chosen on the basis of the suitability of the landscape to allow performance of the geo-electrical soundings and the profiling. Also evaluation on the differences in the materials forming the banks to relate them to recharge and the water in the riverbanks.

3.2 Vertical Electrical Soundings (VES)

Electrical soundings were conducted using ABEM SAS 300B terrameter to determine the maximum probe depth of the lateral infiltration inputs into the selected points lying along/adjacent to the stream course flow direction. These were done in a radius of about 50-100 m away from the riverbed. These depended mainly on the suitability of the area for the electro-sounding. Also, it was guided by observing the possibility of recharge on relating the physical geology exposed in the river channel. These were for example the areas colonized by the presence of very fresh granitiod gneisses Zero recharge probabilities would be expected in such areas. These sounding points in the study were referred to as hypothetical wells as they depicted the level of water in the ground.

3.3 Water Level Determination in the River Banks.

For comparison of the relative water levels in the hypothetical wells in the banks of the river bed and the water rest level in the sand, A *sokia* survey leveling machine was used to determine the reduced levels on the over burden from the banks. This was removing the raise in the banks to allow comparing the water tables both in the banks and in the river channel to determine whether the water was really moving to the banks and replenishing the water table in the adjoining areas. To show the level of the water in the sand, scooped holes were made in the sand to show the water and this would be leveled from the point directly adjacent the hypothetical well.

To determine direction of flow, geoelectrical profiling was conducted using the terrameter. This was meant to determine the general flow direction of the water into these hypothetical wells.

3.4 Marking And Mapping Study Points.

The positions for the hypothetical wells were marked using an *Etrex summit* Global Positioning System was used and also geoelectrical profiling transverses. Mainly the longitudes and latitudes of these areas were marked in the GPS. At some places the GPS was used to measure the distances of the hypothetical wells from the riverbed and the differences in height from the riverbed.

4.0 THEORETICAL BACKGROUND INTO THE GEO- HYDROLOGY AND GEOSTRATIGRAPHY OF THE STUDY AREA.

This gives the general theory on the Geohydrological and Stratigraphic information governing the groundwater flow.

4.1 Historical Geology and Stratigraphy

This covers the historical geological episodes that were responsible for the development of the present geological structures. Also explains the arrangement of the different rock materials that are present in the area (Stratigraphic arrangement of different materials forming the geology of the area).

4.1.1 Historical Geology.

The geology comprises oblique dipping units of highly weathered gneisses of the granitiod and / hornblende biotite species overlain by tertiary sediments and some sedimentary rock units (Rare though, kunkar deposits from the selected localities across the rivers North east-southwesterly stretch. The rocks are mainly metamorphic of the Precambrian order and are both moderately weathered and fractured in the upper zones and the deep seated zones, from the geophysical data after the initial episodes volcanicity that formed granites in the area, subsequent phase of thermal and contact metamorphism, (along side metasomatic changes,) altered the crystalline chemistry of the rock units into their present status.

Added to these are the subsequent tectonic activities that formed geosynclines and synclines in the area. Quaternary deposits resulting from both wind action and fluvial geomorphology then formed, postdating the earlier tectonic activities on the geosynclinals basins. Owing to the minimal silica content of the fluvial deposits on the riverbed and the high river-flow velocity then occasioned, very little water could be traced in the river bed as there existed no suitable trapping medium to act as reservoir t o fast flowing river waters (floodwaters).

Alluvial deposits thus dominated the riverbeds geology and mineralogy so to speak. Owing to the short stints between the occurrence of the waters and evaporation periods, very little water was available to effect significant hydrolysis / geochemical processes on the largely fresh gneisses. This changed, through, when the rather infrequent tectonic forces tore into the subsurface creating micro fractures, faults cracks and fissures which then began to direct the surface water into the subsurface units .The ensuing geochemical exchanges affected the moderate weathering presently noticeable, and it s these weathered portions of the Mozambican belt units which direct lateral inflow from riverbed into the adjacent wells and the hypothetical wells studied. Where geology is dominated by thick sandy deposits, water flows from the sand reservoirs into the adjacent lying sandy beds, the Darcyan style.

NB *For the purpose of our study our hypothetical wells will be a point located 50m – 100m away from the riverbed on either side downstream/upstream and on which a VES sounding has been performed.*

4.1.2 Geo-stratigraphic sequences and the accompanying Geological Processes.

- Volcanicity took place, forming the original country rock from the condensed parent magma.
- With time, pressure and temperature s changes formed metamorphic from these volcanic suites.
- Global tectonic forces prevalent in the Achaean period then acted on the units, forming numerous geosynclinals structures, which include the oldest, known river basins. These were later complemented by local tectonic events.
- Fluvial activities, wind action and weathering resulted into the formation of tertiary sediments overlying the Mozambican belt units.
- The different soil types encouraged the establishment of unique floral successions in the subsequent years.

4.2 Structural Geology and Flow Hydrostatics

Lineation is highly portrayed in the units studied along the river course. These are activities of the Archean gneiss species. The existence of sheared and faulted veins trends elucidate on the observation noted earlier that the tectonic events post-dated the formation of the units.

Pegmatitic veins, sinistral and dextral shears present allude to a high metamorphic grades. Silimanite, Kyanite and Andalusite are the index minerals found in coexistence with pelitic minerals like Muscovites and phlogopites.

A moderately high fracture density is picked on the geophysical curves done on the fresh Hornblende biotite gneisses than on the data taken from the granitiod gneisses, which shows the least intensity of the fracturing.

A high trasmissivity rate is illustrated by the consistently shallow water table depths posted on the geophysical curves through out the 3-4 km stretch down stream. Where the geology is dominated by thick successions of alluvial deposits and kunkar limestone whose both permeability and porosity are low, hence VES curves show nonexistence of shallow aquifers since no suitable structures exist to direct the riverbed water laterally to the investigated aquifer points of the hypothetical wells.

Even the geoelectrical profiling data sets indicate consistently flat rates on the resistivity curves with zero variations as one moves away from the riverbed directly bank wards, over a stretch of 100 m away from riverbed. This is with a profiling interval of 1= 5.0 meters.

4.3 General Hydrology

Generally, The term hydrology comprises all the systems and transformations through which water undergoes in its cycle from the atmosphere and up to it's going back as vapour. It incorporates from precipitation to evapoararation, which is the last stage in the hydrologic cycle. Among the sectors in this cycle are the precipitation, which takes different forms like rainfall, storms, fogs and falling ice. After precipitation this water on the ground flows as run off.

4.3.1 run off

Run off is considered synonymous with stream flow. This synonymity is because the term takes into account all the water that reaches stream channels and it is made up of surface run off which is the water flowing on the land surface and the ground water flow. On falling to the ground, when the rate of precipitation is higher than the rate of infiltration, surface flow begins and this is what is described as the surface run off. The thin film of water is formed in the soil and this is called the inter flow. Then the rest of the water goes to the ground water and this forms the base flow of the river. This movement of water through the surface of the soil is a function of a number of factors, which determine the flow and infiltration capacities. These are; The intensity of precipitation, permeability of the ground surface, duration of precipitation, vegetation cover, area of drainage basin, the river geometry, depth to water table, slope of the land surface etc

Run off portion of the water falling directly in the river channel is called channel precipitation. When the storage of the foliage and depressions becomes saturated, and more water infiltrate the ground, land flow begins and this becomes the surface run off.

Hydrologic cycle, therefore, includes the distribution of water and the path followed by the water after it precipitates on the land until it goes to the stream channel or directly to the atmosphere through Evapotranspiration.

4.3.2 Evapotranspiration.

Through Evapotranspiration, the water goes back to the atmosphere. This is usually through evaporation and transpiration and transpiration. It has been difficult however to separate evaporation and transpiration because they take place at the same time and there fore they are taken together and thus the word Evapotranspiration, This happens when the water molecules on a surface acquire enough energy through radiation to escape in gaseous state.

Ground water is never affected by direct evaporation. However, the roots of plants are responsible for ground water discharge. This is by transpiration. The plants loose the water they get from the ground through their leaves. Some plants are known to have roots going to the depths of thirty meters below the surface.

Owing to the nature of the study area being in a semiarid marked by high temperatures and low rainfall. Thus the rates of evapoeraration are quite high making it difficult to have surface water storage.

4.3.3 Infiltration.

Infiltration capacity is defined as the maximum rate at which a given soil can absorb precipitation in a given condition. This rate decreases exponentially in time from maximum capacity decreasing from an initial value to a constant rate depending on various parameters like the soil moisture being the most significant. As soil becomes more saturated the rate of flow becomes slow which eventually becomes constant. This is usually what happens when a dam is newly built. The rate of lateral flow is faster in the first few meters but at some point it stabilizes.

The ability to transmit water of soil is highly variable. In well-sorted sand or gravel, the conductivity will be high and will vary only slightly with time. This explains the differences in the distances from the River course of kiindu that the water as laterally infiltrated due to the diverse soil types marking the river profile.

Chemical weathering, organic activity and time help soil develop a stratified structure, soil profile, in the soil profile, the upper part is considerably more permeable than the lower ones. The lower horizon is made up of clays and colloids and these close when the soil is saturated with water and thus diminishing the transmissivity of the soil. However, this will have minimally influence on the lateral recharge from the river. This is because major consideration in the study is in the horizontal flow and thus typically the flow is along the same horizon.

The stretch of the river studied was comprised of different soil and rock materials making the rates of recharge different depending on the transmissivity of the respective materials. Some portions of the river profile is marked by fresh granitiod gneisses and any recharge occasioned in the se areas was just through the joints and fractures in the rock. Regions marked with loamy sands had quite good recharge. Highly weathered gneisses marked other areas and these were also well recharged.

4.3.4 Percolating water.

This separates the saturated zone from the soil water. The water in the soil water zone and the intermediate zone is called the *vadose* water. It is in a down ward motion under the influence of gravity. Movement of this water is however never uniform owing to the fact that natural material is rarely homogeneous thus the recharge water moves faster through some zones than in others. This mainly happens in arid areas where precipitation rarely exceeds the storage capacities of the soils. Here most recharge takes place through bottoms of stream channels where run off is concentrated and where there are permeable sands and gravels. In these areas, it is likely that this zone has never been well saturated for a long time.

The termination of the intermediate zone is rather abrupt in coarse-grained soils than in fine-grained soils. In clays and silts, it is quite gradual. The difference in moisture content between intermediate zone and the capillary fridge will be quite minimal in fine-grained soils when there is recharge. The surface of this capillary fridge depends on water table and the amount of recharge. However, the upper part of the capillary fridge contains pockets of air that slows the movement of flow of water.

From the capillary fridge, the phreatic water is found. This is the water table. This is the level that approximates the level of the wells that penetrate a short distance into the saturated zone. When there is horizontal flow in the ground water, the water levels in wells that are near each other correspond very closely to the water table. Nevertheless, the presence of these wells distort slightly the flow pattern hence the water levels in the wells. The water table is the level at which the atmospheric pressure equals the hydrostatic pressure in unconfined material.

Below the water table, there is the ground water. This is also known as the zone of saturation. *Aquifers* are the water bearing portions. These both transmit and store water. There are others that never store neither transmit water and these are called *aquifug*es and *aquicludes* store but cant transmits water.

Thus aquifers are defined as the natural zones below the surface that yield water in sufficient amounts to be important economically.

Unconfined water is the water that is in free contact within the atmosphere through open spaces in permeable media. Confined water is separated from the atmosphere by impermeable material. In the case of sand dams, most of the water is in the class of the unconfined water.

4.4 Groundwater Flow Mechanics

4.4.1 *Flow Media for Groundwater*

Water is collected and flows on rock and soil. Different forces like the gravity and pressure difference drive the flow. Rocks and soils form a matrix that is marked by an assembly of voids, pores or interstices, which may be filled with water gasses, or organic matter.
The ratio of volume of the voids over the total volume in the material is known as the porosity of the materials. It is denoted by ***'n'.***

$$n = V_v/V_t$$

Where ***Vv*** *is the volume of voids and* ***V****t is the total volume.*

Porosity depends on the parking of the grains in the material, shape, arrangement, and size distribution. Porosity is higher in a material with well-sorted grains than in material with mixed grains sizes. The value of **'n'** is assigned to a point in space whether falling in side or outside a pore. This pore volume is always smaller than the total volume and is usually between 0 and 1.In alluvial sediments it is between 0.3 to 0.4, rumble rock 0.42, sand stone 0.15,clays they are high as 0.6.

On a macroscopic scale, a plane with surface area A (L) Where '**A**' is compared with the dimensions of a single pore per unit time, water flowing through this plane is denoted by **Q** (L^3T^{-1}) This is called the specific discharge denoted by **'q'**.

$$q=Q/A$$

This means the volume of water flowing across a unit area per unit time '**q**' exists in every point in space.

Ground water flows due to difference in energy. This energy is from pressure due to elevation of water column. When flowing, ground water experiences energy loss due to the friction of the media through which it is flowing through. This loss per unit distance traveled is proportional to the velocity of ground water in a laminar flow in sandy aquifers or seepage through earth embankments.

Ground water flow is a function of different parameters, which include, the dimension of the flow, the boundaries through which the water flows and fluid properties.

Evaluation of ground water flow can be done quantitatively when velocity, pressure, density temperature and viscosity are known. However, parameters like density and pressure in water have negligible variations thus they can be neglected in determining the flow of the water.

Head gradient is of vital importance in determination of this flow. This is normally the driving force for ground water flow. Darcy's law says how much water flows at a certain head gradient. Implying a line of relation between the specific discharge and the head gradient. ie.

$$q=-ki$$

Pressure distribution is quite important for flow to occur. It is expressed with atmospheric pressure as the zero reference pressure. Water table or the phreatic water is the level at which the pressure equals atmospheric pressure or p=0. However, where fluid density is constant, the distribution is done in terms of Piezometric head**. ω**

$$\omega=p/\rho g+z$$

Where **ω** is called the hydraulic head, ground head or just head. Its dimension is length.

Heads are more applicable in water than pressure because the density of water is considered constant.

In the above equation, **p/ρg** is called the pressure head while **z** is the elevation head, which is usually taken at a certain level at local basis. In the study, the bottom of the aquifer is used for the elevation. Thus for the above equation, the constant head and pressure distribution is a linear function **z: p=ρg (ω-z).** This is the hydrostatic pressure distribution. In such a case vertical equilibrium exists and no vertical flow occurs. Thus with a head difference, ground water begins to flow.

The difference in ground water head $\Delta\omega=\omega_2-\omega_1$ is always associated with a certain distance $\Delta x=x_2-x_1$. Thus head difference is talked of over a certain distance **Δx**, denoted by **i**

$$i=\omega_2-\omega_1 / x_2-x_1=\Delta\omega/\Delta x$$

'**k**' being the permeability or the hydraulic conductivity with dimensions of length over time. (LT^{-1}) Dimension of velocity. As **Δx** approaches zero **Δω/Δx**.is replaced by **δω/δx**. In the three dimensions, the Darcy's law becomes

$$q_x=-k\,\delta\omega/\delta x\ ;\ q_y=-k\,\delta\omega/\delta y\ ;\ q_z=-k\,\delta\omega/\delta z$$

4.4.2 Dimensional character.

Water in unconfined situation flows in three dimensions. However, in practice it is difficult to solve the three-dimension flow of water problem. Symmetry features can allow reduces the number of dimensions involved to two or one.

4.4.2.1 Flow in one dimension.

The ground water flow in Kiindu River is considered as unconfined flow**.** The driving force for migration of this water is the head gradient. This gradient is as a result of the raised water levels in the river channel due to obstruction of flow by sand dams. Both vertical and the horizontal flows are active. However, Horizontal flow is more active and it is the one of interest in he study. This is the recharge going to the banks from the river. The vertical flow is less important given that the dams in the river have stabilized the water tables and little of this water is lost and the head in that direction is constant. Equilibrium is established. This assumption is known as D*upuits-Forchheimer* approximation. This enables in simplifying the case to one-dimensional flow.

Taking the water in the river recharging to the banks through unconfined media, continuity equation and Darcy's law are combined to solve this equation. Ground water recharge is also included denoted by N.

$\delta\omega/\delta x$=N

Where **Q =ωq**- flow in the horizontal direction. The base of the aquifer is the reference level for **ω**

Substituting the Darcy's law becomes.

$\delta/\delta x\ (\omega\delta\omega/\delta x)$=-N/k

Discharge through land mass can be calculated as

$Q = k/2\ (\omega_2{}^2\ -\omega_1{}^2/x_2-x_1)$

4.5 Theoretical Background Of Geophysical Surveys

Electrical prospecting uses three phenomenon and properties namely: -

1. *Resistivity, or the reciprocal of the conductivity:* -, Governs the amount of current that passes through the rock when a specified potential difference is applied.

2. *Electrochemical Activity:* -. Caused by the electrolyte in the ground. It is the basis for the magnetic, self-potential and induced potential methods

3. *The dielectric constant:* -*G*ives information on the capacity of a rock material to store electric charges and governs, in part, the response of the rock formations in the high frequency alternating current introduced into the earth by conductive or inductive means.

4.5.1 Resistivity:

The electrical resistivity of any material is defined as the electrical resistance of a cylinder with a cross section of unit area and with a unit length. If the resistivity of a conducting cylinder having a length L and cross sectional area S is **ρ**, the resistance is expressed by:

R =ρS/L

The generally accepted unit of resistivity is *Ohm-m*, denoted by *Ωm*. The current density *J*, is related to the electric field *E* and the resistivity through the ohms law:

$$J = 1/\rho E \text{ or } J = \sigma E$$

For a continuous medium, not circuit board, the conductivity **σ** of a material is defined as **1/ρ**, the reciprocal of its resistivity.

The unit of conductivity in SI is the mho/m or Siemens/m

In many rock materials, like the fractured/ weathered basement system Gneisses prevalent in kiindu stream river bed geology, the porosity and the chemical content of the water, filling the pore spaces are more important in governing the resistivity than the conductivity of the mineral grains of which the rock is composed.

The salinity of the water in the pores is probably the most critical factor determining the resistivity, given that, a good number of riverbed portions of the kiindu river channel yield saline sand wells upon scooping a few inches of the sand.

When porous rocks lie above the water table, (namely laterite, weathered Hornblende or Hornblende-Biotite Gneiss) at shallow depths, or when they occur at such great depths so that the ambient pressure closes all the pore spaces, the current flow through them is maintained through the electronic conduction and takes place within the mineral grains themselves.

Under these conditions, the resistivity of the rock will depend on the intrinsic microscopic rock properties. When the pores are saturated with fluids, it will be governed by the fluid resistivity and the main conduction mechanism is electrolytic.

An empirical relation for the dependence of the resistivity on the porosity **Φ** and the fluid resistivity ρ_w is given in the Archie's law: -

$$\rho = a\, \Phi^{-m}\, s^{-n}\, \rho_w$$

Where ‘S’ is the fraction of the pores that are fluid filled, n=2, while ‘a’ and ‘m’ are constants,
that is: -

$$0.6<a<2.5 \quad \text{and } 1.3<m<2.5$$

NB *It should be noted that, all resistivity –sensing, surface electrical methods detects the bulk resistivity of a volume of the rock depth (in-situ) with the resistivity values reflecting the combined effects of all the modes of conduction.*

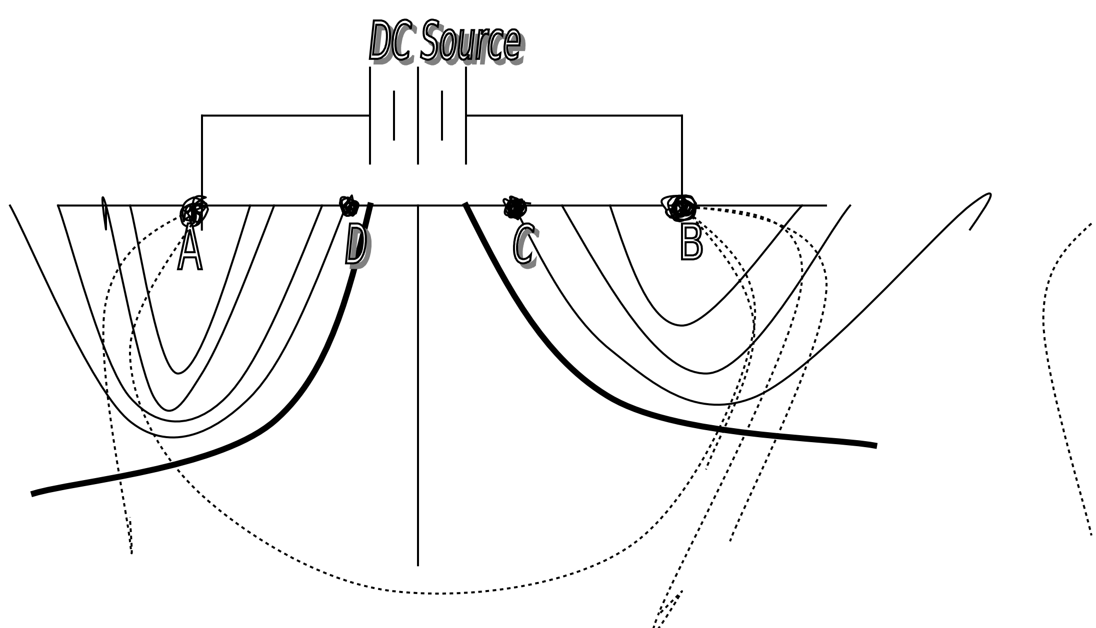
4.5.2 Direct Current Resistivity Methods:

Since resistivity is a fundamental electrical property of rock materials closely related to their lithology, the determination of the subsurface distribution of resistivity from measurements on the surface can yield useful information on the structure of composition of the buried formations.

A common method for carrying out such measurements involves the transmission into the earth of direct current. Four electrode arrays are generally used at the surface; one pair for introducing the current into the earth, the other pair for measurement of the potential associated with the current. The method has proved useful in mining, ground water and engineering applications.

If two electrodes are inserted into the ground and an external voltage is applied across them, there will be a flow of current through the earth from one electrode to the other. The lines of flow are always perpendicular to the surface along which the potential is constant, the later being referred to as equipotentials.

The following diagram illustrates the relationship.



-------------- *lines of current.*
——— *Equipotential lines.*

The potential difference impressed across electrodes A and B is distributed along the space between them. In an homogenous conductor, the potential w.r.t A along a vertical plane cutting the surface at C which is the mid way between A and B, will be half as great as its value at B.

If one could measure the potential underground, he would observe that, the potential is the same as at any surface point such as D, wherever the ratio of the distances from the point to A and B, respectively is the same as the ratio at the surface point. In the case of D, this ratio is one third.

The full line extending down wards from D and bending back under A is the trace of this equipotential surface on the vertical plane containing A and B.

These equipotential lines must always be perpendicular to the lines of current flow, since the component of the current vector at any point can flow along the equipotential line.

The electric field (*E*) is defined by the gradient of a potential function V.

$$E = -\nabla V$$

This potential decreases as $1/r$, the distance from the current electrodes. If the current (I) is injected into an homogenous half space of the resistivity (**ρ)** through an electrode at the space, the potential at another point **ρ** at a distance 'r' from the source electrode will be;

$$V_p = I\rho/2\pi \,.\, 2/r$$

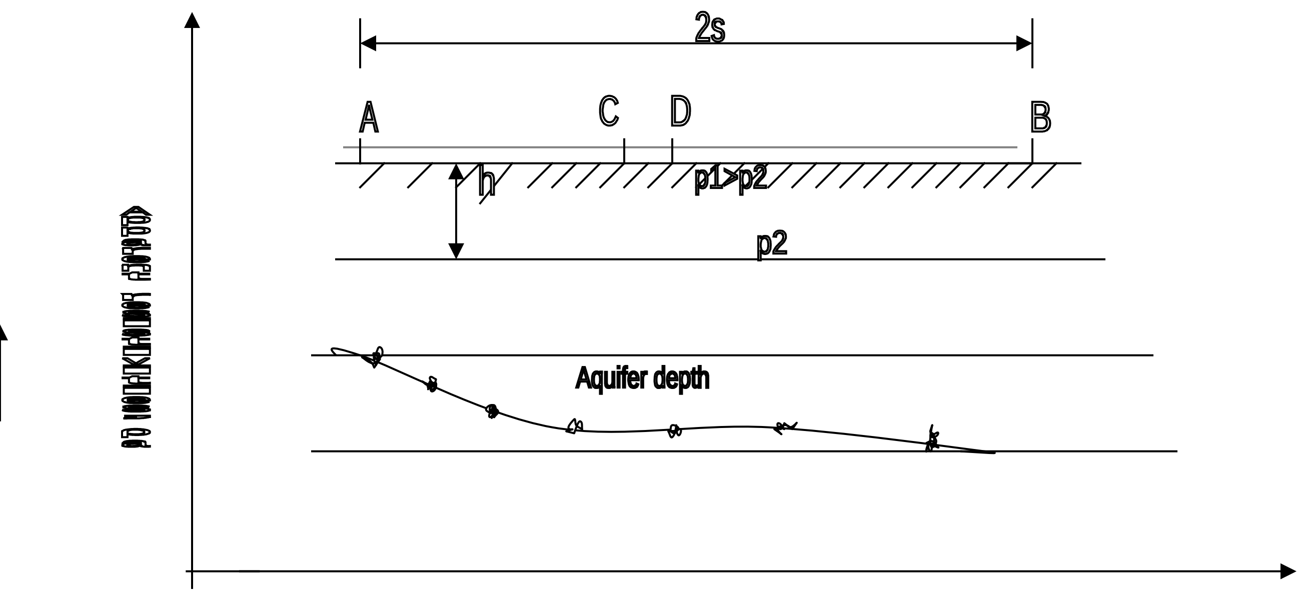
The objective of the direct current soundings is to deduce from surface measurements the source strength (I) and the induced voltage, (▼V), and the nature and distribution of the electrical resistivities under the surface.

As a general rule, one can say that as the spacing and aerial extent of the surface current and voltage electrodes increases, the resistivity variations are sensed at greater depths. This last observation is true even if some lateral variations or heterogeneities of the sub surface resistivities exist.

4.5.3 Electrode Arrangement and Field Procedures.

In actual practice, a number of different conventional surface configurations are used for the current and potential electrodes. In many arrangements, both sets of electrodes are laid out along a line .The current electrodes are generally placed on the outside of the potential electrodes. The Wenner arrangement and the Schlumberger arrangements are quite relevant to the ground water investigations and thus will be briefly looked at.

For convenience, (V) will denote the measured voltage, while the potential difference will be denoted as (Δv),



Current electrode separations, S (or AB/2) on a logarithmic scale of y-axis

4.5.3.1 Wenner Arrangement:

One common electrode arrangement for the resistivity measurement is the *Wenner configuration*. In this Array, each potential electrode is separated from the adjacent current electrode by a radius 'a' which is one third the separation of the current electrodes, so that;

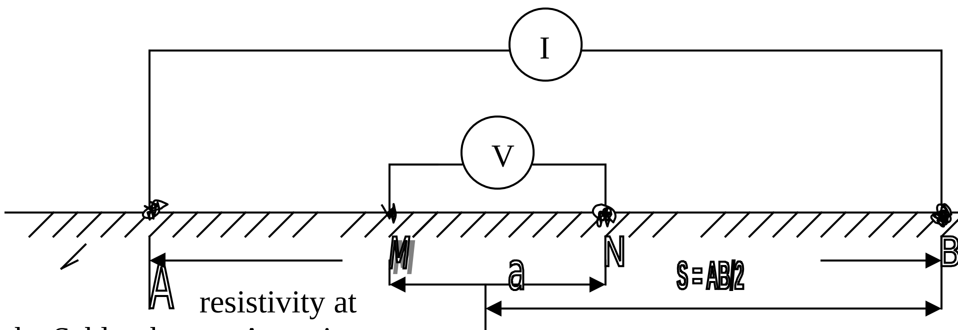
$$\rho_a = 2\pi a . \Delta V / I$$

This is the special case of the Schlumberger Array, discussed below.

4.5.3.2 Schlumberger Arrangement:

This is the method settled for, in the case of the anticipated field investigations on the river kiindu.

The operators expand the electrode spacing by increasing the distance between the current electrodes typically on a logarithmic scale during the course of the measurement. The potential electrode spacing is assumed to be infinitesimal and the observed values of the potential can be adjusted accordingly. The arrangement is illustrated below: -



The apparent resistivity at the center of the Schlumberger Array is;

$$\rho a = \pi\,(s^2 - a^2/4)/a .\ \Delta V/I$$

Where S =AB/2m, while a =MN/2m.

4.5.4 Interpretation.

The quantitative interpretation of direct current resistivity soundings has been the subject of the numerous mathematical modeling studies for several decades, the simplest form of interpretation is the case of anomaly detection along a continuous study profile.

This will only require the identification of the anomaly above the noise level.
The next level of complexity in interpretation is the construction of a 1-D model whose calculated response matches the field observations.

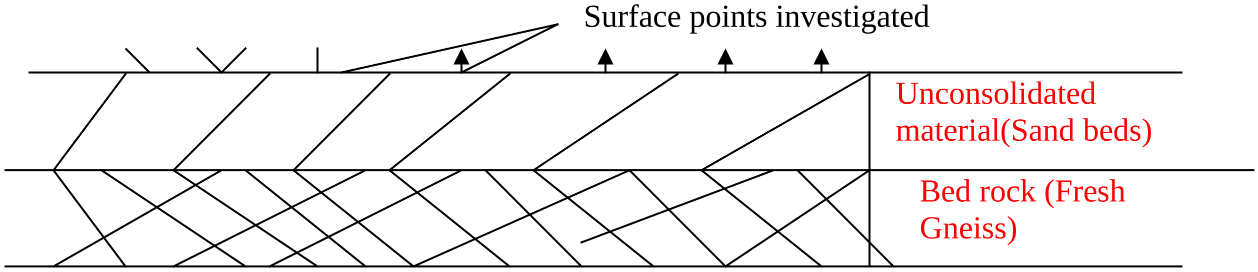
Many geological features of economic interest can be represented quite adequately by simple layering picture. Where there exists an unconsolidated over burden over a bedrock. (As would be the case in kiindu river study) It may be possible to estimate the depth to solid rock from resistivity measurements by use of the formulae for a two-layer configuration.

4.5.4.1 Two-layer case

A Frequent application is the determination of the depth of the water table (AB/2). Many resistivity surveys carried out for engineering purposes area designed to yield this type of information, as would be required in the geo-technical study along kiindu river basin. The interpretation of apparent resistivity curves in terms of 1-D model is relatively well understood, and a number of forward and inverse modeling solutions exist.

As the geoelectrical situation becomes more complex, and includes 3-D lateral heterogeneities, the interpretation becomes more involving and requires multidimensional modeling algorithms.

This occurs when the objective itself is in homogeneous, or in the interpretation of the deep seated structures / aquifers complicated by variations in shallow resistivities and topographic relief.



4.5.4.2 Two-layer case: Master Curve Aided Interpretation.

Historically, the most common device for interpreting resistivity data for a small number of horizontal layers was an assemblage of master curves. Each such curve is a plot of apparent resistivity vs. electrode separation for the arrangement of electrodes employed in the field and for specified layering configurations, various thickness and resistivity ratios being assumed for the individual layers. The use of the master curve will be discussed for the simple, two layer case. Similar master curves are available for models with more layers.

In the two-layer case involving a single layer of specified thickness 'h' overlying an indefinitely thick homogenous substratum, a family of curves is plotted for different values of 'h' and 'k'. The apparent resistivity (Actually $\mathbf{2\pi a\Delta v/I}$ in the case of Wenner Array surveys) is plotted vs. **'a'** at the same scale as the master curves, and the curve of the observed data is matched with the theoretical; curves.

The correct values of '**h'** and **'k'** are then established from the characteristics of the master curve giving the best match.

From these, the values **‘h’** (representing **AB/2**) is taken as the appropriate probe depths, with **‘a’** representing the actual resistivity **(ρ)** in **Ωm** at this particular depth. Several such readings plotted define a curve whose kink is then noted and given a geophysical interpretation based on its geometry. Different curve geometry represents different aquifer types in given rock types e.g. typical curves in sedimentary terrains differ from their volcanic counterparts.

5.0 FIELD INVESTIGATIONS AND SURVEYS.

5.1 Hydrology Of Kiindu River Basin.

The area receives rainfall of averaging 900mm p.a. Much of this water gets to the river as run off though little is held in the ground as retention. Eventually this retention water gets to the river as base flow. However, depending on the retention capacities of the material forming the riverbed, percolation and infiltration in the river channel will take place. Owing to the relatively short period of time this water is in the channel, these processes are limited. Thus lengthening the period of time the water is stays in the channel will aid in the replenishing the ground water. Sand dams, therefore play an important role in promoting both lateral and vertical infiltration by not only slowing the rate of flow but also stopping it consequently, this enhances saturation in this riverbed and which thus raises the water tables.

5.1.1 Impact of Sand Dams On The Fluvial Hydrology

Prior to the establishment of the sand dams, most of these rivers had no sand. The riverbed comprised mainly country rock and clayey soils. These soils are known to have low porosity and poor transmissivity. Thus, no matter how long the water would remain on the riverbed very low critical volume would be held in these soils owing to their low water retention capacity. Sand, being highly porous with porosities of about forty percent, Filling the river cannel after the construction of the sand dam, forty percent of the total volume of the channel filled with the sand will be water.

Time being one of the functions of infiltration, This water will slowly infiltrate to the ground both laterally and vertically saturating it, as no evaporation or leakage takes place .Due to Darcyian flow mechanics, this water moves to areas with lower piezometric head gradients saturating them with water.

With time, the material deposited in the reservoir gets refined as the speed of water is reduces further from the dam. Thus, the heavier material (being the course grained sand which is more porous) is left furthest but eventually fills the dam meaning higher amount of water held in the sand. Also this sand is equi-grannular, meaning more spaces. This is attributed to Attrition collision and abstraction forces active on the ground to the extent. Prolonged exposure to these forces have lead to sculpturing of the rocks forming smooth, rounded pebbles dotting the riverbeds weirs present complement the roles(s) of the sand dams maximizing the reservoir storage potential of the sand dams.

5.1.2 Geohydrology And The Sand Dams.

Oblique dipping of the geologic units in the upper portions of the river direct much of the water in these regions, directing the recharge towards these directions. On the banks, soils are clayey and the sandy loams with a sloping landscape, occation very little percolation input thus. There is little retention in these soils and the retained water eventually reaches the river channel as base flow.

It is evident in some portions of the river that the water table is so high that the levels are noticed above the sands forming ponds that have water at the same level all through the back flow of the dam. The level of the water was the same all through the stretch up to the base of the next dam.

On average, the water levels ranged between 2.5 to 3.4 m in the first aquifer whereas other aquifers were found deeper but the range was common in all soundings done in the area. This depth range collaborated with the water rest levels in the scoop holes in the river channel.

5.2 Field Geophysical Investigations

This formed the backbone of the field investigations. An *ABEM SAS 300B* Terrameter was used with MN/2(Potential Electrode radii) varied between *MN/2=0.5m, MN/2=5m* from *AB/=20m to 40m* and *MN/2=10m* from *AB/2=40 to 63m,* so that the results so obtained were plotted on the logarithmic scale with ρ(resistivity) on the y-axis and AB/2(probe depths) plotted on the x-axis (AB/2 is the current electrode) radius, equivalent to the vertical probe depth) This forms the basis of the Schlumberger Array geophysical surveys and this first case illustrates the method as used for vertical electrical soundings

Geoelectrical profiling was then conducted at some selected points across the river with the following parameters.

a) At AB/2=16, K=803, MN/2=0.5m

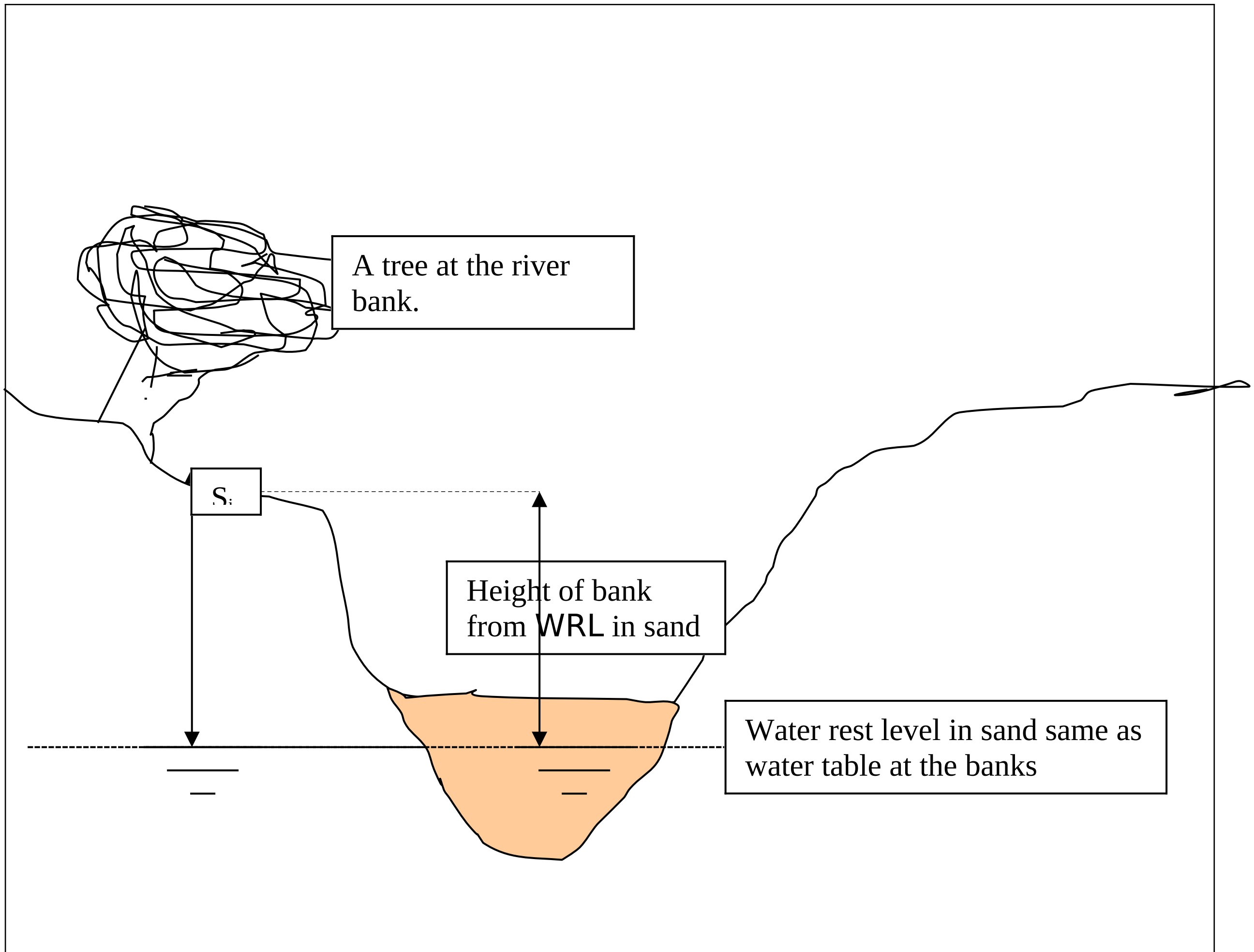
b) At AB/2=25, k=188, MN/2=5.0

c) At AB/2=40m, k=495, MN/2=5.0m

The following table gives the shallow aquifer depths in the points investigated alongside their radii away from the riverbed.

Table 1 Vertical Electrical Soundings Data depicting shallow aquifer depths along river channel.

Geophysical curve No	Longitude/latitude	First aquifer depth	Bank height from the riverbed	Distance from the bank.
R-001/2003	$27^{o.011E}$	3.1	3.43	50
R-002/2003	$27^{o.016}$	3.2	3.48	100
R-003/2003	$27^{o.210E}$	3.5	2.44	80
R-004/2003	$27^{o.249E}$	3.2,4.0	4.31	50
R-005/2003	$27^{o.417E}$	3.2,4.0	-	50
R-006/2003	$27^{o.534E}$	2.5,3.2	-	40
R-007/2003	$27^{o.314E}$	3.5	-	55
R-008/2003	$27^{o.259E}$	3.2,4.0,5.1	5.19	20
R-009/2003	$27^{o.278E}$	4.0,5.0	3.83	80
R-010/2003	$27^{o.568E}$	3.3	3.42	40
R-011/2003	$27^{o.716E}$	4.0,5.0	3.5	40
R-012/2003	$27^{o.814E}$	4.0,5.0	3.7	35
R-013/2003	$27o^{752E}$	3.3	2.94	70
R-014/2003	$28^{o.\ 021E}$	3.2,4.0	3.1	60
R-015/2003	$28^{o.205'E}$	3.2,4	3.0	60
R-016/2003	$28^{o..273'E}$	2.5,3.2	2.7	60
R-017/2003	$28^{o.295E}$	2.0,3.2	2.10	80
R-018/2003	$28^{o.348E}$	4.0,5.0	3.9	80
R-019/2003	$28^{o.417E}$	2.5,3.2	2.7	150
R-021/2003	$28^{o.\ 350E}$	3.2	2.9	100
R-022/2003	$28^{o.\ 706'E}$	5.0	4.2	40
R-023/2003	$28^{o.\ 533'E}$	3.2	2.94	40
R-024/2003	$28^{o}.^{716'E}$	2.7	2.3	80
R-025/2003	$28^{o817'E}$	2.8	2.37	70
R-026/2003	$28^{o.791'E}$	2.95	2.74	60
R-027/2003	$28^{o}.^{920'E}$	2.7	2.3	100
R-028/2003	$28^{o}.^{954'E}$	4.0	3.5	100
R-029/2003	$28^{o}.^{916'E}$	4.1	3.68	90



This figure explains the relationship between the water levels in the river channel and at the banks. Table 1 confirms this hypothesis.

5.3 Geoelectrical Profiling.

This was conducted to determine the flow direction of the water. It was to determine whether the river is recharging the banks of the water is flowing from the banks to the river

Table 2 Geoelectrical Profiling At Selected Points Along River Course

Profile number	**Profile 1** (Ωm)	**Profile 2** (Ωm)	**Profile 3** (Ωm)	**Profile 4** (Ωm)	**Profile 5** (Ωm)
1	73	88	25	57	46
2	81	88	25	80	42
3	81	100	37	80	36
4	88	110	35	103	36
5	90	110	30	107	28
6	103	117	30	107	24
7	111	127	30	119	23
8	113	137	35	117	17
9	121	147	38	118	17
10	121	145	40	117	16
11	127	147	88	127	13
12	124	169	73	125	13
13	128	167	80	136	
14	125	167	80	131	
15	126	200	80	130	
16	125	210	30		
17		218	26		
18		188	26		
19		180	25		
20		175	45		
21			55		
22			40		
23			41		
24			43		

5.3.1 Geoelectrical Profiling 1

Geoelectrical profiling data set 1 taken at *AB/2=16m, MN/2=0.5m*.Taken adjacent to hypothetical well R-001/2003.

Interpretation.
Resistivity values appear lowest at the edge of the riverbank indicating maximized saturation with water and intensity of weathering. Plotted data reveals a shear fracture at this depth, the hypothetical well study site included. Also the high hydraulic gradient established through water saturation aids it. The VES value of the resistivity at the site R-

001/2003 is duplicated /repeated in the course of the electrical profiling on the same spot, i.e., in the VES data, p=125 ohms while during profiling, this value remains 125 ohms.

Again the shear fracture lies within a rock unit (weathered biotite gneiss), which is more weathered and saturated near the riverbed than away from it. The further away from the riverbed the harder (fresher) the rock encountered and the less saturated with water it becomes.

5.3.2 Geoelectrical profiling 2

Reference point is next to Hypothetical well *R-007/2003*
This was undertaken at the depth of *25m (AB/2=25.0)* and the potential electrode radii of *MN/2=5.0* with the profiling interval of *5.0m* between the station.

5.3.3 Geoelectrical profiling 3

This was conducted at site reference *R-013/2003*.
With the following parameters *AB/2=25.0m, MN/2 =5.0m, k=5.0*.
Station intervals I=*5.0m* Carried out towards the river.

Interpretation.

The data still reveals same story about the rocks. They are richer in water near the river than further away from it. Resistivity figures posted close to the river are lower (ρ=30 ohms) than those further away (ρ=80 ohms at station 14)

5.3.4 Geoelectrical profiling 4

This was conducted at site reference *R-012/2003 with AB/2=40, MN/2=5, k=495*
With profiling interval of I=5.0m

5.3.5 Geoelectrical profiling 5

This was conducted at reference site R-016/2003. Along the road leading to kitundu primary school. It was performed away from the riverbank. The surveying parameters were: *AB/2=13, MN/2=0.5, k=530*. Profiling interval remains *I=5.0m*

NB the exceptionally low resistivity in station 10, 11, and 12 depict high mineral content of water .The donkey on the photograph is licking the mineral salts, probably calcium chloride and /or phosphorous.

6.0 STUDY FINDINGS AND CONCLUSIONS.

1. The areas 50-100m from away the river course next to the dams studied have formed a continuous aquifer, which is attributed to the lateral replenishment from the water retained in the dams over the six year period the sand dams have been in place. This is mainly at the depth rage of ten to eighteen feet on the banks, which is the average height of the banks from the water rest level the riverbed.

2. There is lateral infiltration of water in to the banks from the river course and from these banks to the adjacent lying areas. Geophysical studies conducted reveal that the closer the study site is to the river bed, the higher the water table encountered, whereas the further away the site from the river bed the lower the water table. *The areas adjacent to the river are more saturated with water than those further away.*

3. *An alignment of floral successions next to the riverbed depicts a wetland*. Some portions of the river have bushes of phreototypes that are between four to five years old. This reflects an increase in the amount of water available for the plants to grow. The taxonomic units differ from one point on the riverbank to another depending on the amount of recharge from the nearest dam. Electrical Soundings in these areas show relatively shallow aquifer water tables, thus suggesting existence of a wetland. This can be attributed to the presence of the continuous shallow aquifer as noted in observation number one..

4. *Sounding curves in most areas show first aquifer depths to be at relatively similar* depth range i.e. at 2.5 to 3.4 m. This also depicts that this level is constant and is the average height of the banks from the water rest levels in the sand. This again implies direct contact between the water in the sand and in the banks.

5. *Dams have impacted positively on the changes noticeable along the gradient of the river-course due to the accumulation of sand*. This has hence increased the reservoir capacity of the river through the increased height. When super-saturation has been attained and tends where water loss via vertical seepage is minimal, the stored water infiltrates laterally through the fissures and micro fractures. This water is channeled to various recipient aquifers on the rivers adjacent lying regions, a phenomenon best exemplified where the rock units along which the water flows are moderately weathered and fractured.

6. *The portions along the river with clayey soils have low infiltrationrates into the banks.* This is because of the low tansmissivity of the material. These portions are highly mineralized, and have low aquifer potentials. This is also observed in areas marked by fresh granitiod gneisses. The mineralisation in the areas with the clayey soils post quite low resistivities. They post resistivity readings as low as

p=8.0 ohms. Ther most recharged areas are the portion with highly weathered gneisses and with the sandy loams. These areas reflect water tables the conform to the water rest levels in the river bed.