# RELATIONSHIPS BETWEEN GEOELECTRIC AND HYDRAULIC PARAMETERS IN PARTS OF GANGA-YAMUNA INTERFLUVE, NORTH INDIA

## A DISSERTATION

***Submitted in partial fulfillment of the requirements for the award of the degree of***

**MASTER OF TECHNOLOGY**
**in**
**HYDROLOGY**

By

**RANJAN SINHA**



**DEPARTMENT OF HYDROLOGY**
**INDIAN INSTITUTE OF TECHNOLOGY ROORKEE**
**ROORKEE -247 667 (INDIA)**

**JUNE, 2006**

**DEDICATED TO MY FATHER**

# CANDIDATES'S DECLARATION

I hereby certify that the work which is being presented in this dissertation entitled **"RELATIONSHIPS BETWEEN GEOELECTRIC AND HYDRAULIC PARAMETERS IN PARTS OF GANGA - YAMUNA INTERFLUVE, NORTH INDIA"** in partial fulfillment of the requirement for the award of the Degree of Master of Technology in Hydrology, submitted in the Department of Hydrology, Indian Institute of Technology, Roorkee, is an authentic record of my own work carried out during the period from July 2005 to June 2006 under the supervision and guidance of Dr. D.C Singhal, Professor, Department of Hydrology, Indian Institute of Technology, Roorkee, and Dr. M. Israil, Associate Professor, Department of Earth Sciences, Indian Institute of Technology, Roorkee.

The matter covered in this dissertation has not been submitted by me for the award of any other degree.

Roorkee

Date : 7/6/06

Ranjan Sinha.

**RANJAN SINHA**

This is to certify that the above statement made by the candidate is correct to the best of our Knowledge.


**Dr. M. ISRAIL**
Associate Professor,
Department of Earth Sciences,
Indian Institute of Technology,
Roorkee (India)

**Dr D.C SINGHAL**
Professor,
Department of Hydrology,
Indian Institute of Technology,
Roorkee (India)

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Ranjan Sinha.

**(RANJAN SINHA)**

# ABSTRACT

The objective of this study is to develop surface electrical resistivity methods for estimating hydraulic conductivities in alluvial aquifers. The hydrogeological framework in the Ganga-Yamuna Interfluve is evaluated in view of formulating and testing relationships between hydraulic parameters and geo-electric parameters for alluvial aquifers under anisotropic conditions.

Resistivity of the aquifer is determined from results of Schlumberger electrical soundings conducted at twenty three sites in parts of Ganga-Yamuna interfluve, North India where pumping tests had previously been made. The data of pumping tests were analyzed using different methods including Neuman's (1975) method to calculate vertical hydraulic conductivity. The resistivities of collected water samples were determined to compute the formation factor. Computed formation factor were correlated with hydraulic conductivity. The formation factor is directly related to hydraulic conductivity. The normalized aquifer resistivity, normalized transverse resistivity, normalized longitudinal resistivity was correlated with hydraulic conductivity, and normalized transverse resistance with aquifer transmissivity. A four parameter empirical relation between hydraulic conductivity, modified longitudinal resistivity, modified transverse resistivity, and hydraulic anisotropy is developed for anisotropic aquifers underlain by conductive layer (clay). Results indicate that electrical parameters determined from soundings can be used to predict aquifer parameters.

# NOTATIONS/ABBREVIATIONS

| NOTATIONS/ABBREVIATIONS | DESCRIPTION |
|---|---|
| VES | Vertical Electrical Sounding |
| SP | Self Potential |
| PR | Point Resistance |
| IP | Induced Polarization |
| Pfe | Percentage Frequency Effect |
| Ω | Ohm |
| Ω-m | Ohm-m |
| $mVV^{-1}$ | Millivolt per volt |
| br | Aquifer Thickness from resistivity |
| AB | Current Electrode Spacing |
| MN | Potential Electrode Spacing |
| av | Average |
| $\rho_{app}$ | Apparent Resistivity |
| $\rho$ | Bulk Resistivity of Rock |
| $\rho_w$ | Resistivity of formation Water |
| $\rho_w$(avg) | Average Aquifer Water Resistivity |
| $\rho_l$ | Longitudinal Resistivity |
| $\rho_t$ | Transverse Resistivity |
| $\sigma$ | Electrical Conductivity |
| $\sigma_l$ | Longitudinal Conductivity |
| $\sigma_t$ | Transverse Conductivity |
| $\rho'$ | Modified Aquifer Resistivity |
| $\rho'_l$ | Modified longitudinal Resistivity |
| $\rho'_t$ | Modified transverse Resistivity |
| R | Transverse Resistance |
| C | Longitudinal Conductance |
| R' | Modified Transverse Resistance |
| D | Original Saturated Aquifer Thickness |
| T | Transmissivity |
| K | Hydraulic Conductivity |

| | |
|---|---|
| $K_h$ | Horizontal Hydraulic Conductivity |
| $K_v$ | Vertical Hydraulic Conductivity |
| B | Hydraulic Anisotropy |
| $W(U_A,\beta)$ | Well function ( Early time) |
| $W(U_B,\beta)$ | Well function (Late time) |
| $S_A$ | Storage Coefficient |
| $S_Y$ | Specific Yield |
| r | Distance from the pumped well |
| s | Drawdown |
| RMSE | Root Mean Square Error |
| bgl | Below ground Level |
| m | Cementation factor |
| $^oC$ | Degree Centigrade. |

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# CHAPTER-1

# INTRODUCTION

## 1.1 Rationale of The Study

Ground water is an important natural resource with high economic value and sociological significance. Its development should be carried out in such a manner that a depletion of this resource (both in quantity and quality) is avoided and the adverse environmental impacts (land subsidence etc.) are restrained within acceptable limits. The technical factors, institutional and social acceptability are important in addressing sustainability. The development of Ground water resources and the regime of its activity largely depend on the porosity and permeability of water bearing formations. Aquifer transmissivity is also an important parameter in ground water hydrology but due to various constraints it often becomes difficult to find adequate field values of this vital parameter. Its estimation on other random locations may be made from the field values using appropriate mathematical/ statistical tools. Further there are electrical parameters which are easy to obtain in the field but can be utilized in improving the interpolated estimates of transmissivity.

Geophysical resistivity method is, one of the powerful tools employed in delineating aquifers in various areas. This is normally a first step in the ground water exploration projects. The hydrogeological investigations such as pumping test etc. are conducted to estimate transmitting and storing properties of aquifers. However, if the permeability values are low, it may be difficult to employ the customary pumping test data analysis techniques for evaluation of the hydraulic characteristics of the aquifer.

However cost of carrying out pumping tests is often higher than the elaborate geological and geophysical surveys. Information gathered through resistivity methods alone will not replace test drilling even under favorable conditions.

Although the two methods are based upon different physical laws, geoscientists have been working to establish a viable analogy between the two techniques and establish correlation between the two electrical and hydrogeological parameters.

In the light of the ongoing efforts to relate the geoelectrical and hydraulic parameters of aquifers, a study was planned to study the anisotropic alluvial aquifers of Ganga-Yamuna interfluve in north India and ascertain the relationship between the hydraulic & geoelectric parameters of the aquifers in the region.

## 1.2 Location & Extent Of Study Area

The study area (Figure1.1) form parts of Haridwar and Saharanpur districts of Northern India is located between latitude $29^0$54'N to $30^0$8'12" N and longitude $77^0$14'5" to $77^0$57'35"E. It covers an area of 5500 $km^2$ approximately The area encompasses the Ganges alluvial plain which lies south of Himalayan foot hills. Its western boundary is near river Yamuna and eastern boundary is near river Ganga, whereas Muzaffarnagar, district is situated towards its south.

## 1.3 Climate & Rainfall

The study area has moderate subtropical monsoon climate. The air temperature ranges from $3^0$C in winter to about $42^0$C in summer. The average annual rainfall is 1016 mm. The maximum rainfall occurs in the foot hills of Himalayas and gradually reduces towards south.

## 1.4 Physiography and Drainage

The area of study is generally a plain with mild slope towards south. The altitude of land in the area ranges from 260 to 400m above mean sea level generally rising from south to north. In the vicinity of the Siwalik hills, the gradient is steep and is about 10 m/km from north to south.

The principal drainage in the area pertains to the Ganges river system where Ganga and Yamuna are the main perennial rivers. The Ganga river enters the study area from the northeastern end. Its tributaries are Ratmau Rao and Solani river. The solani river remains dry most of the time during the year but carries large flows in rainy season. The river originates in the Siwalik as branches in dendritic form which becomes parallel in Bhabar zone. The river flows along the general direction of SW in Bhabar-Tarai region. On entering the plains, it flows in southeastern direction influenced by Solani fault ( Pandey et al., 1963).

The river Yamuna is another major river of Northern India and it is the largest tributary of river Ganga. Its source is at Yamunotri, in the Uttaranchal Himalayas. The Yamuna river enters the study area from the northwestern side. It's tributaries are the Hindon and Nagdeo which originate in the Siwalik hills towards north while other streams like Kali, Krishni etc. originate in the plains. The Hindon River flows almost in a linear fashion from Saharanpur to its point of confluence with the River Yamuna near Delhi.

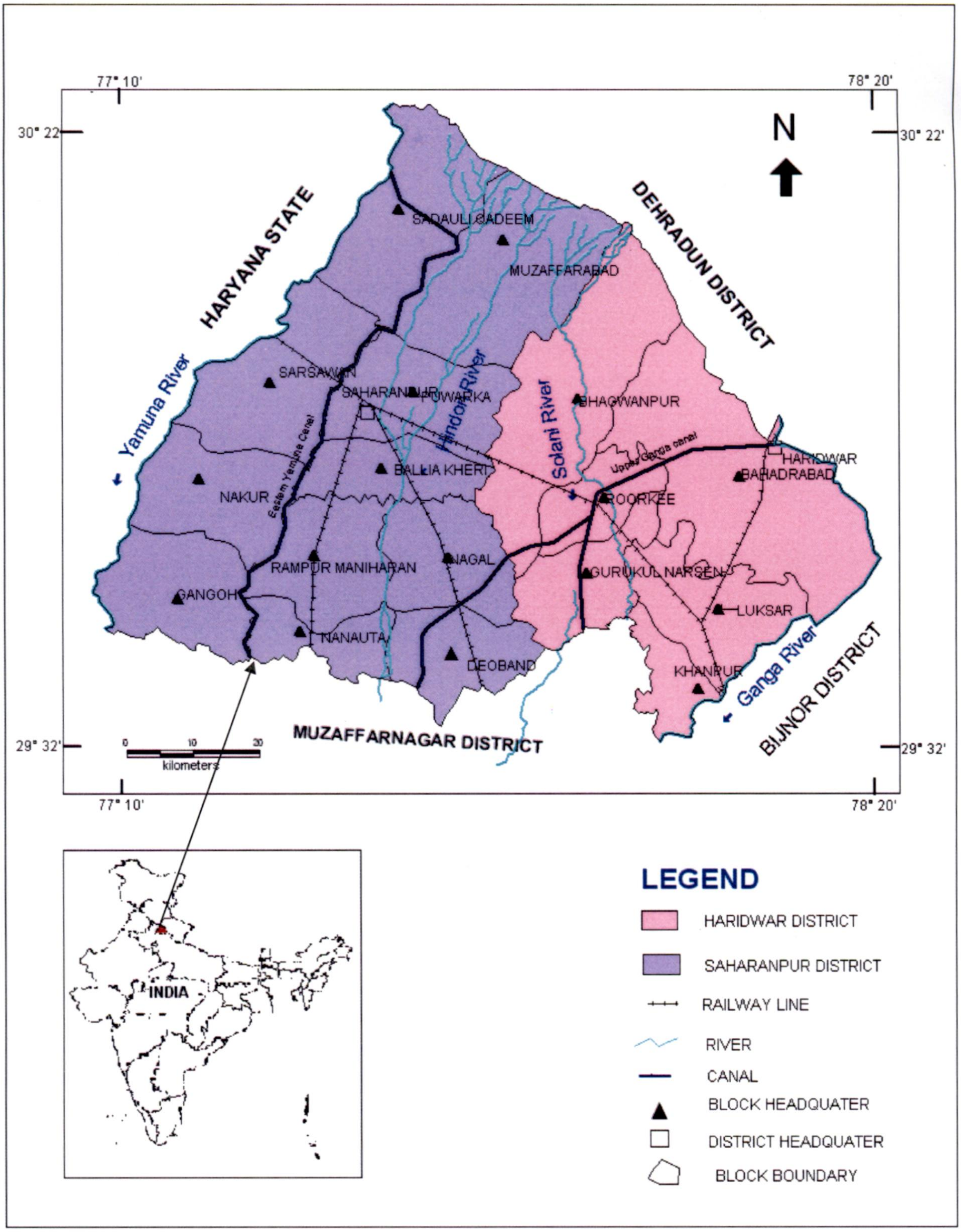



Figure 1.1 Index map of the study area

## 1.5 Literature Review of Hydrogeological Conditions of Study Area

Numerous workers have studied the geology and hydrogeology of the study area. Raghav Rao (1965) described the geology and ground water conditions of Saharanpur and Haridwar districts. Devendra Kumar (1972) studied the ground water condition in Roorkee University (IIT) campus with the help of resistivity sounding data. Sunder (1978) studied the aquifers of Roorkee and its surrounding area with the help of sub-surface lithological fence diagram. Ground water investigation organization, Roorkee (1983) made an extensive water balance study of Yamuna –Hindon doab and estimated specific yield of aquifers from various methods. They have also calculated aquifer parameters by analysis of pumping test data. Mathew (1983) has estimated the transmissivity of the aquifers by using the results from surface resistivity sounding data and compared these values with the field transmissivity values computed from analysis of pumping test data of nearby tubewells. Agashe et al (1984) studied the hydrogeological conditions of upper Yamuna basin (CGWB report). Murali (1984) has studied the geomorphology and land use of upper Hindon basin around Saharanpur town. Sriniwas and Singhal (1985) estimated transmissivity and hydraulic conductivity of aquifers of U.P including parts of study area, using surface resistivity data. These values are compared with the values, obtained from analysis of pumping test data, of near by tubewells. Khan (1987) has calculated the aquifer parameters of alluvial sandy aquifers of Yamuna-Hindon doab of Uttar Pradesh, using grain size parameters and compared the same with hydraulic conductivity values obtained from pumping test analysis. Joshi (1987) presented hydrochemical studies of Saharanpur and Haridwar districts. Adam (1992) estimated aquifer transmissivity from resistivity data around Roorkee. Musampa (1994) carried out integrated studies of hydrogeological conditions of Roorkee town. Wani (2002) studied tubewell design and ground water quality in IIT Roorkee campus. Sharma (2002) reviewed methods of estimation of aquifer transmissivity from electrical resistivity sounding data for IIT, Roorkee campus.

## 1.6 Scope of Study

The present study has been undertaken with the following objectives:

- Evaluation of hydrogeological framework, in the Ganga-Yamuna Interfluve.
- Interpretation of existing pumping test data for various selected tubewell sites.
- Carrying out field vertical electrical soundings (VES) in the vicinity of existing sites of pumping tests and interpretation of (VES) data to estimate true resistivities and thickness.
- Carrying out a review of available/existing geophysical techniques for evaluating aquifer properties.
- Formulating and testing relationship(s) between hydraulic parameters and electrical resistivity parameters for alluvial aquifers under anisotropic conditions.
- Checking validity of developed relations for the alluvial aquifers of the study area.

# CHAPTER-2

## GEOLOGY & HYDROGEOLOGY OF THE STUDY AREA

---

## 2.1 Geology

Physiographically, the study area can be divided into hilly area comprised of the Siwalik Range and Ganga basin. Taylor(1959) has divided the Ganga basin into three belts, which are termed as Bhabar, Tarai and Alluvial plain from North to South ( Figure 2.1)

### 2.1.1 Siwalik Range :

This forms the outermost range of Himalayas and is comprised of Tertiary group of rocks. It commences with a gentle slope from Bhabar area from an altitude of about 400m and then steeply rises northward attaining a height of about 600m where it ends abruptly. The Siwalik range is further divided into Upper, Middle and Lower Siwalik Zones. The upper Siwalik zone is constituted of calcareous banded pebble-boulder conglomerates, sandy rocks and clay beds. The pebble and boulder are mostly of quartzite types. The upper Siwalik zone is the most permeable and porous of the entire Siwalik sequence. Middle Siwalik zone comprises mainly of Sandstone and serves as moderate to good aquifer. Lower Siwalik Zone is made up of hard and massive sandstone, clays, and shale beds. The Lower Siwalik Zone bears poor water transmitting and storage capacity than the middle and upper Siwalik sandstone. In the deep borings conducted by the Oil and Natural Gas Commission (India), at certain locations in the Indo-Gangetic basin, the upper and middle Siwalik rocks were found to underlie the alluvial deposits at a depth varying from 2800m near the Himalayan foot hills, which gradually diminishes to about 1000m at Ujhani (Badaun, U.P.) and to 620m at Kasganj (Etah,U.P.) (Pandey et al.,1963; Mithal et al., 1973).

### 2.1.2 Bhabar Belt :

Bhabar is the piedmont zone formed along the foothills of Siwalik and is the upper most group of sedimentary deposits. It is formed by flooding hill torrents and nullah (also locally termed as "rao"). Alluvial fans in these piedmont zones are wider and longer when formed along mature large streams. The topography is normally characterized by badlands ( high undulations, noncohesive soils and sparse vegetation). The sediment matrix of Bhabar therefore, exhibits high porosity and permeability. The incisions by hill torrents and rushing nullahs have developed several longitudinal spurs and depressions all along the Bhabar zone. Considerable amount of ground water recharge is taking place in this zone through direct infiltration of precipitation. Within the Gangetic alluvial basin, the water table in the Bhabar zone occurs at high elevations and represents the maximum recharge head available to the aquifer systems occurring within the plains ( Pandey et al., 1963).

### 2.1.3 Tarai Belt :

The Tarai belt is formed by the deposition of the finer outwash of Bhabar. It consists mainly of clayey formations often impregnated with Kankar (Calcium carbonate concretions), coarse sand and pebbles and little amount of fine sand and sandy clay. The granular beds occur mostly as lenses. The Tarai belt is relatively flat with respect to Bhabar. Shallow watertable and swampy grounds characterize the break in topographic slope. Along Bhabar-Tarai contact, a number of springs and seepages occur in the depressions and along the nullahs. The southern limit of Tarai is not clearly defined and is generally taken as the zone where flowing conditions cease to exist in the tube wells which indicates beginning of the plains ( Pandey et al.,1963).

Tarai receives groundwater recharge by downward percolation and through lateral flows from the Bhabar belt. Thus, the groundwater storage capacity in this belt is large.

### 2.1.4 Gangetic Alluvial Plain:

The region south of the Tarai is occupied by the Gangetic Alluvial plain, which forms greater part of the north Indian Plains. Lithologically, the alluvium is composed of unconsolidated and semi-consolidated deposits of sand, clay and Kankar that provide a good ground water reservoir ( Pandey et al., 1963).

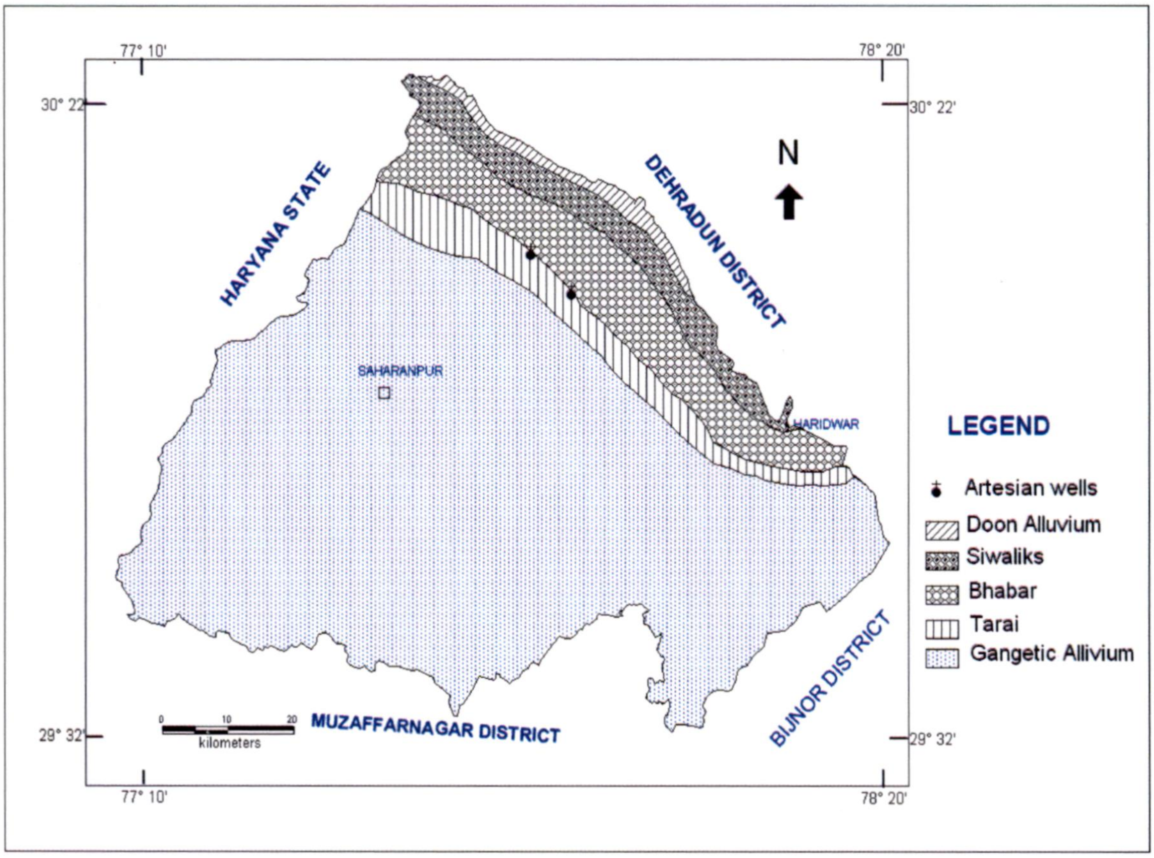



Figure 2.1 Hydrogeological map of the study area (After Pandey et al, 1963)

## 2.2 Hydrogeology and Aquifer Geometry

The alluvial plain is composed of sand, clay, and Kankar which are semi-consolidated and fluviatile in nature. The alluvial sediments of the plain are also largely derived from the Himalayas and are deposited by the streams flowing southward, south-westward or south-east ward.

The various lithological units in the alluvial plain in the study area reveal an erratic distribution. Most of these occur in lenticular form showing inter-fingering. Existing borehole logs indicate a lithological continuity along the N-S sections while E-W sections are discontinuous.

The ground water conditions in alluvial parts are considerably influenced by the varying lithology of the subsurface formations. As for the general nature of fluviatile deposits of Indogangetic plains, it has been observed that the strata exhibit great variation both laterally and vertically. The main source of water which sustains groundwater body in the area is rainfall. Other sources of ground water replenishment are infiltration from rivers, canals and return flow from irrigation, and inflow from the neighboring areas.

The most common ground water structures in the study area are shallow and deep tubewells. Dugwells are also used as source of drinking water as well as irrigation, but to a limited extent.

Based on the lithological logs two to three types of aquifers have been delineated in the area (Figure2.4-2.9). The upper one is the shallow unconfined aquifer which generally extends to depths of around 25m to 140m. The deeper aquifers are confined to semi-confined in nature.

### 2.2.1 Demarcation of Marker Horizons and Aquifer Groups

Some of the basic criteria which are used in the work have been briefly discussed here and drawn from CGWB report (Agashe et al, 1984) & UP state Govt. reports. All the lithological units occurring under the surface have their characteristic electrical and other geophysical properties. The geophysical properties changes with the lithology changes and the electrical log faithfully records the variation of these properties (with respect to depth). In the field of ground water, the interstitial fluid saturating the formations greatly modifies the electrical properties. The presence of clays or clayey formations because of their poor permeable nature always acts as hydrologic barriers within the ground water reservoir and when extensive in aerial spread, these generally cause separation of the ground water body into different aquifer groups. True identification of aquifer in a borehole may be possible if the lithology obtained from drill cutting samples is supplemented with information contained in the geophysical logs. Based on the interpretations of self potential (S.P), resistivity logs and drilling information, a composite lithological section is prepared.

The sands, (permeable granular strata) forming a single hydrologic group (an aquifer group) bounded within two regionally extensive clayey layers will show some similarity of the log characteristics and may be treated as a marker horizon.

In the present study the typical characteristics of SP and point resistance( PR) less were used as distinguishing marker horizons.

Interpretations were based on SP in conjunction with resistance or resistivity logs as per the availability of logs. For the regional sub-surface correlation, initially each log was considered separately and groups having diagnostic characteristics were identified. Each group generally comprised of a number of individual beds. The comparative characteristics of these groups in relation to those overlying and underlying horizons were also noted. Further, with the help of the characteristics observed, these markers were identified along selected sections, and extended from one well location to the other. Finally, the various sub-surface geological sections so prepared were synthesized in space to evolve the Fence diagram.

Any marker horizon, to qualify that label, should have distinctive geophysical characteristics, sharp contrast against the neighboring strata and spatial extension throughout the area. For this purpose, identification of the marker horizons is critically important in this study. Only those markers are utilized that definitely persist from one well to the other.

Figure 2.2 shows a typical electrical log of the area at Gandhinagar. Here the saturated granular zones occurring between 7 to 147m depth are characterized by the highest negative SP values and high resistance. This is marked as group I. The SP value for the sand layers within this depth is -18mV. Below the clay underlying the above aquifer group (from

147 to 157m) there is a marked change in SP. The shale base line too has shifted drastically towards right. The SP recorded for the sand layers within the 2nd group vary from 157m to 272 m has shifted towards right (+ive). The group II is underlain by a thick clayey group from 272-292m.b.g.l. This clayey marker group is instrumental in changing the log characteristics of sand zone down below. In the third aquifer group (292-386m) below the aforesaid clayey group the SP values of the sandy zones remain more or less the same .

### 2.2.2 Mapping Of Major Aquifer Systems

The hydrological mapping of the basin showing different potential aquifer groups was done for a depth upto 450m by interpretation of lithological and electrical logs of 20 boreholes on the basis of observed geophysical responses. Groups of strata having similar response were identified on the basis of clay marker horizons. Each such group comprised of a number of individual sandy or clayey layers. But an individual group had diagnostic characteristics by which it was separated from others. Full use of the observed changes in shale base shift, hydrochemical character as seen from spontaneous potential and resistivity logs and the lithological information available was made while identifying the major aquifer groups. Further, with the help of these marker horizons, subsurface geoelectrical sections connecting several exploratory sites (as shown in Figure 2.3) were prepared.

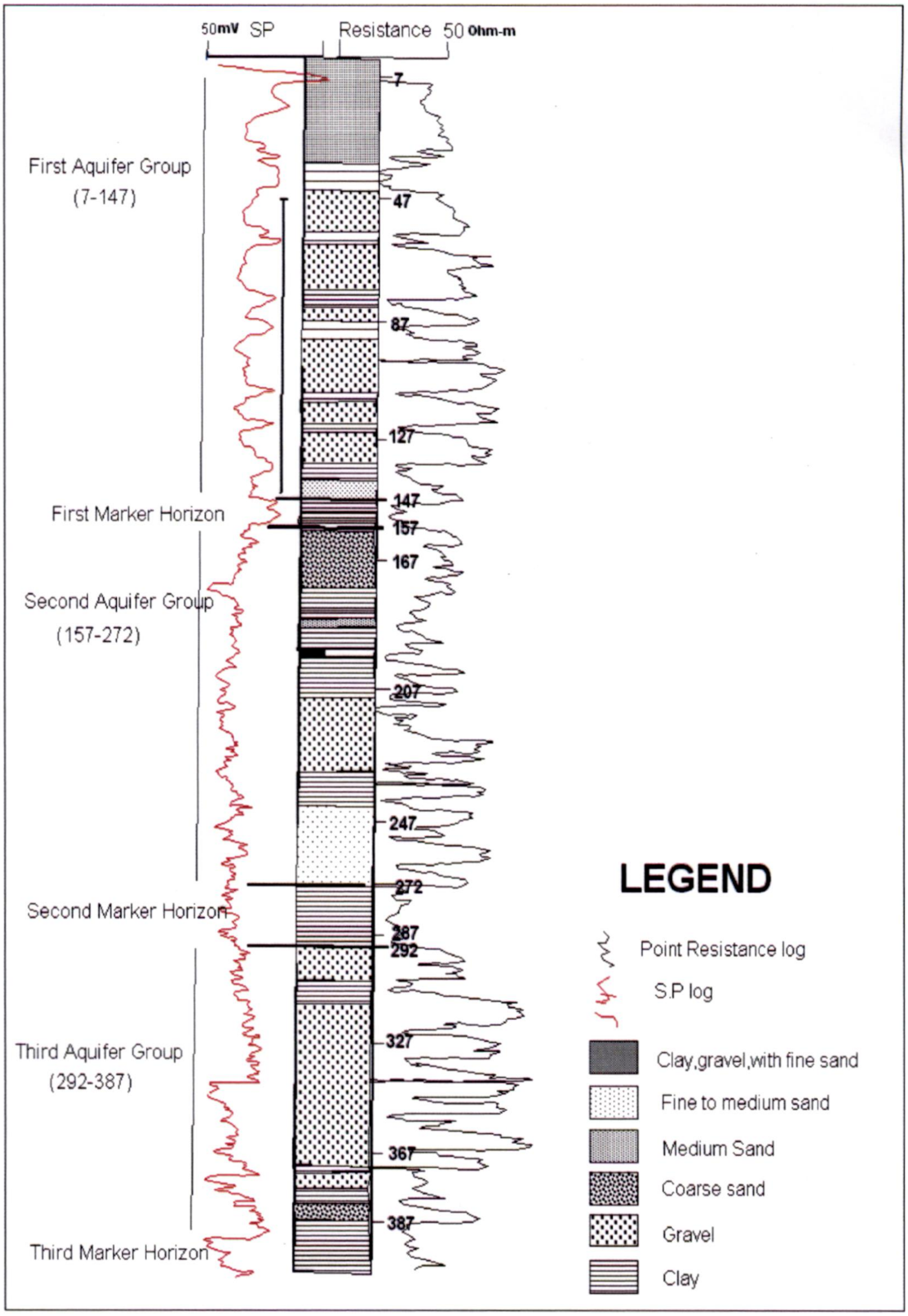



Figure 2.2 Composite lithological log of Gandhinagar Site

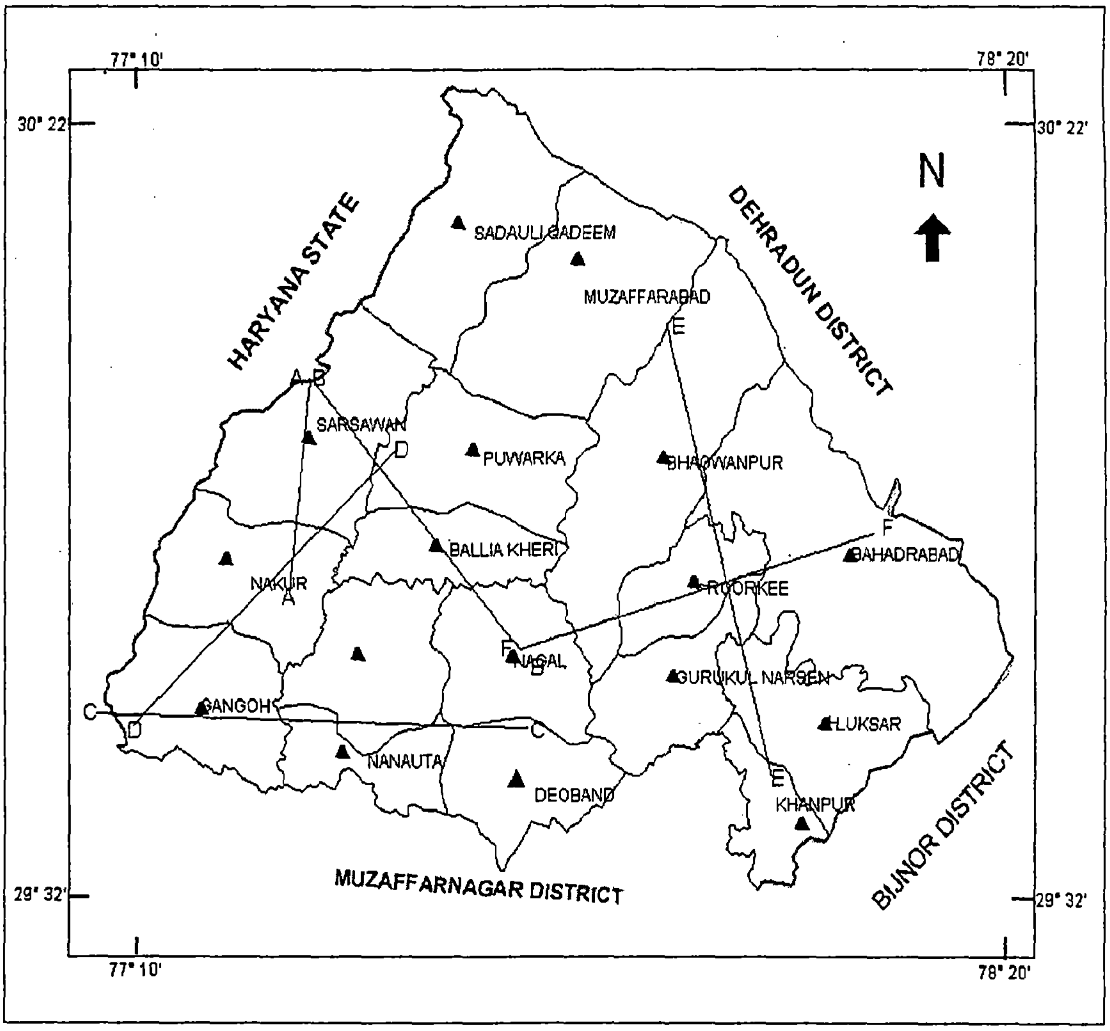



Figure 2.3 Map showing Section lines

### 2.2.2.1. Section A-A:

Figure-2.4 shows the section A-A extending from Yamuna bridge at north to Ambehta at south. The marker clay horizon at Ambehta (towards south) separating aquifer-I and aquifer-II is at shallower depth as compared to that at Yamuna bridge. At Salehpur there are four marker clay horizons. There are two markers between aquifer groups I & II resulting in presence of another intervening narrow aquifer zone at Salehpur but this zone merges with the adjacent/overlying aquifer group-I at Yamunabridge and with the aquifer group-II at Ambehta. Between Yamunabridge and Salehpur the aquifer group-I is hydraulically connected with a aquifer group II between Salehpur and Ambehta sites. Groupwise lithofacies remain the same from north to south but coarser material is present in the group I as compared to other groups. The marker horizon separating aquifer group-II and aquifer group-III is however present throughout the section.

### 2.2.2.2. Section B-B:

The section B-B (Figure.2.5) is drawn from Yamuna bridge in the northwest to Nagal in the southeast. All the three markers are traceable distinctly at Yamunabridge and Pilkhani. At Hassanpur (towards southeast) however there is presence of clay of limited thickness as inferred in the drilling log but there are no such sharp changes in electrical log. After connecting the Markers, it is observed that the intervening clay layer separating the top two aquifer groups (Group-I & Group-II) is missing at Nagal resulting in a single aquifer system. The first group is comprised of gravel and coarse sand everywhere. The lithology at Nagal (as revealed from drilling samples) reveals that aquifer I is composed of mixed material consisting of gravel, pebble and coarse to medium sand.

### 2.2.2.3. SECTION C-C:

The section C-C connects Karnal( Haryana) towards west to Sakhan in the east across river Yamuna ( Figure.2.6). Delineation of markers reveals that the clay layer underlying the Ist aquifer group is persistent throughout this section. The aquifer group II is distinguished from group III near Karnal but towards east at Papri and Badgaon, they merge together as the intervening clay thins out. A 18m thick localized aquifer is seen occurring within this clay near Karnal site. All along the section, the group III is found to be rather thin and on the whole this group is not well defined. The coarsest sediments are found in the easternmost part and the sediments become finer in size.

### 2.2.2.4. Section D-D:

Figure-2.7 shows the section D-D extending from GandhiNagar in the southwest to Pilkhani in the northeast. Markers I and II are very much distinguishable at all the sites. Marker III is quite distinct and can be traced every where except at Pilkhani due to lack of data (or due to pinch out). Groupwise lithofacies remain the same from North to South but coarser material comprises the Ist group as compared to other groups.

### 2.2.2.5. Section E-E:

Figure-2.8 shows the section E-E extending from Ganeshpur in the north to Shikarpur in the south. The examination of lithologs shows that through out the section combined group I & II aquifers are present in this stretch forming single aquifer system comprising of relatively coarse grained sand and are deposited mainly by Ganga river system. The clay layer underlying this combined aquifer group is persistent throughout this section.

### 2.2.2.6. Section F-F:

Figure-2.9 shows the section extending from Nagal in the west to Jwalapur in the extreme east. Similar to Figure 2.8, the two aquifers groups (I&II) are present as a single aquifer system which are relatively coarser and are deposited mainly by Ganga river system. Further the clay layer underlying this group is persistent throughout the section.

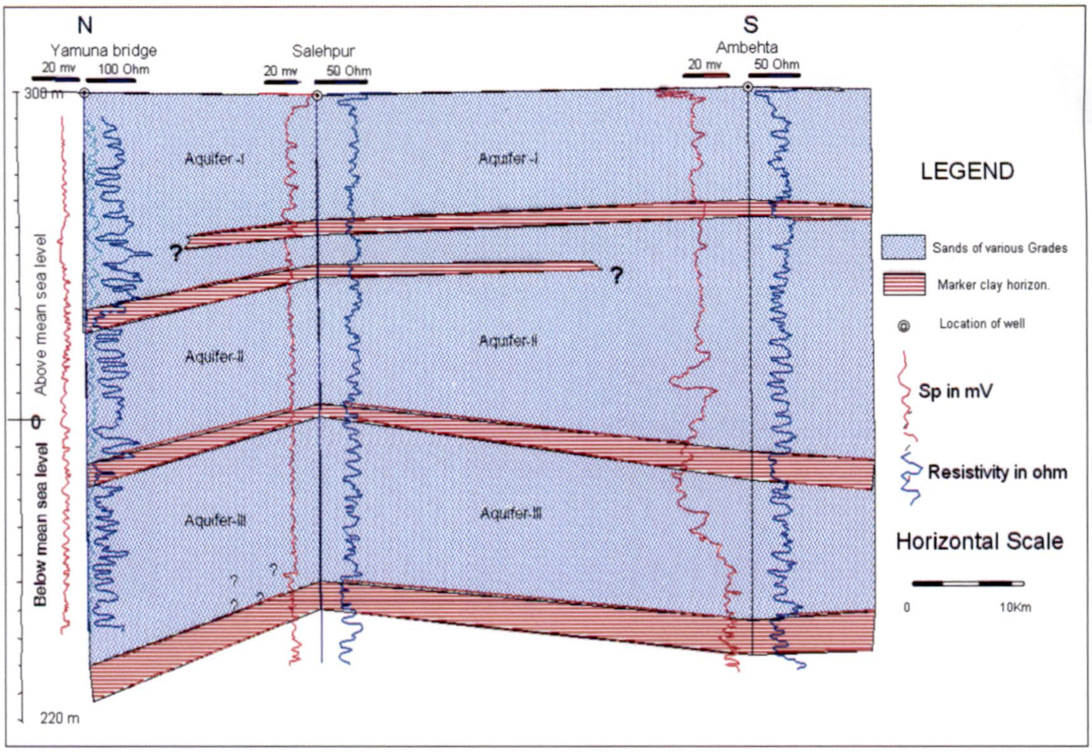



Figure 2.4 Hydrogeological section along A-A

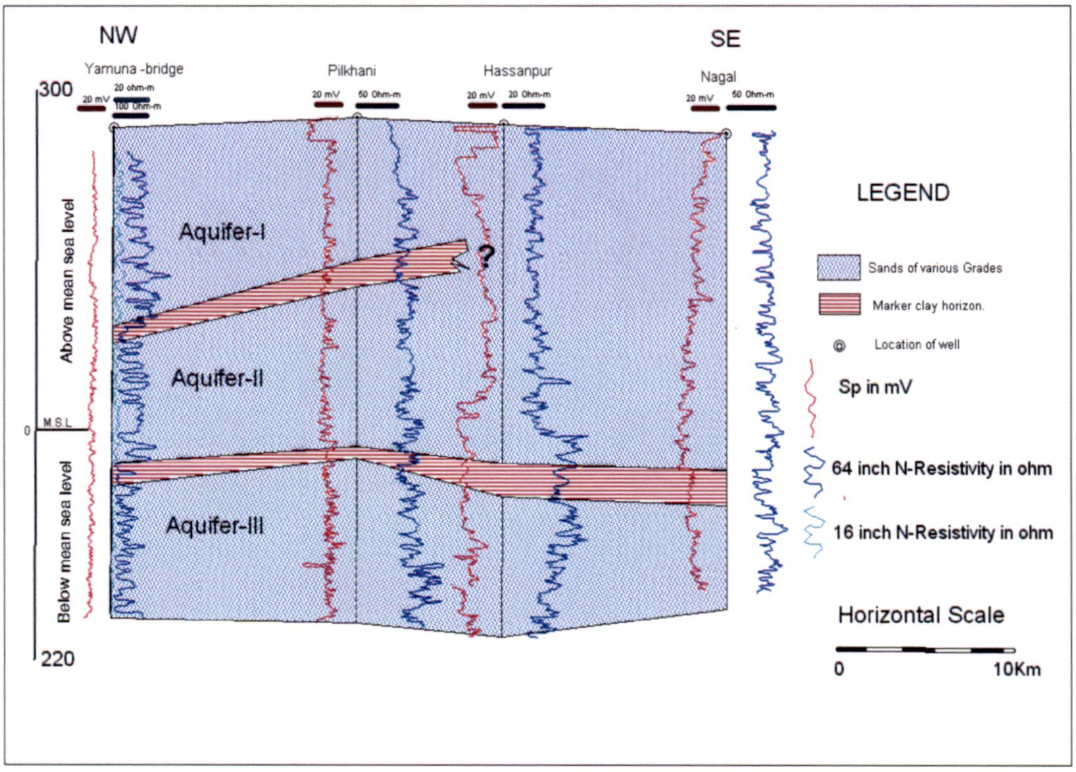



Figure 2.5 Hydrogeological section along B-B

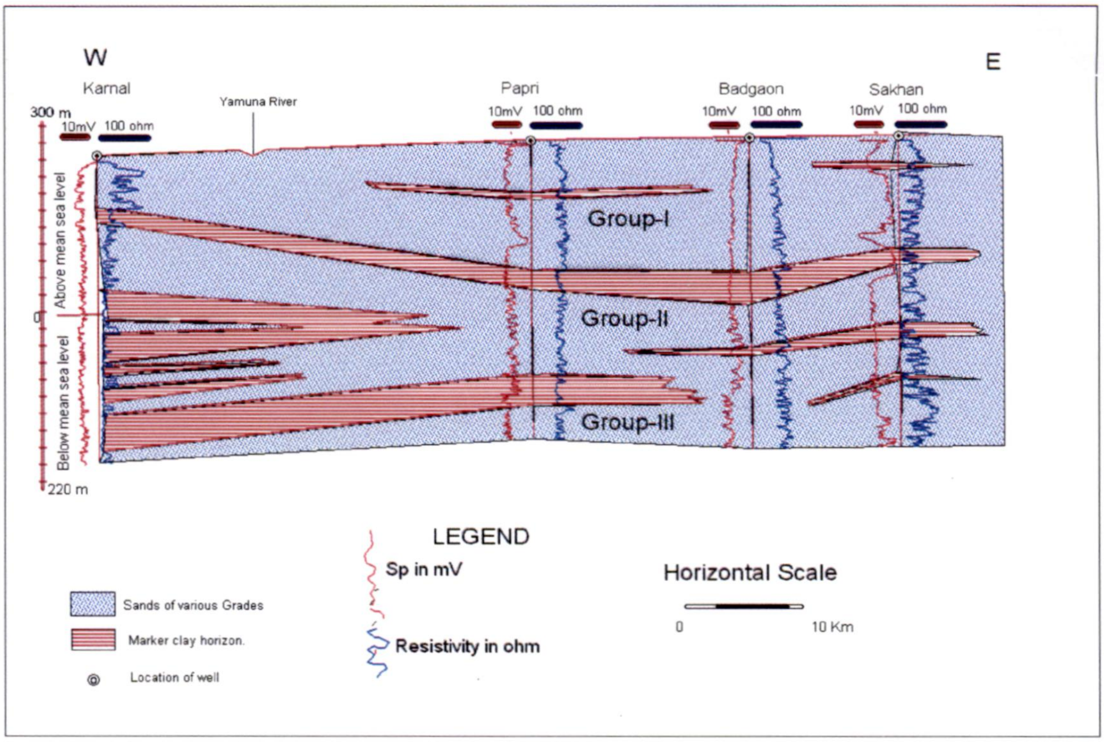



Figure 2.6 Hydrogeological section along C-C

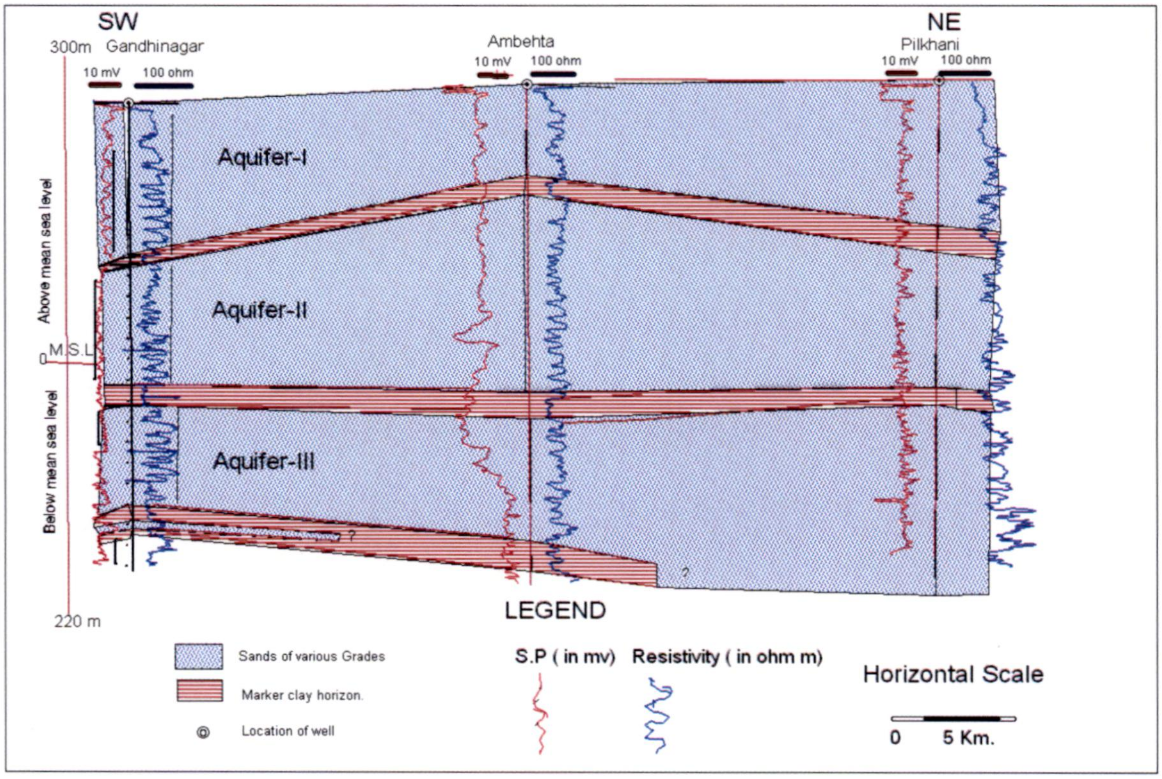



Figure 2.7 Hydrogeological section along D-D

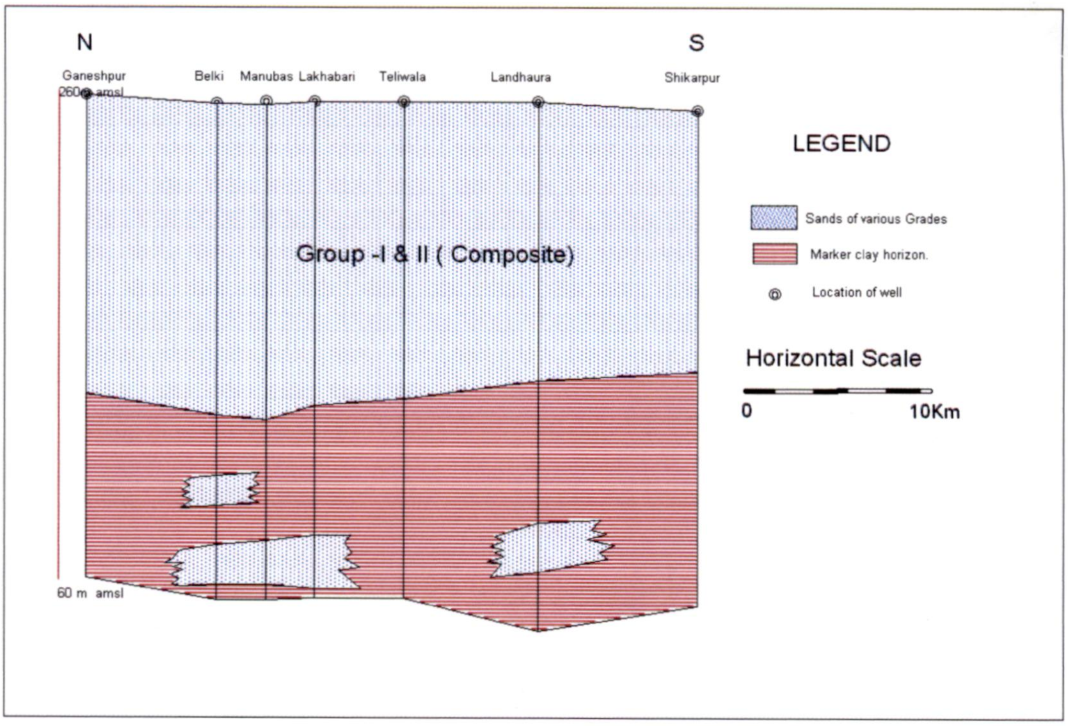



Figure 2.8 Hydrogeological section along EE

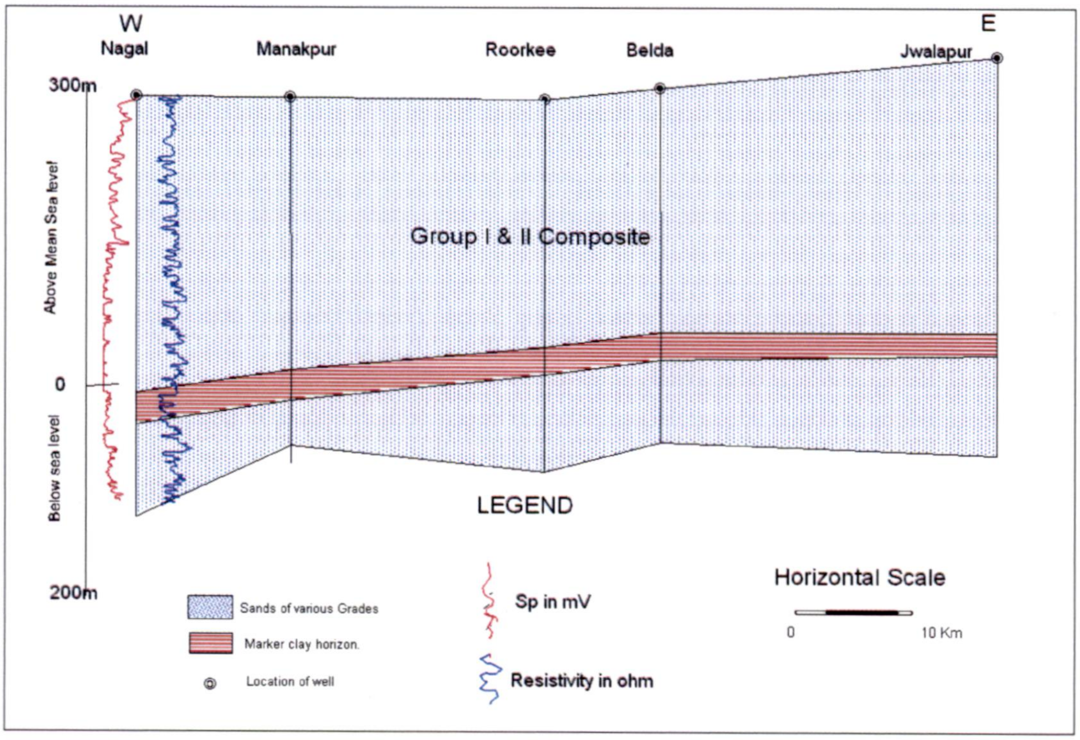



Figure 2.9 Hydrogeological section along F-F

### 2.2.3 Fence Diagram

The above correlation sections help in visualizing the number, disposition, and extension of aquifer groups in the study area as a whole. The Fence diagram of the study area is drawn (as shown in Figure2.10) using the available electrical log at 12 sites and lithological logs of 25 sites. The regional picture of subsurface geology which emerges from the study is that except in Bhabhar region and in eastern part of the study area, four distinct groups of permeable granular zones with uniformity coefficient ranging from 2 to 3 (After Agashe et al.1982) separated by three different poorly permeable/impermeable horizons were identified( hydrogeologic unit-1). Where as in the eastern part of the area the different aquifer groups forms a single aquifer system comprising of coarser unsorted material with uniformity co-efficient more than 4 ( hydrogeologic unit-2) as discussed below and shown in Fence diagram.

#### 2.2.3.1 Aquifer Group –I

The unconfined aquifer group extends from water table down to a maximum of 167m.bgl and occurs all over the basin. This is composed of relatively coarse sediment and contains fresh formation water. This group is sub divided at places into subgroup IA and IB by occurrence of a sub-regional clayey layer. It is underlain by a clayey horizon 10 to 15m thick which is regionally extensive except near Nagal, Ambehta and towards Bhagwanpur and Jwalapur. Thus at these places, the aquifer –I seems to be directly in contact with aquifer –II.

#### 2.2.3.2 Aquifer Group –II

This aquifer group consisting of different sand and clay lenses occurs at variable depths ranging from 65m to 283m bgl and displays distinguishing characteristics at same places where at other locations it is separated because of the distinguishing features of the overlying groups. The sediments of this group are finer in size than aquifer –I and are admixed with Kankar at sites towards River Yamuna. The quality of water is reasonably fresh except in southwestern parts. The group is underlain by another clayey horizon, which is considerably thick at places and appears to be regionally extensive. This aquifer is under semi-confined to confined conditions.

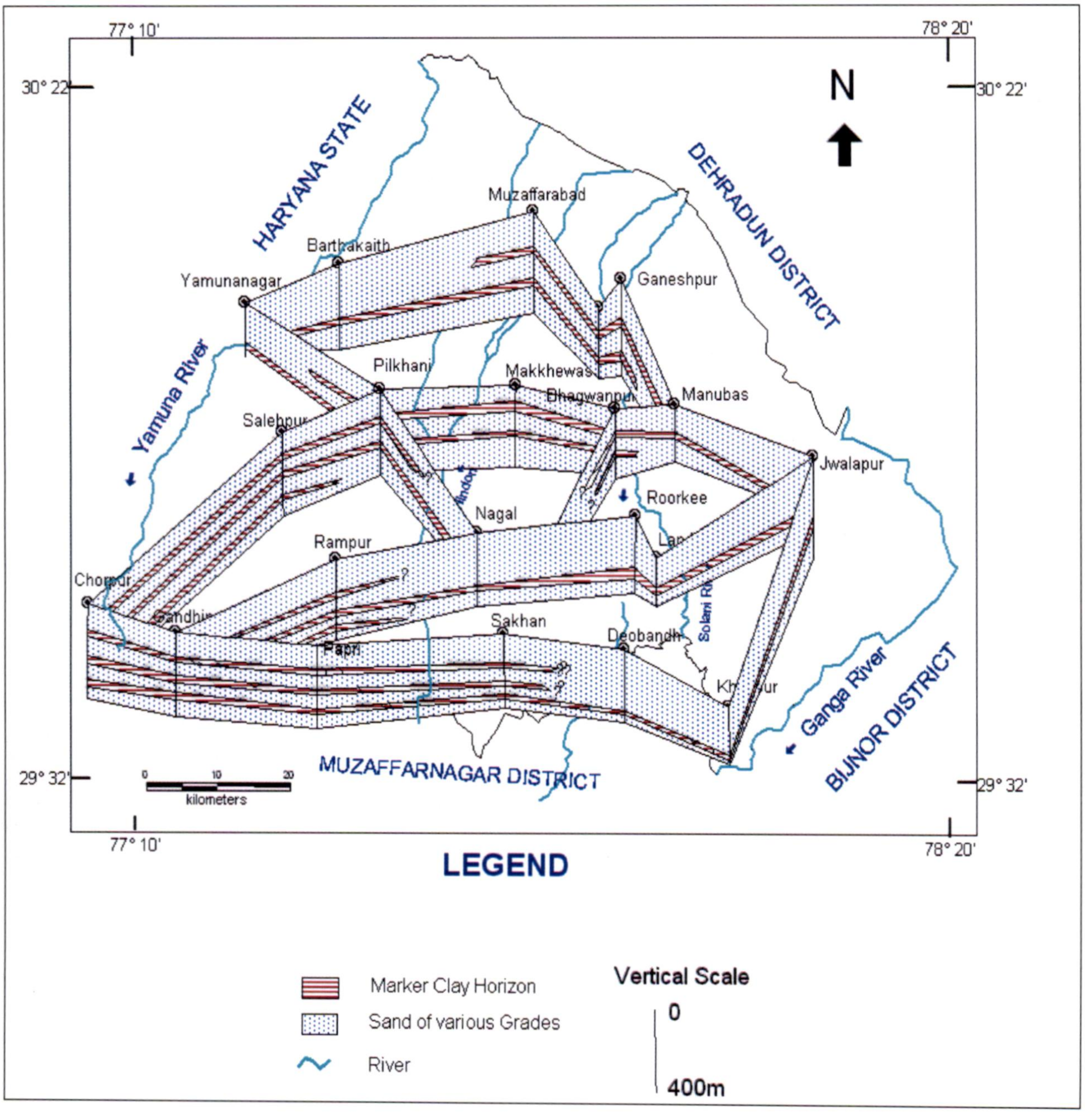



Figure 2.10 Fence Diagram of The Study Area

### 2.2.3.3 Aquifer Group – III

This group comprised of thin sand layers alternating with thicker clay layers occurs at variable depths ranging between 197m and 346m bgl. The granular material of this group is generally finer in texture more so in southern parts. Kankar commonly occurs in Northern parts. This aquifer group is under confined conditions.

### 2.2.3.4 Aquifer Group – IV

The aquifer – III is underlain, in turn, by a thick clayey horizon, which in turn is underlain by another permeable granular horizon. This aquifer group is not fully penetrated by tubewells and is thus less investigated. This aquifer is also under confined condition.

### 2.2.3.5 Conclusions:

- Each aquifer group embodies a number of granular layers alternating with thick or thin clay lenses having almost similar log characteristics indicating hydraulic continuity between them.
- The aquifer group-I in the eastern part of study area is generally comprised of coarse grained sand deposited mainly by Ganga river system ( hydraulic unit-2) which grades into fine grained sand towards the western part in the alluvium deposited by Yamuna river & its tributaries (hydraulic unit-1).
- Lensing and pinching out of individual sand and clay layers within the single aquifer group is not ruled out.
- The major clay groups intervening between these aquifer groups extend regionally and pinch out against the aquifer groups only at some places.
- The aquifer group-I extends all over the basin with varying thickness. This group is composed generally of coarser sediments as compared to other groups.

- This group-I is underlain by an extensive clay group which is about 10 to 15m thick. However it is found to be missing around Nagal, Ambehta, and Tikaula in the east.
- Thus group-I & II form a single hydraulic unit, in the eastern part of the study area pertaining to the alluvium of the Ganga river.

# CHAPTER-3

## AQUIFER CHARACTERISTICS AND THEIR EVALUATION

### 3.1 Basic Concepts of Well Hydraulics

When working on problems of Ground water flow, it is necessary to find reliable values for the hydraulic characteristics of the geologic formations through which ground water is moving.

The important hydraulic properties of aquifers and confining layers are porosity, hydraulic conductivity, transmissivity, storage co-efficient, hydraulic diffusivity, leakage co-efficient, leakage factor, etc. Properties of materials that is responsible for the resistance to flow usually show variations with the direction of measurement at any given point in a geologic formation. The property of spatial variation is called Heterogeneity, where as the property of directional variation is termed Anisotropy. If the hydraulic conductivity K is independent of position within a geologic formation, the formation is Homogeneous.

If an X,Y,Z coordinate system is set up in a such a way that the coordinate directions coincide with the principal directions of anisotropy, the hydraulic conductivity values in the principal directions can be specified as $K_X$, $K_Y$ and $K_Z$. At any point (X,Y,Z) an isotropic formation will have $K_X=K_Y=K_Z$, where as an anisotropic formation will have $K_X \neq K_Y \neq K_Z$. If $Kx= Ky \neq Kz$, as is common in horizontal bedded sedimentary deposits, the formation is said to be transversely isotropic.

The individual particles of a geological formation however are seldom spherical so that, when deposited under water, they tend to settle on their flat sides. Such a formation can still be homogeneous, but its hydraulic conductivity in horizontal direction $K_h$, will be significantly greater than its hydraulic conductivity in vertical direction $K_V$. This phenomenon is called anisotropy.

## 3.2 Ground Water Flow and Well Hydraulics

### *3.2.1* Steady and Unsteady Flow

There are two types of well-hydraulics Equations. Steady and unsteady state flow. Steady-state flow is independent of time. This means that the water level in the pumped well and in the surrounding piezometers does not change with time. Steady state flow occurs, for instance, when the pumped aquifer is recharged by an outside source, which may be rainfall, leakage through aquitards from overlying and /or underlying unpumped aquifers, or from a body of open water that is in direct hydraulic contact with the pumped aquifer. In practice, it is said that steady-state flow is attained if the changes in the water level in the well and piezometers have become so small with time that they can be neglected. As pumping continues, the water level may drop further, but the hydraulic gradient induced by the pumping well will not change. In other words, the flow towards well has attained a pseudo-steady state.

Unsteady state flow occurs from the moment pumping starts until steady-state flow is reached. Consequently, if an infinite, horizontal, completely confined aquifer of constant thickness is pumped at a constant rate, there will always be unsteady-state flow. In practice, the flow is considered to be unsteady as long as the changes in water level in the well and piezometers are measurable or, in other words, as long as the hydraulic gradient keeps changing in a measurable way.

### 3.2.2 Darcy's Law

Darcy's law states that the rate of flow through a porous medium is proportional to the head loss and inversely proportional to the length of the flow path.

$$V = K\frac{\Delta h}{\Delta l} \tag{3.1}$$

or, in differential form

$$V = K\frac{dh}{dl} \qquad (3.2)$$

where

V=Q/A, which is the specific discharge, also known as the Darcy velocity or Darcy flux (Length/Time),

Q : volume rate of flow( length /Time)

A : area of cross section normal to the flow direction ( Length$^2$)

$\Delta h = h_2 - h_1$, which is the head loss

$h_1$ & $h_2$ : are the hydraulic heads measured at points 1 and 2 ( length)

$\Delta l$ : the distance between points 1 and 2 ( length)

$\frac{dh}{dl} = i$, which is hydraulic gradient (dimensionless)

K : hydraulic conductivity a constant ( Length/Time)

Alternatively, Darcy's law can be written as

$$Q = K\frac{dh}{dl}A \qquad (3.3)$$

In case of anisotropic medium, the velocity components in a rectangular coordinate system may be given by

$$V_X = -K_X \frac{dh}{dx} \qquad (3.4)$$

$$V_Y = -K_Y \frac{dh}{dx} \qquad (3.5)$$

$$V_Z = -K_Z \frac{dh}{dx} \qquad (3.6)$$

### 3.2.3 Equations Governing Groundwater Flow

Ground water satisfies the Equation of continuity. It expresses the principle of conservation of matter, i.e. the net inward flux through an elemental volume of an aquifer in the flow field must equal the rate at which matter is accumulating within the element (De Wiest, 1965). The continuity Equation, in its general form may be expressed as

$$\frac{d(\rho V_X)}{dX}+\frac{d(\rho V_Y)}{dY}+\frac{d(\rho V_Z)}{dZ}=\rho S_s\frac{dh}{dt} \tag{3.7}$$

Where $S_s$ are the specific storage of the aquifer and is defined as the volume of the water which a unit volume of aquifer releases from storage because of expansion of water and compression of aquifer under a unit decline in head. ρ is the density of the fluid.

Expressing the velocity components in terms of hydraulic gradients from Darcy's law and simplifying Equation (3.7) becomes

$$\frac{d^2h}{dX^2}+\frac{d^2h}{dY^2}+\frac{d^2h}{dZ^2}=\frac{S_S}{K}\frac{dh}{dt} \tag{3.8}$$

In the special case of a confined aquifer of thickness D the storage coefficient $S= S_SD$ and the transmissivity T of the aquifer, T=KD may be introduced, so Equation (3.8) becomes

$$\frac{d^2h}{dX^2}+\frac{d^2h}{dY^2}+\frac{d^2h}{dZ^2}=\frac{S}{T}\frac{dh}{dt} \tag{3.9}$$

Under steady-state flow condition the velocity and the pressure distribution do not change with time and Equation (3.9) reduces to:

$$\frac{d^2h}{dX^2}+\frac{d^2h}{dY^2}+\frac{d^2h}{dZ^2}=0 \tag{3.10}$$

This is known as Laplace's Equation which governs the steady-state flow of ground water in a homogeneous and isotropic aquifer. The solution of the above Equation is a function h(x,y,z) that describes the value of the hydraulic head h at any point in a three dimensional flow field.

## 3.3 Evaluation of Aquifer Properties Using Pumping Test

The evaluation of aquifer characteristics through analysis of pumping test data has become a standard procedure in the evaluation of ground water resources potential. The principle of pumping test is that if the water from a well is pumped, the discharge and the drawdown is measured at a known distance from the well, these measurements can be substituted into an appropriate well-flow Equation, the hydraulic characteristics of the aquifer can be calculated.

The assumptions underlying all methods can be generalized as follows:

- The aquifer is infinite in areal extent
- The aquifer is homogeneous, isotropic and of uniform thickness over the area influenced by the pumping test.
- Prior to pumping, the piezometric surface and /or phreatic surface are nearly horizontal over the area influenced by the pumping test.
- The aquifer is pumped at a constant discharge rate.
- The pumped well penetrates the entire aquifer thickness and thus receives water from the entire thickness of the aquifer by horizontal flow.

### 3.3.1 Theis Type Curve Analysis

Theis (1935) was the first to develop a non steady state formula which introduces the time factor and the storage coefficient.

The non steady-state or Theis Equation which was derived from the analogy between the flow of groundwater and the conduction of heat, may be written as

$$s = \frac{Q}{4\pi KD}\int_u^\alpha \frac{e^{-y}}{y}dy = \frac{Q}{4\pi KD}W(u) \tag{3.11}$$

where,

$u = r^2S/4KDt$ and consequently $S = 4KDtu/r^2$

s: Drawdown in meter measured in a piezometer at a distance r meters from the pumped well.

Q : The constant well discharge in $m^3$/day

S : The dimensionless co-efficient of storage.

KD(T) : The Transmissivity of the aquifer in $m^2$ /day

K: hydraulic conductivity

D: Thickness of the aquifer.

t : The time in days since pumping started.

The exponential integral is written symbolically as W(u), which is generally read "well function"of u or Theis well function and is given as :

$$W(u) = -0.5772 - \ln u + u - \frac{u^2}{2.2!} + \frac{u^2}{3.3!}\text{.......} \qquad (3.12)$$

The following additional assumptions, and limiting conditions should be satisfied for Theis method ( Kruseman and Deridder,1972).

- The flow to the well is in unsteady state, i.e the draw down differences with time are not negligible nor is the hydraulic gradient constant with time.
- The water removed from storage is discharged instantaneously with decline of head.
- The diameter of the pumped well is very small, i.e. the storage in the well can be neglected.

Although the aquifer is assumed to be of uniform thickness, this condition is not met if the drawdown is large compared with the aquifer's original saturated thickness, A corrected value for the observed drawdown is then has to be applied. Jacob (1946) proposed the following correction for unconfined condition.

$$s' = s - (s^2/2D) \qquad (3.13)$$

where

s' = corrected drawdown

s = observed drawdown

D = original saturated aquifer thickness

### 3.3.2 Cooper -Jacob Method

Jacob's straight line method (Cooper and Jacob, 1946) is based on Theis's Equation. Jacob has shown that for small value of u ( $u \leq 0.01$) i.e when r is small and t is large, the Equation (3.11) can be simplified and expressed as,

$$s = \frac{2.30Q}{4\pi T} \log \frac{2.25Tt}{r^2 S} \qquad (3.14)$$

Because Q,KD,and S are constant,if we use drawdown observations at a short distance r from the well, a plot of drawdown s versus the logarithm of t forms a straight line. If this straight line is extended until it intercepts the time-axis where s=0, the interception point has the coordinates s=0 and $t=t_o$.

Substituting these values into Equation (3.14) gives

$$0 = \frac{2.3Q}{4\pi T} \log \frac{2.25Tt_0}{r^2 S}$$

and because $\frac{2.3Q}{4\pi T} \neq 0$, it follows that $\frac{2.25Tt_0}{r^2 S} = 1$

$$S = \frac{2.25Tt_0}{r^2} \qquad (3.15)$$

The slope of the straight line i.e the drawdown difference Δs per log cycle of time $\log t/t_0=1$,is equal to $2.30Q/4\pi T$. Hence

$$T = \frac{2.3Q}{4\pi \Delta s} \qquad (3.16)$$

Similarly, it can be shown that, for a fixed time t, a plot of s versus r on semi-log paper forms a straight line and the following Equations can be derived

$$T = \frac{2.3Q}{2\pi \Delta s} \qquad (3.17)$$

$$S = \frac{2.25Tt}{r_{20}^2} \qquad (3.18)$$

where,

$r_0$ : the distance intercept in metres corresponding to interception of straight line with zero drawdown axis

$\Delta s$ : slope of the straight line

For use of Jacob's methods, the following assumptions and limiting conditions need to be satisfied in addition to the Theis conditions

- The values of u are small ($u \leq 0.01$) i.e r is small and t is large.

### 3.3.3 Boulton's Method

Boulton (1954, 1963, and 1964) derived an Equation considering delayed yield from the storage and prepared delayed yield type curves method for the analysis of time-drawdown data. The applicability of the method depends upon the following assumptions:

- The unconfined aquifer is infinite in extent.
- The aquifer is homogeneous, isotropic and of uniform thickness over the area influenced by the pumping test.
- Before pumping, water table is nearly horizontal.
- The pumped well should be fully penetrated and flow towards the well is horizontal.
- The aquifer is unconfined and shows delayed yield nature.
- The flow to the well is in unsteady state.

The storage in the well can be neglected and assumes that effective storativity of an unconfined aquifer is:

$$S_A + S_Y = NS_A \quad (3.19)$$

Or

$$N = 1 + S_Y/S_A \quad (3.20)$$

where, N : a factor

$S_A$ : Storativity

$S_Y$ : Specific yield

The general flow Equation for an unconfined aquifer with delayed yield, in analogy to the Theis Equation is expressed as:

$$s = \frac{Q}{4\pi T} W(U_A, U_Y, r/\mathrm{B}) \qquad (3.21)$$

$W(U_A, U_Y, r/B)$ : Well function of Boulton for the first segment of time drawdown curve,

The above Equation(3.21) reduces to;

$$s = \frac{Q}{4\pi T} W(U_A, r/B) \qquad (3.22)$$

where, $U_A$= r2S/4Tt

Similarly, for the last segment the Equation( 3.21) becomes:

$$s = \frac{Q}{4\pi T} W(U_Y, r/B) \qquad (3.23)$$

r : distance of observation well from the pumped well.

The formulae are valid when N tends to α.. In effect, it may imply that Boulton's method is not applicable when N < 100; however, in practice it may be applied when 30≤N<100 which leads to a nearly horizontal second segment.

$$B = DrainageFactor = \sqrt{T} / \alpha S_Y \qquad (3.24)$$

1/α is called Boulton's delayed index(T).

### 3.3.4 Neuman's Curve Fitting Method

Neuman, (1972) developed a theory of delayed water table response which is based on well-defined physical parameters of the unconfined aquifer. Neuman treats the aquifer as a compressible system and the water table as a moving material boundary. He recognizes the existence of vertical flow components and his general solution of the draw down is a function of both the distance from the well r and the elevation head. When considering an average drawdown, he is able to reduce his general solution to one that is a function of r alone. Mathematically, Neuman simulated the delayed water table response by treating the elastic storativity $S_A$ and the specific yield $S_Y$ as constants.

Neuman's drawdown Equation (Neuman, 1975) reads

$$S = \frac{Q}{4\pi KD} W(U_A, U_B, \beta) \tag{3.25}$$

Under early-time conditions, this Equation describes the first segment of the time-drawdown curve Equation (3.25) reduces to

$$S = \frac{Q}{4\pi KD} W(U_A, \beta) \tag{3.26}$$

where

$$U_A = \frac{r^2 S_A}{4KDt} \tag{3.27}$$

$S_A$ = Volume of water instantaneously released from storage per unit surface area per unit decline in head (= elastic early-time storativity).Under late time conditions, Equation (3.25) describes the third segment of the time-draw-down curve and reduces to

$$S = \frac{Q}{4\pi KD} W(U_B, \beta) \tag{3.28}$$

where

$$U_B = \frac{r^2 S_Y}{4KDt} \tag{3.29}$$

$S_Y$ = Volume of water released from storage per unit surface area per unit decline of water table i.e .released by dewatering of the aquifer ( = specific yield).

Neuman's parameters β is defined as

$$\beta = \frac{r^2 K_V}{D^2 K_h} \tag{3.30}$$

where

$K_V$ = hydraulic conductivity for vertical flow, in m/d

$K_h$ = hydraulic conductivity for horizontal flow, in m/d

For isotropic aquifers, $K_V = K_h$, and $\beta = r^2/D^2$

Neuman's curve-fitting method can be used if the following assumptions and conditions are satisfied:

- The assumptions listed in Section 3.3;
- The aquifer is isotropic or anisotropic;
- The flow to the well is in an unsteady state;
- The influence of the unsaturated zone upon the drawdown in the aquifer is negligible;
- $S_Y/S_A>10$;
- An observation well screened over its entire length penetrates the full thickness of the aquifer;
- The diameters of the pumped and observation wells are small, i.e. storage in them can be neglected.

## 3.4. Analysis of Field Pumping Test Data

For the present work twenty three wells were selected in the Interfluve parts of Ganga-Yamuna rivers of North India whose locations are shown in Figure 3.1. The data of pumping tests for each of the twenty three locations (as available from U.P state Ground water Department, Roorkee and Central Ground water Board, Chandigarh) were analyzed. The results of aquifer transmissivity and specific yield/storage coefficient computed from analysis of pumping tests analysis by using different methods are given in Table 3.1-3.21. As the original pumping test data of Roorkee, Gudam and Fatehpur were not available, so aquifer parameters reported by other workers were utilized (Table3.1). The pumping test data for pumping well of Ismailpur, Ganeshpur and Jwalapur were available (without observation well data), hence only transmissivity and horizontal hydraulic conductivity were calculated. In these computations aquifer parameter are estimated using different method described in this chapter and finally average value is assigned for each site as the parameter for that site. The time drawdown data of the pump test well is given in Appendix-1.

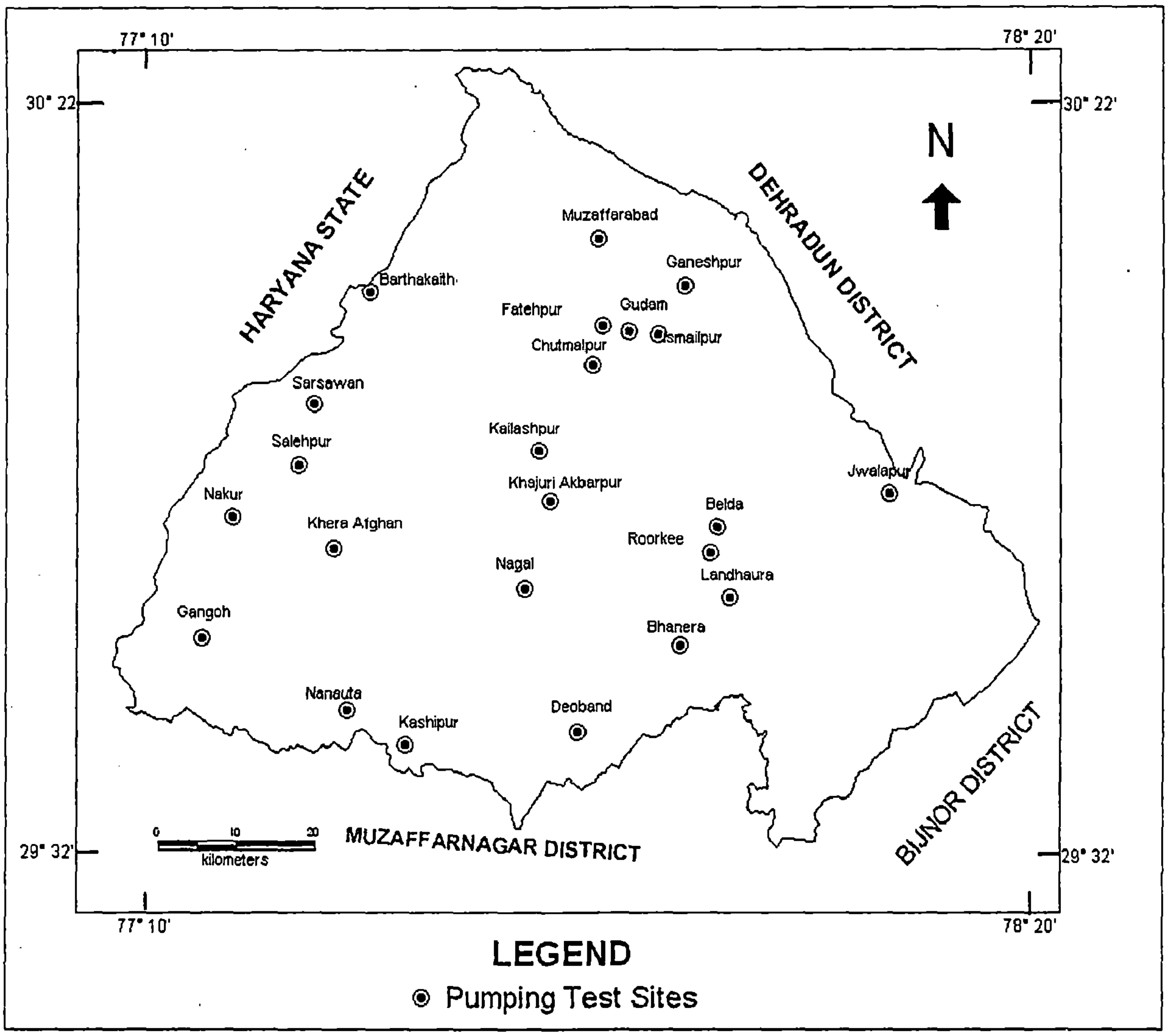



Figure 3.1 Map showing pumping test sites.

## TABLE-3.1 Aquifer Characteristics of Roorkee,Gudam & Fatehpur Sites

| Hydraulic Parameters | SITES | | |
|---|---|---|---|
| | Roorkee | Gudam | Fatehpur |
| T($m^2$/day) | 1850.00 | 920.00 | 1340.41 |
| $K_h$(m/day) | 26.43 | - | 15.23 |

**TABLE 3.2 Aquifer Characteristics of Nakur Site**

| Employed Method- Theis* | | | | | |
|---|---|---|---|---|---|
| | Hydraulic Parameters | | | | |
| | $T (m^2/day)$ | | $K_h (m/day)$ | $S_A$ | $S_Y$ |
| Observation Well-1 | 1929.39 | | 77.17 | 0.12 | |
| Observation Well-2 | 1780.97 | | 71.23 | 0.13 | |
| Observation Well-3 | 1929.39 | | 77.17 | 0.12 | |
| **Employed Method- Boulton's** | | | | | |
| | Hydraulic Parameters | | | | |
| | $T (m^2/day)$ | | $K_h (m/day)$ | $S_A$ | $S_Y$ |
| Observation Well-1 | 1514.89 | | 60.59 | $1.0557 \times 10^{-3}$ | 0.1612 |
| Observation Well-2 | 1223.54 | | 48.94 | $1.1097 \times 10^{-3}$ | 0.1563 |
| Observation Well-3 | 1134.00 | | 45.36 | $1.2857 \times 10^{-3}$ | 0.1667 |
| **Employed Method- Neuman's** | | | | | |
| | Hydraulic Parameters | | | | |
| | $T (m^2/day)$ | $K_h (m/day)$ | $K_V (m/day)$ | $S_A$ | $S_Y$ |
| Observation Well-1 | 1478.89 | 59.15 | 2.8876 | $1.0257 \times 10^{-3}$ | 0.1612 |
| Observation Well-2 | 1354.26 | 54.17 | 2.93 | $1.1557 \times 10^{-3}$ | 0.1557 |
| Observation Well-3 | 1450.91 | 58.03 | 2.77 | $1.2557 \times 10^{-3}$ | 0.1425 |

| | | |
|---|---|---|
| **Average Transmissivity** | : | **$1532.29 m^2/day$** |
| **Average Horizontal Hydraulic conductivity** | : | **61.29m/day** |
| **Average Vertical Hydraulic conductivity** | : | **2.87m/day** |
| **Average Storage co-efficient** | : | **$1.1315 \times 10^{-3}$** |
| **Average Specific yield** | : | **0.1568** |

* These methods were applied to find characteristics of unconfined aquifers after applying Jacob (1946) correction to Theis & Cooper Jacob Equations

## TABLE 3.3 Aquifer Characteristics of Gangoh Site

| Employed Method- Theis * | | | | |
|---|---|---|---|---|
| | Hydraulic Parameters | | | |
| | $T (m^2/day)$ | $K_h (m/day)$ | $S_A$ | $S_Y$ |
| Observation Well-1 | 630.94 | 27.43 | $4.1557 \times 10^{-4}$ | |
| Observation Well-2 | 585.13 | 25.44 | $3.57 \times 10^{-4}$ | |
| Observation Well-3 | 577.25 | 25.09 | $4.16 \times 10^{-4}$ | |
| **Employed Method- Cooper-Jacob*** | | | | |
| | Hydraulic Parameters | | | |
| | $T (m^2/day)$ | $K_h (m/day)$ | $S_A$ | $S_Y$ |
| Observation Well-1 | 599.30 | 26.05 | 0.001 | - |
| Observation Well-2 | 575.32 | 25.01 | 0.006 | - |
| Observation Well-3 | 625.35 | 27.18 | 0.0022 | - |
| **Employed Method- Boulton's** | | | | |
| | Hydraulic Parameters | | | |
| | $T (m^2/day)$ | $K_h (m/day)$ | $S_A$ | $S_Y$ |
| Observation Well-1 | 588.57 | 25.59 | $4.995 \times 10^{-4}$ | 0.2171 |
| Observation Well-2 | 555.87 | 24.16 | $6.86 \times 10^{-4}$ | 0.2035 |
| Observation Well-3 | 607.49 | 26.41 | $4.966 \times 10^{-4}$ | 0.1432 |

| Employed Method- Neuman's | | | | | |
|---|---|---|---|---|---|
| | Hydraulic Parameters | | | | |
| | $T (m^2/day)$ | $K_h (m/day)$ | $K_V (m/day)$ | $S_A$ | $S_Y$ |
| Observation Well-1 | 601.53 | 26.15 | 1.76 | $4.129 \times 10^{-4}$ | 0.2256 |
| Observation Well-2 | 595.26 | 25.88 | 1.61 | $6.36 \times 10^{-4}$ | 0.145 |
| Observation Well-3 | 593.26 | 25.79 | 1.64 | $4.139 \times 10^{-4}$ | 0.1359 |

**Average Transmissivity : $595.0 m^2/day$**
**Average Horizontal Hydraulic conductivity : 25.87m/day**
**Average Vertical Hydraulic conductivity : 1.667m/day**
**Average Storage co-efficient : $1.1315 \times 10^{-3}$**
**Average Specific yield : 0.1568**

* These methods were applied to find characteristics of unconfined aquifers after applying Jacob (1946) correction to Theis & Cooper Jacob Equations

## TABLE 3.4 Aquifer Characteristics of Nanauta Site

| Employed Method- Theis* | | | | |
|---|---|---|---|---|
| | Hydraulic Parameters | | | |
| | T($m^2$/day) | $K_h$(m/day) | $S_A$ | $S_Y$ |
| Observation Well-1 | 428.09 | 19.72 | 1.4 x $10^{-4}$ | |
| Observation Well-2 | 585.25 | 26.97 | 1.3 x $10^{-4}$ | |

| Employed Method- Boulton's | | | | |
|---|---|---|---|---|
| | Hydraulic Parameters | | | |
| | T($m^2$/day) | $K_h$(m/day) | $S_A$ | $S_Y$ |
| Observation Well-1 | 484.89 | 22.34 | 1. 57 x $10^{-4}$ | 0.1612 |
| Observation Well-2 | 473.54 | 21.82 | 1.47 x $10^{-4}$ | 0.1563 |

| Employed Method- Neuman's | | | | | |
|---|---|---|---|---|---|
| | Hydraulic Parameters | | | | |
| | T($m^2$/day) | $K_h$(m/day) | $K_V$(m/day) | $S_A$ | $S_Y$ |
| Observation Well-1 | 428.09 | 19.72 | 1.32 | 1.89 x $10^{-4}$ | 0.235 |
| Observation Well-2 | 432.68 | 19.93 | 1.36 | 1.256 x$10^{-4}$ | 0.1987 |

**Average Transmissivity : 472.09$m^2$/day**
**Average Horizontal Hydraulic conductivity : 21.76m/day**
**Average Vertical Hydraulic conductivity : 1.34m/day**
**Average Storage co-efficient : 1.1415 x $10^{-3}$**
**Average Specific yield : 0.1689**

* These methods were applied to find characteristics of unconfined aquifers after applying Jacob (1946) correction to Theis & Cooper Jacob Equations

## TABLE 3.5 Aquifer Characteristics of Nagal Site

| Employed Method- Boulton's | | | | |
|---|---|---|---|---|
| | Hydraulic Parameters | | | |
| | $T(m^2/day)$ | $K_h(m/day)$ | $S_A$ | $S_Y$ |
| Observation Well-1 | 601.35 | 30.06 | $1.1x\ 10^{-3}$ | 0.1612 |
| Observation Well-2 | 779.0 | 38.95 | $1.1097\ x\ 10^{-3}$ | 0.1563 |
| Observation Well-3 | 756.49 | 37.82 | $1.2857x\ 10^{-3}$ | 0.1667 |

| Employed Method- Neuman's | | | | | |
|---|---|---|---|---|---|
| | Hydraulic Parameters | | | | |
| | $T(m^2/day)$ | $K_h(m/day)$ | $K_V(m/day)$ | $S_A$ | $S_Y$ |
| Observation Well-1 | 603.91 | 30.19 | 1.791 | - | - |
| Observation Well-2 | 619.93 | 30.99 | 1.762 | - | - |
| Observation Well-3 | 684.26 | 34.21 | 1.766 | - | - |

**Average Transmissivity : $674.16m^2/day$**
**Average Horizontal Hydraulic conductivity : 33.71m/day**
**Average Vertical Hydraulic conductivity : 1.773m/day**
**Average Storage co-efficient : $1.1155x\ 10^{-3}$**
**Average Specific yield : 0.1532**

## TABLE 3.6 Aquifer Characteristics of Khajuri-Akbarpur Site

| Employed Method- Theis* | | | | | |
|---|---|---|---|---|---|
| | Hydraulic Parameters | | | | |
| | $T (m^2/day)$ | $K_h (m/day)$ | | $S_A$ | $S_Y$ |
| Observation Well-1 | 968.23 | 11.00 | | $1.2 \times 10^{-3}$ | |
| Observation Well-2 | 880.69 | 10.00 | | $1.3 \times 10^{-3}$ | |
| Observation Well-3 | 846.23 | 9.61 | | | |
| Observation Well-4 | 850.26 | 9.66 | | $1.2 \times 10^{-3}$ | |
| **Employed Method- Boulton's** | | | | | |
| | Hydraulic Parameters | | | | |
| | $T (m^2/day)$ | $K_h (m/day)$ | | $S_A$ | $S_Y$ |
| Observation Well-1 | 854.6 | 9.71 | | $1.0557 \times 10^{-3}$ | 0.1562 |
| Observation Well-2 | 923.54 | 10.49 | | $1.1097 \times 10^{-3}$ | 0.1653 |
| Observation Well-3 | 889.35 | 10.10 | | $1.3597 \times 10^{-3}$ | 0.1687 |
| Observation Well-4 | 934.00 | 10.61 | | $1.2857 \times 10^{-3}$ | 0.1457 |
| **Employed Method- Neuman's** | | | | | |
| | Hydraulic Parameters | | | | |
| | $T (m^2/day)$ | $K_h (m/day)$ | $K_V (m/day)$ | $S_A$ | $S_Y$ |
| Observation Well-1 | 891.5 | 10.13 | 0.106 | $1.324 \times 10^{-3}$ | 0.165 |
| Observation Well-2 | 905.2 | 10.28 | 0.108 | $1.658 \times 10^{-3}$ | 0.175 |
| Observation Well-3 | 907.2 | 10.30 | 0.109 | $1.897 \times 10^{-3}$ | 0.102 |
| Observation Well-4 | 889.2 | 10.10 | 0.102 | $1.987 \times 10^{-3}$ | 0.158 |

**Average Transmissivity : $895.00 m^2/day$**
**Average Horizontal Hydraulic conductivity : 10.17m/day**
**Average Vertical Hydraulic conductivity : 0.106m/day**
**Average Storage co-efficient : $1.716 \times 10^{-3}$**
**Average Specific yield : 0.1539**

* These methods were applied to find characteristics of unconfined aquifers after applying Jacob (1946) correction to Theis & Cooper Jacob Equations

## TABLE 3.7 Aquifer Characteristics of Kashipur Site

| Employed Method- Theis* | | | | | |
|---|---|---|---|---|---|
| | Hydraulic Parameters | | | | |
| | $T(m^2/day)$ | $K_h(m/day)$ | | $S_A$ | $S_Y$ |
| Observation Well-1 | 1613.82 | 53.79 | | | |
| Observation Well-2 | 1490.97 | 49.69 | | | |
| **Employed Method- Cooper-Jacob*** | | | | | |
| | Hydraulic Parameters | | | | |
| | $T(m^2/day)$ | $K_h(m/day)$ | | $S_A$ | $S_Y$ |
| Observation Well-1 | 1574.55 | 52.48 | | $1.25 \times 10^{-2}$ | 0.1557 |
| Observation Well-2 | 1544.76 | 51.49 | | $1.50 \times 10^{-2}$ | 0.1601 |
| **Employed Method- Boulton's** | | | | | |
| | Hydraulic Parameters | | | | |
| | $T(m^2/day)$ | $K_h(m/day)$ | | $S_A$ | $S_Y$ |
| Observation Well-1 | 1534.89 | 51.16 | | $1.2557 \times 10^{-2}$ | 0.1612 |
| Observation Well-2 | 1423.54 | 47.45 | | $1.2097 \times 10^{-2}$ | 0.1463 |
| **Employed Method- Neuman's** | | | | | |
| | Hydraulic Parameters | | | | |
| | $T(m^2/day)$ | $K_h(m/day)$ | $K_V(m/day)$ | $S_A$ | $S_Y$ |
| Observation Well-1 | 1572.26 | 52.40 | 2.192 | $1.253 \times 10^{-2}$ | 0.1812 |
| Observation Well-2 | 1538.97 | 51.29 | 2.078 | $1.37 \times 10^{-2}$ | 0.1956 |

| | | |
|---|---|---|
| **Average Transmissivity** | : | **$1536.72 m^2/day$** |
| **Average Horizontal Hydraulic conductivity** | : | **51.22m/day** |
| **Average Vertical Hydraulic conductivity** | : | **2.135m/day** |
| **Average Storage co-efficient** | : | **$1.1725 \times 10^{-2}$** |
| **Average Specific yield** | : | **0.1869** |

* These methods were applied to find characteristics of unconfined aquifers after applying Jacob (1946) correction to Theis & Cooper Jacob Equations

## TABLE 3.8 Aquifer Characteristics of Barthakaith Site

| **Employed Method- Theis*** | | | | | |
|---|---|---|---|---|---|
| | Hydraulic Parameters | | | | |
| | $T(m^2/day)$ | $K_h(m/day)$ | | $S_A$ | $S_Y$ |
| Observation Well-1 | 1243.36 | 15.73 | | $2.64 \times 10^{-3}$ | |
| **Employed Method- Cooper-Jacob*** | | | | | |
| | Hydraulic Parameters | | | | |
| | $T(m^2/day)$ | $K_h(m/day)$ | | $S_A$ | $S_Y$ |
| Observation Well-1 | 1260 | 15.94 | | $2.1 \times 10^{-3}$ | - |
| **Employed Method- Neuman's** | | | | | |
| | Hydraulic Parameters | | | | |
| | $T(m^2/day)$ | $K_h(m/day)$ | $K_V(m/day)$ | $S_A$ | $S_Y$ |
| Observation Well-1 | 1217 | 15.40 | 0.589 | $2.253 \times 10^{-3}$ | 0.25 |

| | | |
|---|---|---|
| **Average Transmissivity** | : | **1240.00m²/day** |
| **Average Horizontal Hydraulic conductivity** | : | **15.7m/day** |
| **Average Vertical Hydraulic conductivity** | : | **0.589m/day** |
| **Average Storage co-efficient** | : | **$1.1415 \times 10^{-2}$** |
| **Average Specific yield** | : | **0.1689** |

## TABLE 3.9 Aquifer Characteristics of Salehpur Site

| **Employed Method- Cooper-Jacob*** | | | | | |
|---|---|---|---|---|---|
| | Hydraulic Parameters | | | | |
| | $T(m^2/day)$ | $K_h(m/day)$ | | $S_A$ | $S_Y$ |
| Observation Well-1 | 1048.23 | 10.69 | | $6.2 \times 10^{-4}$ | - |
| Observation Well-2 | 995.65 | 10.15 | | $6.36 \times 10^{-4}$ | - |
| **Employed Method- Neuman's** | | | | | |
| | Hydraulic Parameters | | | | |
| | $T(m^2/day)$ | $K_h(m/day)$ | $K_V(m/day)$ | $S_A$ | $S_Y$ |
| Observation Well-1 | 1041.4 | 10.62 | 0.1159 | $5.1 \times 10^{-4}$ | - |
| Observation Well-2 | 1114.0 | 11.36 | 0.1157 | $5.2 \times 10^{-4}$ | - |

| | | |
|---|---|---|
| **Average Transmissivity** | : | **1050.00m²/day** |
| **Average Horizontal Hydraulic conductivity** | : | **10.71m/day** |
| **Average Vertical Hydraulic conductivity** | : | **0.1158m/day** |
| **Average Storage co-efficient** | : | **$5.30 \times 10^{-4}$** |
| **Average Specific yield** | : | **-** |

* These methods were applied to find characteristics of unconfined aquifers after applying Jacob (1946) correction to Theis & Cooper Jacob Equations

## TABLE 3.10 Aquifer Characteristics of Khera Afghan Site

| Employed Method- Theis* | | | | | |
|---|---|---|---|---|---|
| | Hydraulic Parameters | | | | |
| | $T(m^2/day)$ | $K_h(m/day)$ | | $S_A$ | $S_Y$ |
| Observation Well-1 | 2620.00 | 25.68 | | $2.45 \times 10^{-3}$ | |
| Observation Well-2 | 2425.35 | 23.77 | | $1.9 \times 10^{-3}$ | |
| **Employed Method- Cooper-Jacob*** | | | | | |
| | Hydraulic Parameters | | | | |
| | $T(m^2/day)$ | $K_h(m/day)$ | | $S_A$ | $S_Y$ |
| Observation Well-1 | 2636.23 | 25.74 | | $1.9 \times 10^{-3}$ | |
| Observation Well-2 | 2300.35 | 22.55 | | $2.56 \times 10^{-3}$ | |
| **Employed Method- Neuman's** | | | | | |
| | Hydraulic Parameters | | | | |
| | $T(m^2/day)$ | $K_h(m/day)$ | $K_V(m/day)$ | $S_A$ | $S_Y$ |
| Observation Well-1 | 2125.3 | 20.83 | 0.381 | $2.89 \times 10^{-3}$ | 0.28 |
| Observation Well-2 | 2414.0 | 23.66 | 0.352 | $2.23 \times 10^{-3}$ | 0.29 |

**Average Transmissivity : 2420.00$m^2$/day**
**Average Horizontal Hydraulic conductivity : 23.63m/day**
**Average Vertical Hydraulic conductivity : 0.359m/day**
**Average Storage co-efficient : 2. 45 x $10^{-3}$**
**Average Specific yield : 0.285**

* These methods were applied to find characteristics of unconfined aquifers after applying Jacob (1946) correction to Theis & Cooper Jacob Equations

## TABLE 3.11 Aquifer Characteristics of Sarsawan Site

| **Boulton's Method** | | | | |
|---|---|---|---|---|
| | Hydraulic Parameters | | | |
| | T($m^2$/day) | $K_h$(m/day) | $S_A$ | $S_Y$ |
| Observation Well-1 | 1200.82 | - | 1.14 x $10^{-3}$ | 0.15 |
| Observation Well-2 | 1876.09 | - | 1.36 x $10^{-3}$ | 0.08 |

| **Employed Method- Neuman's** | | | | | |
|---|---|---|---|---|---|
| | Hydraulic Parameters | | | | |
| | T($m^2$/day) | $K_h$(m/day) | $K_V$(m/day) | $S_A$ | $S_Y$ |
| Observation Well-1 | 1538.44 | - | - | 2.49 x $10^{-3}$ | 0.23 |
| Observation Well-2 | 1310.61 | - | - | 1.05 x$10^{-3}$ | 0.13 |

**Average Transmissivity : 1481.49$m^2$/day**
**Average Horizontal Hydraulic conductivity : -**
**Average Vertical Hydraulic conductivity : -**
**Average Storage co-efficient : 1.51 x $10^{-3}$**
**Average Specific yield : 0.14**

## TABLE 3.12 Aquifer Characteristics of Landhaura Site

| **Employed Method- Neuman's** | | | | | |
|---|---|---|---|---|---|
| | Hydraulic Parameters | | | | |
| | T($m^2$/day) | $K_h$(m/day) | $K_V$(m/day) | $S_A$ | $S_Y$ |
| Observation Well-1 | 1314.0 | 42.38 | 0.89 | 5.23 x$10^{-3}$ | 3.29 |

| **Employed Method- Boulton's** | | | | |
|---|---|---|---|---|
| | Hydraulic Parameters | | | |
| | T($m^2$/day) | $K_h$(m/day) | $S_A$ | $S_Y$ |
| Observation Well-1 | 1389.30 | 44.81 | 6.24 x $10^{-3}$ | 4.04 |

**Average Transmissivity : 1335.00$m^2$/day**
**Average Horizontal Hydraulic conductivity : 43.06m/day**
**Average Vertical Hydraulic conductivity : 0.89m/day**
**Average Storage co-efficient : 5.51 x $10^{-3}$**
**Average Specific yield : 0.37**

## TABLE 3.13 Aquifer Characteristics of Kailashpur Site

| **Employed Method -Boulton's Method** | | | | |
|---|---|---|---|---|
| | Hydraulic Parameters | | | |
| | T(m²/day) | $K_h$(m/day) | $S_A$ | $S_Y$ |
| Observation Well-1 | 2169.35 | - | 5.26 x$10^{-3}$ | 0.19 |
| Observation Well-2 | 1452.36 | - | 2.34 x$10^{-3}$ | 0.23 |
| Observation Well-3 | 1842.61 | - | 2.24 x$10^{-3}$ | 0.25 |
| Observation Well-4 | 1976.09 | - | 2.41 x$10^{-3}$ | 0.23 |

| **Employed Method- Neuman's** | | | | | |
|---|---|---|---|---|---|
| | Hydraulic Parameters | | | | |
| | T($m^2$/day) | $K_h$(m/day) | $K_V$(m/day) | $S_A$ | $S_Y$ |
| Observation Well-1 | 1551.95 | - | - | 6.76 x$10^{-3}$ | 0.11 |
| Observation Well-2 | 2326.84 | - | - | 2.14 x$10^{-3}$ | 0.13 |
| Observation Well-3 | 1704.10 | - | - | 2.16 x$10^{-3}$ | 0.15 |
| Observation Well-4 | 1975.21 | - | - | 2.03 x$10^{-3}$ | 0.13 |

**Average Transmissivity : 1874.81$m^2$/day**
**Average Horizontal Hydraulic conductivity : -**
**Average Vertical Hydraulic conductivity : -**
**Average Storage co-efficient : 2.98 x $10^{-3}$**
**Average Specific yield : 0.17**

## TABLE 3.14 Aquifer Characteristics of Ganeshpur Site

| **Employed Method- Neuman's** | | | | | |
|---|---|---|---|---|---|
| | Hydraulic Parameters | | | | |
| | T($m^2$/day) | $K_h$(m/day) | $K_V$(m/day) | $S_A$ | $S_Y$ |
| Exploratory Well | 562.93 | 15.91 | - | - | - |

| **Employed Method- Cooper-Jacob*** | | | | |
|---|---|---|---|---|
| | Hydraulic Parameters | | | |
| | T($m^2$/day) | $K_h$(m/day) | $S_A$ | $S_Y$ |
| Exploratory Well | 522.27 | 14.77 | - | - |

**Average Transmissivity : 542.60$m^2$/day**
**Average Horizontal Hydraulic conductivity : 15.35 m/day**
**Average Vertical Hydraulic conductivity : -**
**Average Storage co-efficient : -**
**Average Specific yield : -**

* These methods were applied to find characteristics of unconfined aquifers after applying Jacob (1946) correction to Theis & Cooper Jacob Equations

## TABLE 3.15 Aquifer Characteristics of Muzaffarabad Site

| Employed Method -Boulton's Method | | | | |
|---|---|---|---|---|
| | Hydraulic Parameters | | | |
| | T($m^2$/day) | $K_h$(m/day) | $S_A$ | $S_Y$ |
| Observation Well-1 | 81.92 | 8.95 | $8.26 \times 10^{-4}$ | 0.17 |
| Observation Well-2 | 84.10 | 9.19 | $4.34 \times 10^{-4}$ | 0.07 |
| Observation Well-3 | 94.37 | 10.31 | $1.24 \times 10^{-4}$ | 0.05 |
| Observation Well-4 | 109.21 | 11.93 | $3.41 \times 10^{-4}$ | - |

| Employed Method- Neuman's | | | | | |
|---|---|---|---|---|---|
| | Hydraulic Parameters | | | | |
| | T($m^2$/day) | $K_h$(m/day) | $K_V$(m/day) | $S_A$ | $S_Y$ |
| Observation Well-1 | 102.95 | 11.25 | 0.1106 | $8.76 \times 10^{-4}$ | 0.29 |
| Observation Well-2 | 100.6 | 10.99 | 0.1115 | $3.96 \times 10^{-4}$ | 0.01 |
| Observation Well-3 | 104.10 | 11.37 | 0.112 | $9.16 \times 10^{-4}$ | 0.1 |
| Observation Well-4 | 90.37 | 9.87 | 0.1083 | $8.03 \times 10^{-4}$ | - |

**Average Transmissivity : 95.95$m^2$/day**
**Average Horizontal Hydraulic conductivity : 10.49 m/day**
**Average Vertical Hydraulic conductivity : 0.1106m/day**
**Average Storage co-efficient : $6.21 \times 10^{-4}$**
**Average Specific yield : 0.11**

* These methods were applied to find characteristics of unconfined aquifers after applying Jacob (1946) correction to Theis & Cooper Jacob Equations

## TABLE 3.16 Aquifer Characteristics of Bhanera-Tanda Site

| Employed Method -Boulton's Method | | | | |
|---|---|---|---|---|
| | Hydraulic Parameters | | | |
| | T($m^2$/day) | $K_h$(m/day) | $S_A$ | $S_Y$ |
| Observation Well-1 | 880.31 | 44.01 | $1.12 \times 10^{-3}$ | 0.18 |
| Observation Well-2 | 1176.80 | 58.84 | $4.11 \times 10^{-3}$ | 0.22 |

| Employed Method- Neuman's | | | | | |
|---|---|---|---|---|---|
| | Hydraulic Parameters | | | | |
| | T($m^2$/day) | $K_h$(m/day) | $K_V$(m/day) | $S_A$ | $S_Y$ |
| Observation Well-1 | 1012.95 | 50.64 | 1.712 | $1.76 \times 10^{-3}$ | 0.19 |
| Observation Well-2 | 1038.36 | 51.91 | 1.433 | $1.96 \times 10^{-3}$ | 0.21 |

**Average Transmissivity : 1028.56$m^2$/day**
**Average Horizontal Hydraulic conductivity : 51.43 m/day**
**Average Vertical Hydraulic conductivity : 1.585 m/day**
**Average Storage co-efficient : $1.81 \times 10^{-3}$**
**Average Specific yield : 0.21**

## TABLE 3.17 Aquifer Characteristics of Jwalapur Site

| Employed Method- Neuman's | | | | | |
|---|---|---|---|---|---|
| | Hydraulic Parameters | | | | |
| | T($m^2$/day) | $K_h$(m/day) | $K_V$(m/day) | $S_A$ | $S_Y$ |
| Exploratory Well | 1996.3 | 30.46 | - | - | - |

| Employed Method- Cooper-Jacob* | | | | |
|---|---|---|---|---|
| | Hydraulic Parameters | | | |
| | T($m^2$/day) | $K_h$(m/day) | $S_A$ | $S_Y$ |
| Exploratory Well | 1973.7 | 30.11 | - | - |

**Average Transmissivity : 1985.00$m^2$/day**
**Average Horizontal Hydraulic conductivity : 30.29 m/day**
**Average Vertical Hydraulic conductivity : -**
**Average Storage co-efficient : -**
**Average Specific yield : -**

* These methods were applied to find characteristics of unconfined aquifers after applying Jacob (1946) correction to Theis & Cooper Jacob Equations.

## TABLE 3.18 Aquifer Characteristics of Belda Site

| Employed Method- Theis * | | | | |
|---|---|---|---|---|
| | Hydraulic Parameters | | | |
| | $T(m^2/day)$ | $K_h(m/day)$ | $S_A$ | $S_Y$ |
| Observation Well-1 | 559.37 | 16.95 | 0.29 | - |
| Observation Well-2 | 549.35 | 16.64 | 0.17 | - |
| Observation Well-3 | 569.34 | 17.25 | 0.18 | - |

| Employed Method- Boulton's | | | | |
|---|---|---|---|---|
| | Hydraulic Parameters | | | |
| | $T(m^2/day)$ | $K_h(m/day)$ | $S_A$ | $S_Y$ |
| Observation Well-1 | 489.30 | 14.82 | $5.74 \times 10^{-4}$ | - |
| Observation Well-2 | 538.44 | 16.31 | $3.21 \times 10^{-4}$ | - |
| Observation Well-3 | 523.69 | 15.86 | $1.58 \times 10^{-4}$ | - |

| Employed Method- Neuman's | | | | | |
|---|---|---|---|---|---|
| | Hydraulic Parameter | | | | |
| | $T(m^2/day)$ | $K_h(m/day)$ | $K_V(m/day)$ | $S_A$ | $S_Y$ |
| Observation Well-1 | 578.89 | 17.54 | 0.196 | $4.02 \times 10^{-4}$ | - |
| Observation Well-2 | 524.26 | 15.88 | 0.198 | $2.15 \times 10^{-4}$ | - |
| Observation Well-3 | 541.60 | 16.41 | 0.195 | $1.95 \times 10^{-4}$ | - |

**Average Transmissivity : $541.58 m^2/day$**
**Average Horizontal Hydraulic conductivity : 16.41m/day**
**Average Vertical Hydraulic conductivity : 0.196/day**
**Average Storage co-efficient : $2.75 \times 10^{-4}$**
**Average Specific yield : -**

* These methods were applied to find characteristics of unconfined aquifers after applying Jacob (1946) correction to Theis & Cooper Jacob Equations

## TABLE 3.19 Aquifer Characteristics of Chutmalpur Site

| Employed Method -Boulton's Method | | | | |
|---|---|---|---|---|
| | Hydraulic Parameters | | | |
| | T(m²/day) | $K_h$(m/day) | $S_A$ | $S_Y$ |
| Observation Well-1 | 161.8 | 5.67 | $5.9 \times 10^{-3}$ | 0.10 |
| Observation Well-2 | 159.31 | 5.58 | $4.12 \times 10^{-3}$ | 0.09 |
| Observation Well-3 | 157.80 | 5.53 | $2.11 \times 10^{-3}$ | 0.11 |

| Employed Method- Neuman's | | | | | |
|---|---|---|---|---|---|
| | Hydraulic Parameters | | | | |
| | T(m²/day) | $K_h$(m/day) | $K_V$(m/day) | $S_A$ | $S_Y$ |
| Observation Well-1 | 167.58 | 5.88 | 0.012 | $1.76 \times 10^{-3}$ | 0.19 |
| Observation Well-2 | 138.13 | 4.84 | 0.009 | $1.96 \times 10^{-3}$ | 0.21 |
| Observation Well-3 | 132.51 | 4.64 | 0.021 | $2.16 \times 10^{-3}$ | 0.22 |

| Employed Method- Cooper-Jacob* | | | | |
|---|---|---|---|---|
| | Hydraulic Parameters | | | |
| | T(m²/day) | $K_h$(m/day) | $S_A$ | $S_Y$ |
| Observation Well-1 | 176.33 | 6.18 | $1.89 \times 10^{-3}$ | 0.21 |
| Observation Well-2 | 185.26 | 6.5 | $1.32 \times 10^{-3}$ | 0.02 |
| Observation Well-3 | 182.99 | 6.42 | $1.8 \times 10^{-3}$ | 0.1 |

**Average Transmissivity : 167.58m²/day**
**Average Horizontal Hydraulic conductivity : 5.88m/day**
**Average Vertical Hydraulic conductivity : 0.011 m/day**
**Average Storage co-efficient : $2.55 \times 10^{-3}$**
**Average Specific yield : 0.132**

* These methods were applied to find characteristics of unconfined aquifers after applying Jacob (1946) correction to Theis & Cooper Jacob Equations

## TABLE 3.20 Aquifer Characteristics of Deoband Site

| Employed Method- Neuman's | | | | | |
|---|---|---|---|---|---|
| | Hydraulic Parameters | | | | |
| | T($m^2$/day) | $K_h$(m/day) | $K_V$(m/day) | $S_A$ | $S_Y$ |
| Observation Well-1 | 438.01 | 10.95 | 0.17 | 5.49 x$10^{-3}$ | 0.09 |
| Observation Well-2 | 470.23 | 11.75 | 0.19 | 5.18 x$10^{-3}$ | 0.08 |

| Employed Method- Cooper- Jacob* | | | | |
|---|---|---|---|---|
| | Hydraulic Parameters | | | |
| | T($m^2$/day) | $K_h$(m/day) | $S_A$ | $S_Y$ |
| Observation Well-1 | 421.63 | 10.54 | 4.89 x $10^{-3}$ | 0.07 |
| Observation Well-2 | 436.47 | 10.91 | 5.28 x $10^{-3}$ | 0.07 |

**Average Transmissivity : 439.88$m^2$/day**
**Average Horizontal Hydraulic conductivity : 11.0 m/day**
**Average Vertical Hydraulic conductivity : 0.18 m/day**
**Average Storage co-efficient : 5.21 x $10^{-3}$**
**Average Specific yield : 0.07**

## TABLE 3.21 Aquifer Characteristics of Ismailpur Site

| Employed Method- Neuman's | | | | | |
|---|---|---|---|---|---|
| | Hydraulic Parameters | | | | |
| | T($m^2$/day) | $K_h$(m/day) | $K_V$(m/day) | $S_A$ | $S_Y$ |
| Exploratory Well | 342.93 | 7.4 | - | - | - |

| Employed Method- Cooper-Jacob* | | | | |
|---|---|---|---|---|
| | Hydraulic Parameters | | | |
| | T($m^2$/day) | $K_h$(m/day) | $S_A$ | $S_Y$ |
| Exploratory Well | 333.87 | 7.3 | - | - |

**Average Transmissivity : 338.4$m^2$/day**
**Average Horizontal Hydraulic conductivity : 7.40 m/day**
**Average Vertical Hydraulic conductivity : -**
**Average Storage co-efficient : -**
**Average Specific yield : -**

* These methods were applied to find characteristics of unconfined aquifers after applying Jacob (1946) correction to Theis & Cooper Jacob Equations

# CHAPTER-4

## APPLICATION OF GEOELECTRICAL METHODS

Role of geophysics in ground water investigation is vital to understand the sub-surface conditions accurately and adequately. Since basis of any geophysical application is the contrast between physical properties of the target and the environs, more the contrast in the property or anomaly, better would be the geophysical response and identification. So efficacy of a geophysical technique lies in its ability to sense and resolve hidden subsurface geological and hydrogeological conditions accurately.

Objective of geoelectrical methods is to obtain geological information of the sub-soil, which cannot be gathered otherwise, or only at higher cost. In practice, this means savings on drilling cost.

Success of any geoelectrical method depend on

(a) Degree contrast in resistivity of different rock units.

(b) Correlation of the electrical resistivity with geological / hydrogeological condition of the area

Amongst many geophysical methods, electrical resistivity technique is most commonly used in ground water exploration.

## 4.1 Electrical Resistivity Method

Ground water in the pore spaces of rocks acts as an electrolyte, the flow of electricity in water bearing rocks is mostly affected through the water present in the pores (except for the rocks bearing large concentration of conductive mineral, their conduction depend on mineral contents.) Thus electrical resistivity of rock depends on the quantity and quality of ground water present in the pore apace and the manner in which it is distributed. This dependence of electrical resistivity renders it an effective tool for delineating the wat bearing zones.

Resistivity of a material is defined as the resistance between opposite faces of uni cube of the material. The resistivity in ohm-m may be expressed as $\rho = K\ \Delta V/I$, where K i called the geometric factor. Thus, it is possible to determine the resistivity by measuring th current intensity I (being passed into the ground) and potential difference $\Delta V$ (developed b this current) and by calculating the factor K.

In practice this is accomplished by introducing a known quantity of electric curren into the ground through pair of current electrodes and by measuring potential differenc between another pair of potential electrodes The ratio $\Delta V/I$ is multiplied by Geometri factor K (which depends on the relative electrode spacing) to obtain apparent resistivity. Th apparent resistivity is plotted against half electrode spacing to obtain VES curves. Thes curves are interpreted manually or using computer software to obtain different geoelectrica layers with their true resistivity values and thickness.

If the measurements of resistivity are made over a semi-infinite space homogeneous and isotropic material, then the value of apparent resistivity will be the tr resistivity of that material. However, if the medium is inhomogeneous and (or) anisotrop then the resistivity computed is called an apparent resistivity. The value of apparent resistivi depends on electrode spacing, geometry of electrode array and true resistivity and oth character of the subsurface material such as layer thickness, angle of dip etc. The details the technique have been discussed by several workers (Keller & Frischknechdt, 196 Bhattacharya & Patra, 1968, koefoed 1979).

### 4.1.1 Field Procedure

Two conventional geoelectrical survey techniques are:

- Horizontal electrical profiling, also called constant separation traversing, or trenching.
- Vertical Electrical Sounding (VES).

In horizontal electrical profiling four electrodes configuration at predetermined spacings is moved across the surface, usually along a straight line, to study the lateral variations in a certain, not well defined depth interval. On the other hand Vertical Electrical Sounding (VES) is conducted by progressively increasing the distance between the outer current electrodes. This causes the current to traverse progressively deeper layers whose electrical characteristics contribute to the potential difference observed at the earth surface.

There are numerous electrode arrangements that are practiced in resistivity measurements. The most commonly used electrode arrangements in ground water prospecting are Wenner and Schlumberger.

**Wenner Array :** This configuration was first proposed by Wenner (1916) in which the four electrodes A, M, N and B are placed at the surface of the ground symmetrically along a straight line with equal spacing between them ( Figure 4.1 )

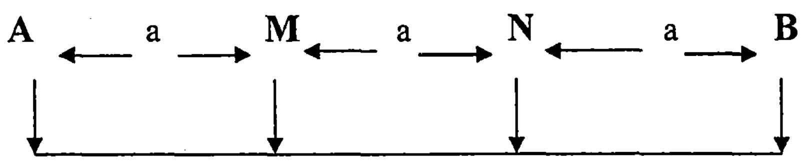



**Figure 4.1. Wenner Electrode array**

The formula of apparent resistivity ( $\rho_a$) for this arrangement is :

$$\rho_a = 2\Pi a ( \Delta V / I) \qquad (4.1)$$

**Schlumberger Array:** Conrad Schlumberger, proposed another collinear electrode arrangement in which the potential electrode M & N are placed as close as possible (Figure

4.2). The schlumberger array is also known as gradient array as potential gradient is measured.

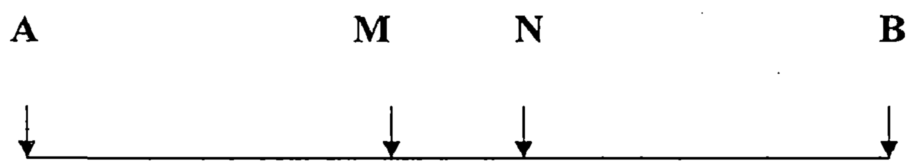



**Figure 4.2. Schlumberger Electrode array**

The apparent resistivity for this configuration is given by :

$$\rho a = \frac{\pi\{(AB/2)^2 - (MN/2)^2}{MN}\frac{\Delta V}{I} \qquad (4.2)$$

Where $\Delta V$ : Potential difference between the two potential electrode

I : Current

AB : Distance between the current electrodes

MN : Distance between the potential electrodes.

In this method of arrangement, the potential electrodes M & N are fixed and only the current electrodes A & B are moved after each measurement. However, M & N are to be shifted when the potential difference is too small to be measured accurately.

### 4.1.2 Interpretation of Resistivity Data

The objective of interpretation of resistivity sounding data is to determine the true resistivity and thickness of different layers based on well defined physical and mathematical rules. These results are subsequently used to obtain a realistic picture of the subsurface within the known geological frame work. The former is referred to as quantitative interpretation, while the latter is known as geological interpretation. The success of geoelectrical methods depends much on both quantitative and the geological interpretation. The quantitative interpretation can be performed by manual or automatic computerized approaches.

### 4.1.2.1 Manual Approach

The quantitative methods are classified as indirect and direct, depending on the manner in which the layer parameters are deduced from field apparent resistivity curves. This starts with the numerical evaluation of Stefanescu's Equation (1930) or some of it's transformed form to give the potential at the surface of earth, the evaluation of which enables the preparation of master curves. In the indirect method of interpretation, the field curve is matched with the standard master curves to obtain layer parameters. However, for the computation of master curves, one has to evaluate the Stefanescu's integral which does not render itself to integration analytically thus posing a basic problem. The success of resistivity interpretation is intimately linked with the successive improvement in the method of efficient numerical integration of Stefanescu's Equation. Kunetz (1966) has given a brief account of various procedures attempted for the solution of the Equation. Zohdy (1965), Keller & Frischknecht (1966), Bhattacharya & Patra (1968), and Koefoed (1979) have elegantly described the techniques used in indirect interpretation.

### 4.1.2.2 Automatic Approach

Numerical evaluation of the Stefanescu's integral has become feasible with the advent of digital computers. Since then a number of methods of automatic resistivity interpretation have appeared in literature, where decision making regarding the adjustment of layer parameters is made by using appropriate software. Koefoed (1979) has given a comprehensive account of various approaches of automatic interpretation of resistivity data. Koefoed has mentioned two streams of automatic iterative interpretation. The interpretation can be done in the apparent resistivity domain (r –domain) or in the resistivity transform domain (λ-domain). In the r-domain interpretation, comparison is made between the observed apparent resistivity and the theoretically computed apparent resistivity data for trial models, where in λ-domain interpretation, first the resistivity transform function is estimated from the observed apparent resistivity function and then a comparison is made between observed and the computed resistivity transform for trial models( Inman et al., 1973; Zohdy et al., 1974; Bichara & Lakshmanan,1976; Johnson,1977; SriNiwas et al.,1982;Zohdy,1989).

## 4.2 INDUCED POLARIZATION METHOD

### 4.2.1 Principle of Induced Polarization

On connecting two grounded current electrodes to a battery, voltage between two points on ground can be detected. If the current is switched off, voltage does not become zero immediately but decays exponentially over a small duration. The residual voltage, also known as over-voltage, is because of induced polarization effect. It is mainly concerned with surface polarization of metallic minerals induced by electric current and redistribution of positive and negative ions in the ground. Process of redistribution of ions can be classified into two groups: Electrode Polarization and Membrane Polarization.

The **Electrode Polarization** occurs when a metallic mineral particle blocks the flow of ions by electrolyte through the pore passage of a rock. Current within the mineral grain is carried by electrons and ionic charges piled up at the particle-electrolyte interface. Positive ions pile up where the current enters the particle and negative ions where it leaves. Pile-up of charges opposes the current flow through the interface and particle is said to be polarized. Additional voltage necessary for the current to flow through the barrier is known as overvoltage. When the current is switched off, charges diffuse back into the electrolyte with time. This type of polarization is detected as a decaying voltage. It is a combined surface (particle- electrolyte interface) effect and therefore, the response is a function of volume of the rock.

The **Membrane Polarization** occurs due to the presence of clay particles partially blocking ionic flow path. Surface of clay particle being negatively charged, attracts free positive ions from electrolyte and a double layer of charge is formed at the surface. Positively charged layer repels other positively charged ions and acts as impeding membrane. On applying electrical potential, positive membrane is disrupted and positive charge carriers easily pass through while negative charge carriers accumulate. When current is switched off, redistribution of ions takes place and is manifested as a decay of voltage between the two electrodes. That is, induced polarization effect is mainly the diffusion of ions. In either case, polarization is a surface effect and therefore greater the surface area of mineral particle or clay, stronger would be the effect. In groundwater exploration membrane polarization is effective and silty or clay mixed sand formation shows maximum polarization.

### 4.2.2 Field Procedure

#### 4.2.2.1 Time Domain

In time domain, a square pulse of current is passed and decaying voltage is measured at preset time intervals during the switch -off period. The output voltage is integrated over an interval and divided by the voltage applied to the current electrodes. The amplitudes and duration of duration of pulses are selected in such a way that decay of voltage is over a second before the reverse pulse is transmitted. The standard cycle time is 8 seconds with each on-off period as 2 seconds. Parameters used to define the polarization or polarizability and chargeability.

***Polarizability***

When measurements are made by passing D.C. pulses of duration T (s) in the ground and $\Delta V$ is the voltage remaining at a definite time t after current cut-off, the magnitude of the observed IP is often expressed as $\Delta V/V$ ( millivolt per volt,$mVV^{-1}$) if $\Delta V$ is measured in milli volts and V, the voltage when the current was on, is measured in volts. Alternatively, the effect is often expressed as percentage (ΔV/V) if both voltages have been measured in volts or mill volts.

***Chargeability***

Sometimes the normalized time integral representing the area under the decay curve between two times $t_1$ and $t_2$ after current cut-off is used to express IP. This measure is known as apparent chargeability denoted by $(M^T_{t1,t2})_a$. Thus,

$$(M^T_{t1,t2})a = (1/V) \int_{t_1}^{t_2} \Delta V_{IP} dt \qquad (4.3)$$

### 4.2.2.2 Frequency Domain

In frequency domain IP, the apparent resistivity is measured at two or more frequencies. The frequency effect is usually defined as

$$f_e = (\rho_{dc} - \rho_{ac}) / \rho_{ac} = \left( \rho_{dc} / \rho_{ac} \right) - 1 \qquad (4.4)$$

while the per cent frequency effect is given by

$$PFE = 100 (\rho_{dc} - \rho_{ac}) / \rho_{ac} \qquad (4.5)$$

where $\rho_{dc}$,$\rho_{ac}$ are apparent resistivities measured at d.c and very high frequency. In practice measurements are made at two or more frequencies and $\rho_{dc}$ being taken as the value obtained at the lowest frequency.

### 4.2.2.3 Relation between Time and Frequency Domain

In theory, since both IP methods measure the same phenomenon; their results ought to be the same. Seigel (1959) defined the relation between time and frequency domain as:

$$M = \frac{f_e}{1+f_e} \tag{4.6}$$

### 4.2.3 Induced Polarization Survey for Ground Water Exploration

Induced polarization survey for ground water exploration is taken up as need based supplementary to resistivity surveys. When it becomes difficult to identify the conductive clay mixed zones, IP measurements help resolve them. In saturated sediments, IP effect is observed only when sands are mixed with some amount of clays. Coarser material show less effect. The effect is prominent in silts. Clean sand will not show any IP effect. A large quantity of clay segregation would show less polarization than the same amount of clay if dispersed. Polarization depends on the type of clay (polarization is more in montmorillonite than kaolinite), depending on ion exchange capacity of clay and salinity of ground water. For fresh water saturated sediments, membrane polarization can also be correlated with hydraulic conductivity. It is also noteworthy that, while the resistivity curve indicates say, four layers, the IP curve may indicate six including clayey zones. This may mean either that a layer in the sequence has the same resistivity through out but different chargeability in its two parts, or that some layer that is suppressed in the resistivity curve, because of small thickness, nevertheless shows up in IP. What is of interest to note that a combination of the two types of measurements leads to a greater resolution than one type alone.

## 4.3 Geoelectrical Investigations in Ganga-Yamuna Interfluve

Geo-electrical field studies were carried out in parts of Ganga-Yamuna interfluve. Vertical Electrical Soundings (VES) were conducted with the help of DC resistivity meter (ABEM SAS 300B & SAS1000) (IP & Resistivity) at selected sites as shown in Figure 4.3. Out of 46 numbers of resistivity soundings, data of 23 (which match closely with the litholog of the pump tested well) were actually taken into consideration. At 7 sites soundings were conducted in perpendicular orientation. At 4 locations the data could not be interpreted. At 3 locations RMS fitting error is calculated to be high and were neglected. Data of six sites could not be used due to non availability of pumping test data at these sites. Eleven numbers of time domain Induced Polarization (IP) soundings were also conducted which were used for interpretation and modification of layer parameters deduced from VES data. One horizontal profiling using Wenner array was conducted to demarcate Bhabhar and Tarrai belts.

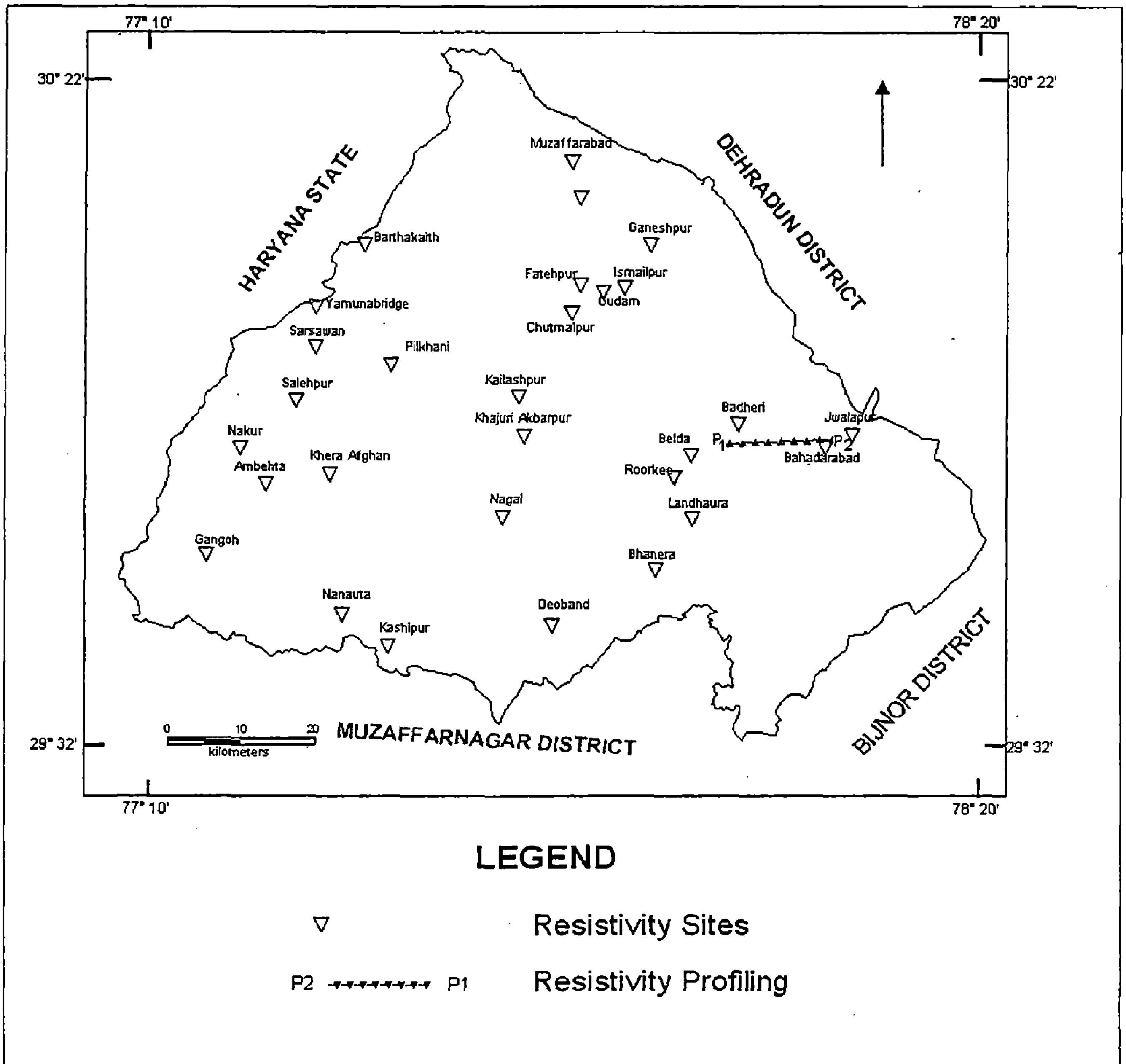



**Figure 4.3 Map showing Vertical Electrical Sounding sites**

### 4.3.1 Interpretation of Resistivity & I.P Sounding Data

Preliminary quantitative interpretation of Vertical Electrical Sounding (VES) curves was attempted to interpret in terms of true resistivity and thickness manually by conventional curve matching technique using master curves and its auxiliary charts given by Orellana and Moony (1966). The results were then modified by using **IX1D Interprex software (Version 2.1).** In case the computed curve did not match with the field curve, the layer parameters were modified. Again, the theoretical curve was computed with modified layer parameters and compared with the field curve. At first the resistivity module of the software is used, and then the interpreted model is taken into account along with the I.P data to identify the conductive clay mixed zones i.e. to separate the unidentified layer if any present in case of resistivity. Again the resistivity module is used to further improve the model, so as to match with the known lithology. The process was repeated till a good match was obtained. During the process, the available lithological information was introduced to arrive at a realistic model.

**IX1D** software first carries out Automatic estimation of a layered model using field data and then the apparent resistivity calculated by manual approach is used to calculate the synthetic curve to minimize the error.

The curve is then analyzed to determine the number of layers present and the resistivity and thicknesses in the model. Then forward modeling is used to calculate the synthetic curve from the estimated model for comparison with the original data.

For Schlumberger data, the offsets between different segments is not removed from the data, but is instead introduced into the synthetics. These offsets occur for overlapping segments where several data points are taken with the same AB/2 values but different MN values. The offsets can be partially due to phenomena related to layered media responses but are in many cases more likely caused by variations in the electrical properties of the ground in the near surface where the potential electrodes are planted.

The RMS fitting error is calculated as :

$$\text{RMSE}=\sqrt{\frac{(\rho_o-\rho_c)^2}{n}}\,.100 \qquad (4.7)$$

Where $\rho_0$ and $\rho_c$ are observed and calculated resistivity.

n is the number of data points.

RMS difference of 5% to 6% was allowed.

Masked points are not used in the calculation of the fitting error. The fitting error is displayed on the window status bar as a percent error. Similar logic is followed in case of Induced polarization.

The interpreted geoelectrical data of the area was compared with the lithology of nearby wells and tube wells to fix the range of resistivity for sandy aquifer material, as under (Table-4.1):

**Table 4.1 Resistivity Characteristics of Litho-Units**

| Lithology | Range of Resistivity |
|---|---|
| Clay (or clay mixed with silt/sand) | < 20 Ω-m |
| Fine and Coarse Sand | 20-150 Ω-m |
| Pebble/Gravel/Boulder | >150 Ω-m |

The layer thicknesses and true resistivity, as interpreted from resistivity sounding data are presented in the Table-4.2 A- Table 4.2G.

### 4.3.2 Geological Interpretation of Resistivity Data

The objective here is to compare the characteristic resistivity ranges indicated above for different geological formations of the area. This is achieved by comparing geo-electric data with the litho logs of nearby wells or tube wells.

**Gangoh** : The resistivity curve is K Type( Figure 4.4 ). The water level of the nearby well recorded 13.25m.bgl. The top zone extends up to a depth of 11.08 m of resistivity 93.06 Ω-m inferring presence of dry coarse sand. The second layer of resistivity 981.75 Ω-m indicates presence of local boulder of thickness 3.79m. The third layer has resistivity of **83.48 Ω-m** indicating very coarse sand( as revealed from lithology) having thickness **22.13m** which is the **aquifer zone** which has been tapped for pumping test. The aquifer zone tapped is underlained by two layers of coarse and medium sand having resistivity of 73.65 Ω-m and 63.79 Ω-m respectively with thickness 10m each. Beyond this there exists a layer consisting of finer sediments having resistivity of 34.61Ω-m. The interpreted results are given in Table 4.2A.

**Nagal:** The apparent resistivity curve at this site is of AKH type (Figure 4.5). The top soil has a thickness of 2.42m. This is followed by a thin layer of coarser sediment (thickness 1.41m) having resistivity 59.3 Ω-m is followed by dry sand having resistivity 73.54 Ω-m (thickness 14.7 m) which is confirmed by the water level of the nearby well (at 13.7 m. bgl). The fourth layer of coarse sand is having resistivity of **73.54 Ω-m** and thickness **18.16m** which is the **aquifer zone** which has been tapped for pumping test. The aquifer zone tapped is followed by layer of high resistivity 165.35 Ω-m and thickness 23.83m which may inferred as pebble. The interpreted results of the sounding are given in Table 4.2 A.

**Nanauta** : The apparent resistivity curve at this site is of HKH type (Figure 4.6 ) indicating a five layered sequence. The top soil consists of two thin layers of resistivity 110

& 14.84 Ω-m having thickness 0.82 & 0.184 m respectively. The water level of the nearby well was recorded at 1.5m.bgl. The third layer has resistivity of **55.2 Ω-m** indicating medium grained sand (as revealed from lithology) having thickness of **22.7m** which is the **aquifer zone** tapped for pumping test. The aquifer zone tapped is followed by a thick layer of low resistivity 31.62 Ω-m and thickness 31.6m which may be inferred as clayey sand which is underlain by a layer having resistivity of 43.65 Ω-m. The interpreted results are given in Table 4.2 A.

**Nakur :** The apparent resistivity curve at this site is of KQH type ( Figure 4.7 ) indicating a five layered sequence. The top soil consists of thin layer of resistivity 56.97 Ω-m having thickness 1.65 m, followed by dry sand of resistivity 278.0 Ω-m (thickness 10.16m) which is confirmed by the water level of the nearby well which recorded to be 13.00m. bgl. The third layer is of coarse sand of resistivity **152.7 Ω-m** and thickness **20.9m** which is the **aquifer zone** tapped for pumping test. The aquifer zone tapped is followed by .layer having resistivity of 20.89 Ω-m and thickness 19.11m which may infer as clay. The resistivity of the last layer is interpreted to be 64.86 Ω-m. The interpreted results of the sounding are given in Table 4.2 A.

**Khajuri-Akbarpur :** The apparent resistivity curve at this site is of KQAA type ( Figure 4.8 ) indicating a six layered sequence. The top soil consists of layer of resistivity 68.03 Ω-m having thickness 6.10 m. The second layer has resistivity of 317.7 Ω-m and inferred as dry sand upto a depth of 9.91m.The water level of the nearby well recorded 11.85m.bgl. The third layer has resistivity of **70.99 Ω-m** indicating coarse grained sand( as revealed from litholog) having thickness **86.41m** which is the **aquifer zone** which has been tapped for pumping test. The aquifer zone tapped is followed by layer of low resistivity 12.40 Ω-m and thickness 85.21m which may inferred clay which is underlained by another clay layer having resistivity of 16.53 Ω-m.of thickness 24.98m. The resistivity of the last layer is interpreted as58.29 Ω-m. The interpreted results of sounding are given in Table 4.2 B.

**Fatehpur :** The apparent resistivity curve at this site is of HKQQH type (Figure 4.9 ) indicating a seven layered sequence. The top soil consists of two thin layers of resistivities 80.73 & 11.41 Ω-m having thickness 0.92 & 1.01 m respectively. The water level of the nearby well was recorded at 2.5m.bgl. The third layer has resistivity of 180.46 Ω-m and inferred as dry sand upto a depth of 3.78m The fourth and fifth layer having resistivity of **80.46 Ω-m** indicating coarse grained sand **and 49.77 Ω-m** indicating medium grained sand( as confirmed from litholog) having thickness **16.95m** and **69.18m** respectively which are the **aquifer zones** tapped for pumping test. The aquifer zones tapped is followed by layer of low resistivity 20.51 Ω-m and thickness 41.97m which may be inferred as clay which is underlained by a layer having high resistivity (399.58 Ω-m). The interpreted results of sounding are given in Table 4.2 B.

**Kashipur** : The resistivity curve is AK Type( Figure 4.10 ) indicating four layered sequence. The water level of the nearby well recorded at 6.25m.bgl. The top soil extends upto a depth of 1.59 m of resistivity 15.38 Ω-m. The second layer of resistivity 56 Ω-m indicates presence of dry coarse sand of thickness 4m. The third layer has resistivity of **224.35 Ω-m** indicating presence of very coarse sand and pebble( as confirmed from litholog) having thickness **31.00m** which is the **aquifer zone** tapped for pumping test. The aquifer zone tapped is underlain by layer of fine sand mixed with clay (as revealed from litholog) having resistivity of 30.0 Ω-m . The interpreted results of sounding are given in Table 4.2 B.

**Barthakaith**: The resistivity curve is AK Type (Figure 4.11) indicating four layered sequence. The water level of the nearby well recorded at 3.5m.bgl. The top soil extends upto a depth of 0.2 m of resistivity 48.3 Ω-m. The second layer of resistivity 44.09 Ω-m indicates presence of dry fine sand of thickness 1.71m. The third layer has resistivity of **74.3 Ω-m** indicating presence of coarse sand ( as revealed from litholog) having thickness **79.4m** which is the **aquifer zone** tapped for pumping test. The aquifer zone tapped is underlain by layer of fine sand mixed with silt (as revealed from litholog) having resistivity of 41.46 Ω-m. The interpreted results of sounding curve are given in Table 4.2 B.

**Khera Afghan** : The resistivity curve is KH Type( Figure 4.12 ) indicating four layered sequence. The water level of the nearby well recorded at 1.0m.bgl. The top soil extends upto a depth of 1.29 m of resistivity 31.60 Ω-m. The second and third layers are the **aquifer zones** tapped for pumping test having resistivity of **475.4 Ω-m** ,inferred as coarse sand mixed with pebble( as revealed from litholog) and **53.56 Ω-m (Coarse sand)** of thickness **29.40m** and **80.51m** respectively. The fourth layer has resistivity of 2803.1 Ω-m .The interpreted results of sounding curve are given in Table 4.2 B.

**Salehpur** : The apparent resistivity curve at this site is of KQH type ( Figure 4.13 ) indicating a five layered sequence. The top soil consists layer of resistivity 69.2 Ω-m having thickness 4.23m, followed by dry sand having very high resistivity 620.19 Ω-m and thickness 7.35m.which is revealed by the water level of the nearby well which recorded at 10.3m bgl. The third layer consists of medium grained sand having resistivity of **54.1 Ω-m** and thickness **105.58m** which is the **aquifer zone** tapped for pumping test. The aquifer zone tapped is followed by layer having resistivity of 13.7 Ω-m and thickness 85.31m which may be inferred as clay. The resistivity of the last layer is interpreted to be 114.66 Ω-m. The interpreted results of sounding curve are given in Table 4.2 B.

**Sarsawan** : The apparent resistivity curve at this site is of KQH type ( Figure 4.14 ) indicating a five layered sequence. The water level of the nearby well recorded at 0.5m bgl.

The top soil consists layer of resistivity **53.27 Ω-m** having thickness **2.45m,** followed by pebble having very high resistivity **606.99 Ω-m** and thickness **2.22m.**The third layer of coarse grained sand having resistivity **64.56 Ω-m** and thickness **22.00m.** The top three layers (saturated) are the **aquifer zones** tapped for pumping test. The aquifer zone tapped is followed by layer of very low resistivity of 4.65 Ω-m and thickness 12.17m which may be inferred as clay. The resistivity of the last layer is interpreted to be 192.53 Ω-m. The interpreted results of sounding curve are given in Table 4.2 C.

**Kailashpur :** The apparent resistivity curve at this site is of KHK type ( Figure 4.15 ) indicating a five layered sequence. The water level of the nearby well recorded to be 3.7m. bgl. The top soil consists layer of resistivity 22.2 Ω-m having thickness 2.7m, followed by very coarse sand having high resistivity of **155.88 Ω-m** and thickness **15.00m.**The third layer of fine grained sand of resistivity **30.00 Ω-m** and thickness **50.0m.** The fourth layer of medium grained sand with resistivity of **48.75 Ω-m** and thickness **45.0m.** The second, third and fourth layers (Saturated) are the **aquifer zones** which are tapped for pumping test. The aquifer zone tapped is followed by layer having resistivity of 17.9 Ω-m may be inferred as clay. The interpreted results of sounding curve are given in Table 4.2 C.

**Gudam :** The resistivity curve is KH Type( Figure 4.16 ) indicating four layered sequence. The water level of the nearby well recorded at 4.5m.bgl. The top soil extends upto a depth of 0.53 m of resistivity 63.2 Ω-m followed by dry sand having very high resistivity of 690.0 Ω-m and thickness 3.8m which is confirmed by the water level of the nearby well. The third layer consists of fine grained sand mixed with silt having resistivity of **26.5 Ω-m** and thickness **134.65m** which is the **aquifer zone** tapped for pumping test ( information regarding zones tapped for pumping test is not available). A perusal of litholog reveals that this zone consists of fine grained sand mixed with silt upto a depth of 150m.The aquifer zone is followed by layer having resistivity of 91.58 Ω-m. The interpreted results of sounding curve are given in Table 4.2 C.

**Muzaffarabad :** The apparent resistivity curve at this site is of HKQH type ( Figure 4.17 ) indicating a six layered sequence. The top soil consists of two thin layers of resistivity 54.25 Ω-m &17.62 Ω-m having thickness 1.23 m and 0.92m respectively. The third layer has resistivity **69.8 Ω-m** and inferred as coarse sand up to a depth of **11.55m** which is the **aquifer zone** tapped for pumping test. The water level of the nearby well recorded at 3.1m.bgl. The fourth layer has resistivity of 17.15 Ω-m indicating clay ( as revealed from litholog) having thickness 9.03m followed by another clay layer of resistivity 12.29 Ω-m and thickness 6.17m. The resistivity of the last layer is interpreted to be 32.47 Ω-m. The interpreted results of sounding curve are given in Table 4.2 C.

**Bhanera :** The apparent resistivity curve at this site is of HKQH type ( Figure 4.18 ) indicating a six layered sequence. The top soil consists of two thin layers of resistivities 333.3 & 152.5 Ω-m having thickness 1.86 & 1.59 m respectively. The third layer of resistivity 1778.3 Ω-m indicates presence of either localized boulder or dry sand upto a depth of 8.1m which is confirmed by the water level of the nearby well at 7.5m. The fourth layer having resistivity of **247.97 Ω-m** indicating coarse grained sand with pebble having thickness **21.22m** which is the **aquifer zone** tapped for pumping test. The aquifer zones tapped is followed by layer of low resistivity 13.81 Ω-m and thickness 4.4m which may be inferred as clay which is underlained by a layer having resistivity of 62.63 Ω-m. The interpreted results of sounding curve are given in Table 4.2 D.

**Belda :** The apparent resistivity curve at this site is of KQHK type ( Figure 4.19 ) indicating a six layered sequence. The top soil consists of two layers of resistivities 157.38 & 637.99 Ω-m having thickness 2.38 & 2.11 m respectively. The third layer has resistivity of

**51.4 Ω-m** indicating medium to coarse grained sand ( as revealed from litholog) having thickness **33.14m** which is the **aquifer zone** tapped for pumping test The water level of the nearby well recorded at 3.3m.bgl. The aquifer zones tapped is followed by the fourth layer having low resistivity resistivity of 10.7 Ω-m indicating presence of clay having thickness 19.14m. The fifth layer recorded a resistivity of 171.14 Ω-m and thickness 39.69m which may be inferred as very coarse grained sand which is underlained by clay layer having resistivity of10 Ω-m. The interpreted results of sounding curve are given in Table 4.2 D.

**Landhaura** : The resistivity curve is HK Type (Figure 4.20) indicating four layered sequence. The water level of the nearby well recorded 5.5m.bgl. The top soil extends upto a depth of 1.67 m of resistivity 80.27 Ω-m followed by dry fine to medium grained sand ( as revealed by litholog) having resistivity 42 Ω-m and thickness 3.12m which is revealed by the water level of the nearby well. The third layer of coarse grained sand mixed with pebble (as revealed by the litholog). of resistivity **325 Ω-m** and thickness **31.86m** which is the **aquifer zone** tapped for pumping test. The aquifer zone is followed by layer of resistivity 90.22 Ω-m. The interpreted results of sounding curve are given in Table 4.2 D.

**Chutmalpur :** The apparent resistivity curve at this site is of KHKQ type ( Figure 4.21 ) indicating a six layered sequence. The top soil consists of two layers of resistivity 71.24 & 393.26 Ω-m having thickness 1.5 & 0.89 m respectively. The third layer has resistivity of 13.83**Ω-m** which is silt as revealed from lithology. The water level of the nearby well recorded at 3.0m.bgl. The fourth layer has resistivity of **90.3 Ω-m** indicating coarse grained sand ( as revealed from lithology) having thickness **27.78m** which is the **aquifer zone** tapped for pumping test. The fifth layer has resistivity of 23.14 Ω-m indicating presence of silt ( as revealed from lithology) having thickness 158.47m which is underlain by clay layer having resistivity of 12.4 Ω-m. The interpreted results of sounding curve are given in Table 4.2 E.

**Deoband:** The resistivity curve is HA type (Figure 4.25) indicating four layered sequence. The water level of the nearby well recorded at 6.5m.bgl. The top soil extends up to a depth of 2.94 m of resistivity 49.11 Ω-m which is followed by silt ( as revealed by litholog) having resistivity 22.86 Ω-m and thickness 5.51m.which is revealed by the water level of the nearby well. The third layer of coarse grained sand ( as revealed by the litholog) having resistivity **51.8 Ω-m** and thickness **41.97m** which is the **aquifer zone** which has been tapped for pumping test. The aquifer zone is followed by layer of resistivity 71.64 Ω-m. The interpreted results of sounding curve are given in Table 4.2 G

**Ismailpur:** The apparent resistivity curve at this site is of KQH type ( Figure 4.23 ) indicating a five layered sequence. Auto flow conditions exist in the area. The Bhabar-Tarai contact is marked by presence of auto flow wells. The top soil consists layer of resistivity 339.47 Ω-m having thickness 1.95m, followed by boulder having high resistivity of 565.98 Ω-m and thickness 2.4m.The third layer of fine grained sand having resistivity **34.26 Ω-m** and thickness **46.39m** are the **aquifer zones** tapped for pumping test. The fourth layer whose resistivity is 15.67 Ω-m and thickness 44.28m, may be inferred as clay. The fifth layer recorded a resistivity of 72.31Ω-m. The interpreted results of sounding curve are given in Table 4.2 E.

**Ganeshpur:** The resistivity curve is KH Type( Figure 4.24 ) indicating four layered sequence. The water level of the nearby well recorded 9.2m bgl. The top soil extends upto a depth of 1.4 m of resistivity 413.43 Ω-m. This layer is followed by layer having resistivity 2262 Ω-m which is inferred as boulder mixed with silty sand and thickness 9.49m. The third layer of coarse grained sand ( as confirmed from litholog) having resistivity **68.6 Ω-m** and thickness **39.00m** which is the **aquifer zone** tapped for pumping test. The aquifer zone is followed by layer of resistivity 174.58 Ω-m. The interpreted results of sounding curve are given in Table 4.2 E.

**Jwalapur :** The apparent resistivity curve at this site is of HAAK type ( Figure 4.25 ) indicating a six layered sequence. The top soil consists of two layers of resistivity 43.65 & 28.36 Ω-m having thickness 1.89 & 2.47 m respectively. The third layer has resistivity of 60.36 **Ω-m** inferred as coarse sand as revealed from litholog though the water level of the nearby well recorded below 19.0m.bgl. The fourth layer has resistivity of **215.93 Ω-m** indicating very coarse grained sand mixed with boulders and pebble ( as revealed from litholog) having thickness of **66.25m** which is the **aquifer zone** tapped for pumping test. The fifth layer has resistivity of 327.49 Ω-m indicating presence of boulder ( as revealed from litholog) having thickness 81.81m which is underlain by silt mixed with clay layer having resistivity of 32.0 Ω-m. The interpreted results of sounding curve are given in Table 4.2 F.

**Roorkee :** The apparent resistivity curve at this site is of HA type ( Figure 4.26 ) indicating a four layered sequence. The top soil consists of layer of resistivity 201.26 Ω-m having thickness 1.89m. The second layer has resistivity of 27.39 Ω-m indicating presence of fine sand mixed with silt. The water level of the nearby well recorded below 7.0m.bgl. The third layer has resistivity of **131.68 Ω-m** indicating presence of very coarse grained sand having thickness **73.5m** which is the **aquifer zone** tapped for pumping test. The fourth layer has resistivity of 165.35 Ω-m indicating presence of boulder/pebble. The interpreted results of sounding curve are given in Table 4.2 F.

### 4.3.3 Resistivity Profiling Along Belda – Bahadarabad Section

A remarkable anomaly was obtained by horizontal profiling using Wenner array along E-W direction (Figure 4.27) using electrode spacing of 40m. From the apparent resistivity curve, it is clear that apparent resistivity values are not constant towards the eastern part i.e near Bahadrabad. The apparent resistivities are constant and are of lower value towards the western part i.e towards Belda. The high value of resistivity depicts that the rock matrix are of bigger size (may be presence of quartzite boulder and gravels) as is clear from drilling data of Jwalapur exploratory well. The lower and constant value in resistivity profile shows that the formation is homogeneous and of fine grained. The abrupt change in apparent resistivity value depicts that there may be change from Bhabhar to Tarrai formation.

### . 4.3.4 Interpretation of Induced Polarization Data

Induced polarization (I.P) sounding was conducted at eleven sites out of which only nine sites have been taken into consideration. Induced polarization data has been used as need based supplementary to resistivity data. The value of interpreted percentage frequency effect (pfe) has not been utilized in any form. IP measurements helped to resolve and to identify the conductive clay mixed zones which were not identified using only resistivity data. The interpreted curves of I.P along with Resistivity have been shown in Figure 4.28 to Figure 4.35.

## 4.4 Computation of Dar Zarrouk Parameters

Many formations are found to conduct the current more easily along the strata than perpendicular to it. Hence, Maillet (1947) suggested that instead of a single value of conductivity ($\sigma$), two distinct conductivities must be considered. They are the longitudinal conductivity ($\sigma_l$) parallel to the strata, and the transverse conductivity ($\sigma_t$) perpendicular to the strata. If $h_1$,$h_2$ are the thickness and ($\sigma_1$), ($\sigma_2$) are the conductivities of the two individual strata, according to Maillet (1947) it is possible to consider an average longitudinal conductivity ($\sigma_l$) and an average transverse conductivity ($\sigma_t$) due to the occurrence of the two different facies made up of thin beds. Therefore, we can have expression of the form

$$( h_1 + h_2) (\sigma_l) = h_1(\sigma_1) + h_2(\sigma_2)$$

$$( h_1 + h_2)/ (\sigma_t) = h_1/(\sigma_1) + h_2/(\sigma_2)$$

here the conductivities $\sigma_l$ and $\sigma_t$ are respectively the longitudinal and transverse conductivities of a composite bed made up of anisotropic material of a total thickness equal to that of the two strata ( $h_1 + h_2$). The parameters defined as transverse unit resistance, ($\sum_{i=1}^{i=n} \sigma_i h_i$ ) and longitudinal unit conductance, $\sum_{i=1}^{i=n} h_i/\sigma_i$ (Maillet, 1947), play a significant role in the interpretation of sounding data. These parameters have often been referred to as **"Dar Zarrouk variable"** and **"Dar-Zarrouk function"**, respectively. The Dar-Zarrouk parameters are calculated for the saturated zone of each investigating site have been given in tabular form in Table 4.3.

# Table 4.2A Results of Vertical Electrical (resistivity) Sounding

| Site | Layer Number | Resistivity (Ω-m) | Thickness (m) | Depth (m) | Inferred Lithology | Water level | Remarks |
|---|---|---|---|---|---|---|---|
| Gangoh VES-1 Latitude 29°47'52" Longitude 77°16'9" Orientation N-S | 1 | 93.068 | 11.08 | 11.08 | Dry,Coarse sand | 13.25 | Used for Correlation |
| | 2 | 981.75 | 3.79 | 14.87 | Peble/Boulder | | |
| | 3 | 83.48 | 22.13 | 37.00 | Coarse grained sand | | |
| | 4 | 73.65 | 10 | 47.00 | Coarse grained sand | | |
| | 5 | 63.79 | 10 | 57.00 | Coarse grained sand | | |
| | 6 | 34.61 | | | Fine grained Sand | | |
| | | | | | | | |
| Nagal VES-2 Latitude 29°51'00" Longitude 77°37'56" Orientation NE-SW | 1 | 32.749 | 2.42 | 2.42 | Top soil | 14.68 | Used for Correlation |
| | 2 | 59.26 | 1.41 | 3.83 | Medium grained sand | | |
| | 3 | 171.55 | 13.34 | 17.17 | Dry,Coarse sand | | |
| | 4 | 73.54 | 18.16 | 35.33 | Coarse grained sand | | |
| | 5 | 165.35 | 23.83 | 59.16 | Peble/Boulder | | |
| Nagal VES-3 Orientation ⊥r to VES-2 | 1 | 55.153 | 1.11 | 1.11 | Top soil | | |
| | 2 | 2.5 | 0.61 | 1.73 | Medium grained sand | | |
| | 3 | 138.78 | 58 | 59.73 | Dry,Coarse sand | | |
| | 4 | 23.426 | | | Coarse grained sand | | |
| | | | | | | | |
| Nanauta VES-4 Latitude 29°43'9" Longitude 77°25'41" Orientation N-S | 1 | 110 | 0.62 | 0.62 | Top soil | 1.5 | Used for Correlation |
| | 2 | 14.84 | 0.184 | 0.80 | Top soil | | |
| | 3 | 55.15 | 22.7 | 23.50 | Medium grained sand | | |
| | 4 | 31.62 | 31.56 | 55.06 | Clayey sand | | |
| | 5 | 43.65 | | | Fine to medium garined sand | | |
| Nanauta VES-5 Latitude 29°42'43" Longitude 77°24'36" Orientation E-W | 1 | 47.85 | 0.79 | 0.79 | Top soil | | |
| | 2 | 14.38 | 5.42 | 6.22 | Top soil | | |
| | 3 | 64.43 | 3.01 | 9.22 | Medium grained sand | | |
| | 4 | 49.09 | 212.78 | 222.00 | Fine to medium garined sand | | |
| | 5 | 3.15 | | | | | |
| Nakur VES-6 Latitude 29°55'35" Longitude 77°18'57" Orientation E-W | 1 | 56.977 | 1.65 | 1.65 | Top soil | 13 | Used for Correlation |
| | 2 | 278.03 | 10.16 | 11.81 | Dry sand | | |
| | 3 | 152.72 | 20.858 | 32.67 | VeryCoarse grained sand | | |
| | 4 | 20.89 | 19.11 | 51.78 | Clay | | |
| | 5 | 64.86 | | | Coarse grained sand | | |

# Table 4.2B Results of Vertical Electrical (resistivity) Sounding

| Site | Layer Number | Resistivity (Ω-m) | Thickness (m) | Depth (m) | Inferred Lithology | Water level | Remarks |
|---|---|---|---|---|---|---|---|
| K.Akbarpur<br>VES-7<br>Latitude<br>29°55'25"<br>Longitude<br>77°39'19"<br>Orientation<br>NE-SW | 1 | 68.03 | 6.10 | 6.10 | Top soil | 11.85 | Used for Correlation |
| | 2 | 317.66 | 3.82 | 9.92 | Dry sand | | |
| | 3 | 70.99 | 86.41 | 96.33 | Coarse grained sand | | |
| | 4 | 14.06 | 70.15 | 166.48 | Clay | | |
| | 5 | 10.35 | 86.20 | 252.68 | Clay | | |
| | 6 | 495.68 | 41.38 | 294.05 | Boulder/pebble | | |
| | 7 | 190.90 | | | Pebble/coarse grained sand | | |
| Fatehpur<br>VES-8<br>Latitude<br>30°02'51"<br>Longitude<br>77°45'31"<br>Orientation<br>N-S | 1 | 80.73 | 0.92 | 0.92 | Top soil | 2.5 | Used for Correlation |
| | 2 | 11.416 | 1.01 | 1.93 | Top soil | | |
| | 3 | 180.46 | 1.85 | 3.78 | Dry sand | | |
| | 4 | 80.46 | 16.95 | 20.73 | Medium grained sand | | |
| | 5 | 49.77 | 69.18 | 89.91 | Coarse grained sand | | |
| | 6 | 20.51 | 41.97 | 131.88 | Clay | | |
| | 7 | 399.58 | | | Boulder/pebble | | |
| Kashipur<br>VES-9<br>Latitude<br>29°39'46"<br>Longitude<br>77°25'5.6"<br>Orientation<br>NE-SW | 1 | 15.389 | 1.60 | 1.6 | Top soil | 6.25 | Used for Correlation |
| | 2 | 56 | 4.00 | 5.60 | Dry sand | | |
| | 3 | 224.35 | 31.00 | 36.60 | Pebble mixed with Coarse grained sand | | |
| | 4 | 30 | | | Fine grained Sand | | |
| | | | | | | | |
| Barthakaith<br>VES-10<br>Latitude<br>30°05'27"<br>Longitude<br>77°26'29"<br>Orientation<br>NW-SE | 1 | 48.26 | 0.20 | 0.2 | Top soil | 3.5 | Used for Correlation |
| | 2 | 44.096 | 1.71 | 1.91 | Dry fine grained sand | | |
| | 3 | 74.26 | 79.38 | 81.29 | Coarse grained sand | | |
| | 4 | 41.76 | | | Fine grained Sand | | |
| | | | | | | | |
| KheraAfghan<br>VES-12<br>Latitude<br>29°54'6.7"<br>Longitude<br>77°23'00"<br>Orientation<br>E-W | 1 | 31.606 | 1.29 | 1.29 | Top soil | 1 | Used for Correlation |
| | 2 | 475.4 | 29.40 | 30.69 | Pebble mixed with Coarse grained sand | | |
| | 3 | 53.56 | 80.51 | 111.20 | Coarse grained sand | | |
| | 4 | 2803.1 | | | Boulder/pebble | | |
| Salehpur<br>VES-14<br>Latitude<br>29°56'58"<br>Longitude<br>77°20'42"<br>Orientation<br>N-S | 1 | 69.17 | 4.23 | 4.23 | Top soil | 10.3 | Used for Correlation |
| | 2 | 620.19 | 7.35 | 11.58 | Dry sand | | |
| | 3 | 54.11 | 105.58 | 117.16 | Medium grained sand | | |
| | 4 | 13.671 | 85.31 | 202.47 | Clay | | |
| | 5 | 114.66 | | | | | |

# Table 4.2C Results of Vertical Electrical (resistivity) Sounding

| Site | Layer Number | Resistivity (Ω-m) | Thickness (m) | Depth (m) | Inferred Lithology | Water level | Remarks |
|---|---|---|---|---|---|---|---|
| Sarsawan<br>VES-15<br>Latitude<br>30$^{0}$00’43”<br>Longitude<br>77$^{0}$25’5.6”<br>Orientation<br>NW-SE | 1 | 53.27 | 2.45 | 2.45 | Top soil | 0.50 | Used for Correlation |
| | 2 | 606.99 | 2.22 | 4.67 | Pebble mixed with Coarse grained sand | | |
| | 3 | 64.56 | 22.00 | 26.67 | Coarse grained sand | | |
| | 4 | 4.65 | 12.17 | 38.84 | Clay | | |
| | 5 | 192.53 | | | | | |
| Sarsawan<br>VES-16<br>Latitude<br>30$^{0}$00’43”<br>Longitude<br>77$^{0}$25’5.6”<br>Orientation<br>$\perp^{r}$ to VES-15 | 1 | 52.88 | 2.74 | 2.74 | Top soil | | |
| | 2 | 520.45 | 2.21 | 4.95 | Pebble mixed with Coarse grained sand | | |
| | 3 | 41.38 | 22.00 | 26.95 | Coarse grained sand | | |
| | 4 | 9.58 | 28.32 | 55.27 | Clay | | |
| | 5 | 995.43 | | | Coarse grained sand | | |
| Kailashpur<br>VES-17<br>Latitude<br>29$^{0}$58’15”<br>Longitude<br>77$^{0}$38’24”<br>Orientation<br>N-S | 1 | 22.23 | 2.70 | 2.7 | Top soil | 3.7 | Used for Correlation |
| | 2 | 155.88 | 15.00 | 17.70 | Coarse grained sand | | |
| | 3 | 30 | 50.00 | 67.70 | Fine grained Sand | | |
| | 4 | 48.75 | 45.00 | 112.70 | Medium grained sand | | |
| | 5 | 17.93 | | | Clay | | |
| Gudam<br>VES-18<br>Latitude<br>30$^{0}$02’46”<br>Longitude<br>77$^{0}$46’09”<br>Orientation<br>NW-SE | 1 | 63.2 | 0.53 | 0.53 | Top soil | 4.5 | Used for Correlation |
| | 2 | 690.03 | 3.84 | 4.37 | Dry sand | | |
| | 3 | 26.484 | 134.65 | 139.02 | Fine grained Sand | | |
| | 4 | 191.58 | | | Pebble mixed with Coarse grained sand | | |
| | | | | | | | |
| Muzaffarabad<br>VES-19<br>Latitude<br>30$^{0}$06’49”<br>Longitude<br>77$^{0}$42’42”<br>Orientation<br>NW-SE | 1 | 54.25 | 1.23 | 1.23 | Top soil | 3.1 | Used for Correlation |
| | 2 | 17.62 | 0.92 | 2.15 | Top soil | | |
| | 3 | 69.75 | 9.4 | 11.55 | Coarse grained sand | | |
| | 4 | 17.15 | 9.03 | 20.58 | Clay | | |
| | 5 | 12.29 | 6.17 | 26.75 | Clay | | |
| | 6 | 32.47 | | | Fine grained Sand | | |
| Muzaffarabad<br>VES-20<br>Orientation<br>N-S | 1 | 141.96 | 1.53 | 1.53 | Top soil | | |
| | 2 | 1.41 | 0.18 | 1.71 | Top soil | | |
| | 3 | 559.50 | 0.59 | 2.30 | Pebble/Boulder | | |
| | 4 | 420.44 | 4.24 | 6.54 | Pebble/Boulder | | |
| | | 2.38 | 13.29 | 19.83 | Clay | | |
| | 5 | 28.64 | | | Silt | | |

## Table 4.2D Results of Vertical Electrical (resistivity) Sounding

| Site | Layer Number | Resistivity (Ω-m) | Thickness (m) | Depth (m) | Inferred Lithology | Water level | Remarks |
|---|---|---|---|---|---|---|---|
| Bhanera VES-21 Latitude 29°46'24" Longitude 77°54'25" Orientation N-S | 1 | 210.34 | 5.17 | 5.17 | Top soil | | |
| | 2 | 6419.50 | 1.18 | 6.35 | Dry Sand/Boulder | | |
| | 3 | 25.21 | 6.91 | 13.26 | Silty sand | | |
| | 4 | 420.44 | | | Pebble/coarse sand | | |
| Bhanera VES-22 Orientation NE-SW | 1 | 145.47 | 6.55 | 6.55 | | | Too High RMSE |
| | 2 | 5596 | 6.25 | 12.81 | | | |
| | 3 | 14.66 | 1.12 | 13.93 | | | |
| | 4 | 27.39 | 110.49 | 124.43 | | | |
| | | 14.92 | | | | | |
| Bhanera VES-23 Orientation ⊥r to VES-21 | 1 | 333.27 | 1.86 | 1.86 | Top soil | 7.50 | Used for Correlation |
| | 2 | 152.48 | 1.59 | 3.45 | Top soil | | |
| | 3 | 1778.3 | 4.65 | 8.1 | Boulder/pebble/Dry sand | | |
| | 4 | 247.97 | 21.23 | 29.33 | Pebble mixed with Coarse grained sand | | |
| | 5 | 13.817 | 4.4 | 33.73 | Clay | | |
| | 6 | 62.63 | | | Coarse grained sand | | |
| Belda VES-24 Latitude 29°47'52" Longitude 77°16'9" Orientation E-W | 1 | 157.38 | 2.38 | 2.38 | Top soil | 3.5 | Used for Correlation |
| | 2 | 637.99 | 2.11 | 4.49 | Top soil | | |
| | 3 | 51.418 | 33.15 | 37.64 | Medium to coarse grained sand | | |
| | 4 | 10.7 | 19.14 | 56.78 | Clay | | |
| | 5 | 171.14 | 39.69 | 96.47 | Pebble mixed with Coarse grained sand | | |
| | 6 | 10 | | | Clay | | |
| Landhaura VES-26 Latitude 29°48'07" Longitude 77°55'44" Orientation NE-SW | 1 | 76.90 | 1.80 | 1.80 | Top soil | | |
| | 2 | 37.79 | 1.05 | 2.85 | Top soil | | |
| | 3 | 315.07 | 70.00 | 72.85 | Coarse grained sand | | |
| | 4 | 40.14 | | | Fine to Medium Sand | | |
| Landhaura VES-27 Orientation ⊥r to VES-26 | 1 | 80.27 | 1.67 | 1.67 | Top soil | 5.5 | Used for Correlation |
| | 2 | 42.29 | 3.12 | 4.79 | Fine to Medium grained sand | | |
| | 3 | 325 | 31.86 | 36.65 | Pebble mixed with Coarse grained sand | | |
| | 4 | 90.22 | | | Coarse grained sand | | |

# Table 4.2E Results of Vertical Electrical (resistivity) Sounding

| Site | Layer Number | Resistivity (Ω-m) | Thickness (m) | Depth (m) | Inferred Lithology | Water level | Remarks |
|---|---|---|---|---|---|---|---|
| Landhaura<br>VES-28<br>Orientation<br>N-S | 1 | 124.43 | 0.50 | 0.50 | Top soil | | |
| | 2 | 47.08 | 6.64 | 7.14 | Fine to Medium grained sand | | |
| | 3 | 972.57 | 11.68 | 18.82 | Pebble mixed with Coarse grained sand | | |
| | 4 | 44.73 | 146.35 | 165.17 | Coarse grained sand | | |
| | 5 | 1493.40 | | | Pebble/Boulder | | |
| Chutmalpur<br>VES-29<br>Latitude<br>$30^{0}$01’27”<br>Longitude<br>$77^{0}$45’18”<br>Orientation<br>N-S | 1 | 71.24 | 1.50 | 1.5 | Top soil | 3.0 | Used for Correlation |
| | 2 | 393.26 | 0.89 | 2.39 | Top soil | | |
| | 3 | 13.83 | 0.93 | 3.33 | Silt | | |
| | 4 | 90.29 | 27.78 | 31.11 | Coarse grained sand | | |
| | 5 | 23.14 | 158.47 | 189.58 | Silt | | |
| | 6 | 12.4 | | | Clay | | |
| Ismailpur<br>VES-31<br>Latitude<br>$30^{0}$06’20”<br>Longitude<br>$77^{0}$49’17”<br>Orientation<br>NW-SE | 1 | 339.47 | 1.95 | 1.95 | Top soil | 3.5 | Used for Correlation |
| | 2 | 565.98 | 2.40 | 4.35 | Boulder | | |
| | 3 | 34.261 | 46.39 | 50.74 | Fine to Medium grained sand | | |
| | 4 | 15.675 | 44.28 | 95.02 | Clay | | |
| | 5 | 72.31 | | | Coarse grained sand | | |
| Ganeshpur<br>VES-32<br>Latitude<br>$30^{0}$08’31”<br>Longitude<br>$77^{0}$52’06”<br>Orientation<br>N-S | 1 | 413.43 | 1.4602 | 1.4602 | Top soil | 9.2 | Used for Correlation |
| | 2 | 2662 | 9.49 | 10.95 | Boulder/pebble/Dry sand | | |
| | 3 | 68.58 | 39.00 | 49.95 | Coarse grained sand | | |
| | 4 | 174.58 | | | Pebble mixed with Coarse grained sand | | |
| Ganeshpur<br>VES-33<br>Orientation<br>$\perp^{r}$ to VES-32 | 1 | 600.50 | 0.90 | 0.90 | Top soil | | |
| | 2 | 1287.60 | 14.73 | 15.63 | Boulder/pebble/Dry sand | | |
| | 3 | 483.52 | 10.00 | 25.63 | Pebble | | |
| | 4 | 300.00 | 14.28 | 39.90 | Pebble | | |
| | 5 | 68.58 | 39.00 | 78.90 | Coarse Sand | | |
| | 6 | 47.31 | 37.43 | 116.33 | Medium sand | | |
| | 7 | 341.74 | | | Pebble | | |

# Table 4.2F Results of Vertical Electrical (resistivity) Sounding

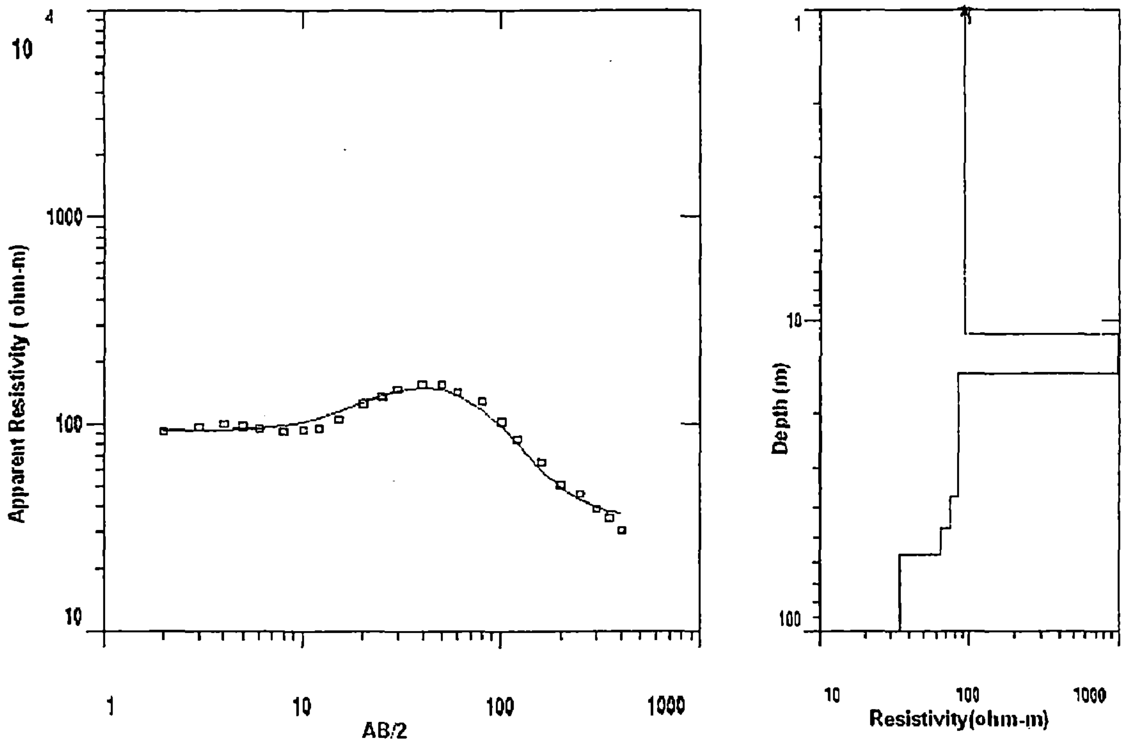
| Site | Layer Number | Resistivity (Ω-m) | Thickness (m) | Depth (m) | Inferred Lithology | Water level | Remarks |
|---|---|---|---|---|---|---|---|
| Ganeshpur VES-34 Orientation N-S 200 North of VES -33 | 1 | 543.24 | 1.94 | 1.94 | | | RMSE too high |
| | 2 | 2728.20 | 7.19 | 9.13 | | | |
| | 3 | 753.22 | 2.15 | 11.28 | | | |
| | 4 | 135.89 | | | | | |
| | | | | | | | |
| Jwalapur VES-35 Latitude 29$^{0}$56'11" Longitude 78$^{0}$07'14" Orientation NE-SW | 1 | 43.65 | 1.89 | 1.89 | Top soil | 19 | Used for Correlation |
| | 2 | 28.366 | 2.47 | 4.36 | Top soil | | |
| | 3 | 60.36 | 13.732 | 18.09 | Coarse grained dry sand | | |
| | 4 | 215.93 | 66.259 | 84.35 | Pebble mixed with Coarse grained sand | | |
| | 5 | 327.49 | 81.811 | 166.16 | Boulder | | |
| | 6 | 32 | | | Fine to Medium grained sand | | |
| Jwalapur VES-36 Orientation $\perp^{r}$ to VES-35 | 1 | 71.87 | 1.58 | 1.58 | | | High RMSE |
| | 2 | 12.54 | 1.09 | 2.66 | | | |
| | 3 | 548.89 | 0.90 | 3.56 | | | |
| | 4 | 54.76 | 62.44 | 66.01 | | | |
| | 5 | 17.32 | 41.28 | 107.29 | | | |
| | 6 | 8803.70 | | | | | |
| Roorkee VES-38 Latitude 29$^{0}$51'38" Longitude 77$^{0}$53'6" Orientation N-S | 1 | 201.26 | 1.99 | 1.99 | Top soil | 7 | Used for Correlation |
| | 2 | 27.39 | 4.29 | 6.28 | Fine sand with silt | | |
| | 3 | 131.68 | 73.50 | 79.78 | Pebble mixed with Coarse grained sand | | |
| | 4 | 165.35 | | | Pebble mixed with Coarse grained sand | | |
| | | | | | | | |
| Roorkee VES-39 Orientation N-S | 1 | 147.81 | 4.23 | 4.23 | Top soil | | |
| | 2 | 33.47 | 17.58 | 21.81 | Fine sand with silt | | |
| | 3 | 74.38 | 9.35 | 31.16 | Coarse Sand | | |
| | 4 | 11.55 | 21.81 | 52.96 | Clay | | |
| | 5 | 77.89 | | | Coarse Sand | | |
| | | | | | | | |
| | | | | | | | |
| Bahadarabad VES-40 Latitude 29$^{0}$55'11" Longitude 78$^{0}$03'09" Orientation N-S | 1 | 47.81 | 4.23 | 4.23 | Top soil | 15.6 | |
| | 2 | 33.47 | 17.58 | 21.81 | Fine sand with silt | | |
| | 3 | 64.38 | 9.35 | 31.16 | Coarse Sand | | |
| | 4 | 71.55 | 21.81 | 52.96 | Coarse sand | | |
| | 5 | 87.89 | | | Coarse Sand | | |
| | | | | | | | |
| | | | | | | | |

## Table 4.2G Results of Vertical Electrical (resistivity) Sounding

| Site | Layer Number | Resistivity (Ω-m) | Thickness (m) | Depth (m) | Inferred Lithology | Water level | Remarks |
|---|---|---|---|---|---|---|---|
| Deoband VES-41 Latitude $29^{0}41'2"$ Longitude $77^{0}44'9.6"$ Orientation N-S | 1 | 49.11 | 2.94 | 2.94 | Top soil | 6.5 | Used for Correlation |
| | 2 | 22.87 | 5.51 | 8.45 | Silt | | |
| | 3 | 51.79 | 41.97 | 50.42 | Coarse grained sand | | |
| | 4 | 71.65 | | | Coarse grained sand | | |
| Pilkhani VES-42 Latitude $29^{0}59'17"$ Longitude $77^{0}28'41"$ Orientation E-W | 1 | 11.68 | 0.29 | 0.29 | Top soil | 8.15 | |
| | 2 | 33.53 | 6.86 | 7.15 | Fine sand | | |
| | 3 | 61.76 | 15.71 | 22.86 | Coarse Sand | | |
| | 4 | 19.34 | 18.60 | 41.46 | Silt | | |
| | 5 | 97.65 | 56.14 | 97.60 | Coarse sand | | |
| | 6 | 16.48 | | | clay | | |
| Ambehta VES-43 Latitude $29^{0}51'55"$ Longitude $77^{0}20'16"$ Orientation NE-SW | 1 | 145.70 | 1.93 | 1.93 | Top soil | 15.0 | |
| | 2 | 85.81 | 1.94 | 3.87 | Top soil | | |
| | 3 | 2274.70 | 4.46 | 8.33 | Dry Sand | | |
| | 4 | 13.10 | 15.00 | 23.33 | clay | | |
| | 5 | 75.78 | 70.78 | 94.12 | Coarse sand | | |
| | 6 | 78.03 | | | Coarse sand | | |
| Yamuna bridge VES-44 Latitude $30^{0}03'31"$ Longitude $77^{0}21'44"$ Orientation E-W | 1 | 68.41 | 1.39 | 1.39 | Top soil | 2.7 | |
| | 2 | 41.26 | 1.43 | 2.83 | Fine sand with silt | | |
| | 3 | 74.46 | 23.02 | 25.85 | Coarse grained sand | | |
| | 4 | 47.46 | 23.60 | 49.45 | mediumgrained sand | | |
| | 5 | 225.34 | 29.34 | 78.79 | Pebble/boulder | | |
| | 6 | 40.85 | | | | | |
| Badheri VES-45 Latitude $29^{0}53'57"$ Longitude $77^{0}58'57"$ Orientation NW-SE | 1 | 1337.60 | 0.31 | 0.31 | Top soil | | |
| | 2 | 169.13 | 6.14 | 6.45 | Top soil | | |
| | 3 | 9.93 | 3.07 | 9.52 | clay | | |
| | 4 | 91.66 | 128.92 | 138.44 | Coarse sand | | |
| | 5 | 19.51 | | | clay | | |
| Badheri VES-46 Orientation $\perp^{r}$ to VES-44 | 1 | 428.66 | 2.51 | 2.51 | Top soil | | |
| | 2 | 51.15 | 24.75 | 27.26 | Coarse sand | | |
| | 3 | 141.08 | 13.08 | 40.34 | Coarse sand | | |
| | 4 | 16.46 | 34.99 | 75.33 | clay | | |
| | 5 | 410.80 | | | Pebble/boulder | | |

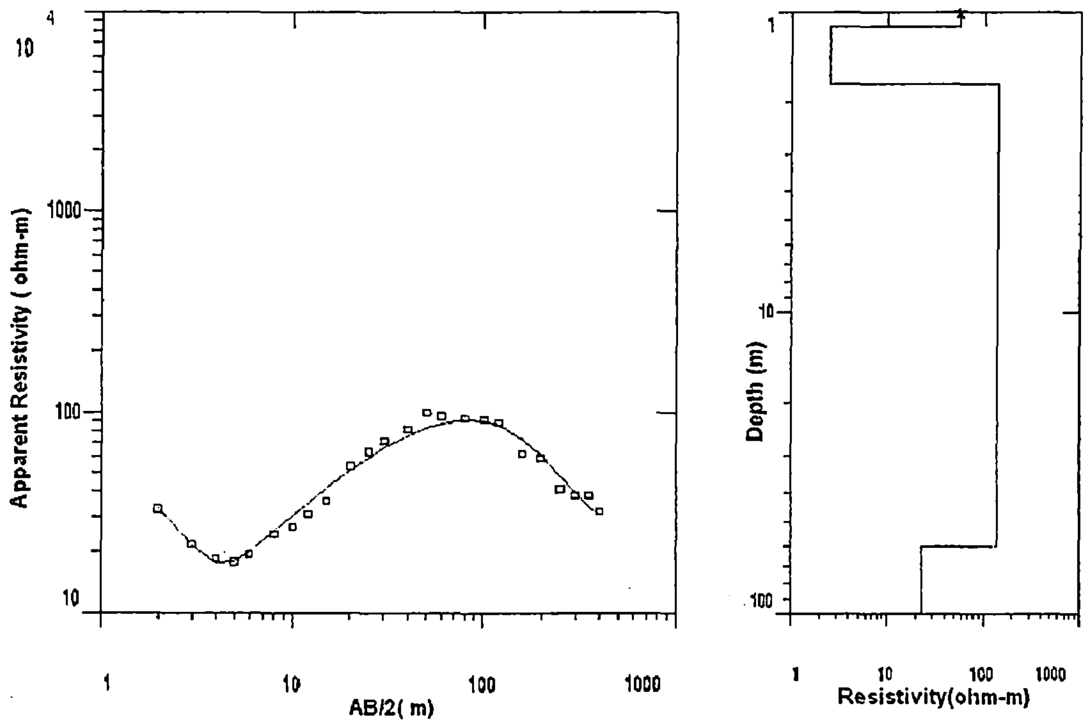
## Table 4.3 Dar Zarrouk Parameters

| Name of Site | **Transeverse resistance** (R=∑ρihi) | **Transverse resistivity** ($\rho_t$ =∑ρihi/br). | **Longitudinal conductance** (S=∑hi/ρi) | **Longitudinal resistivity** ($\rho_l$ =br/∑hi/ρi) |
|---|---|---|---|---|
| Gangoh | 1847.41 | 83.48 | 0.27 | 83.51 |
| Nagal | 1335.48 | 73.54 | 0.25 | 73.54 |
| Nanauta | 1251.9 | 55.15 | 0.41 | 55.10 |
| Nakur | 3185.43 | 152.78 | 0.14 | 154.44 |
| K.Akbarpur | 6134.24 | 70.99 | 1.21 | 71.41 |
| Fatehpur | 4806.88 | 55.81 | 1.60 | 53.83 |
| Kashipur | 6954.85 | 224.35 | 0.14 | 224.48 |
| Barthakaith | 5894.75 | 74.26 | 1.07 | 74.26 |
| KheraAfghan | 18288.88 | 166.40 | 1.57 | 70.23 |
| Salehpur | 5712.93 | 54.11 | 1.95 | 54.11 |
| Sarsawan | 2898.33 | 108.67 | 0.39 | 68.31 |
| Kailashpur | 6031.95 | 53.52 | 2.69 | 41.96 |
| Gudam | 3566.07 | 26.61 | 5.50 | 24.37 |
| M.Bad | 655.65 | 69.75 | 0.13 | 69.78 |
| Bhanera | 5264.4 | 247.97 | 0.09 | 248.01 |
| Belda | 1704.25 | 51.42 | 0.64 | 51.42 |
| Landhaura | 10354.5 | 325.00 | 0.10 | 325.00 |
| Chutmalpur | 2508.25 | 90.29 | 0.31 | 90.29 |
| Deoband | 2173.62 | 51.79 | 0.81 | 51.81 |
| Ismailpur | 1589.32 | 34.26 | 1.35 | 34.26 |
| Ganeshpur | 2674.62 | 68.58 | 0.57 | 68.42 |
| Jwalapur | 14307.31 | 215.96 | 0.31 | 213.02 |
| Roorkee | 9678.26 | 131.68 | 0.56 | 131.25 |



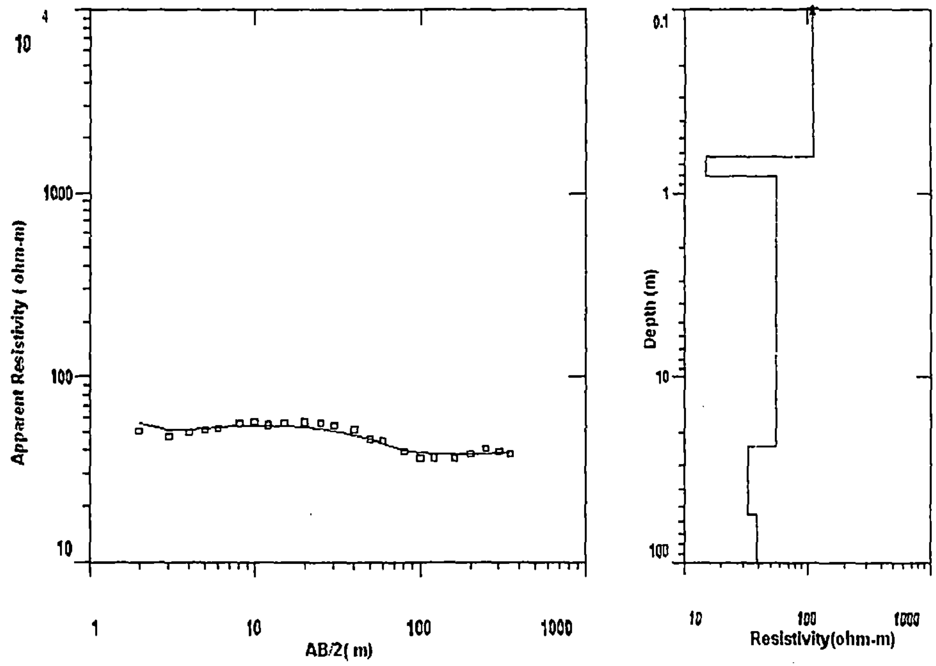

R.M.S.E : 5.81%

Figure .4.4 Interpreted VES curve (Resistivity)- Gangoh Site



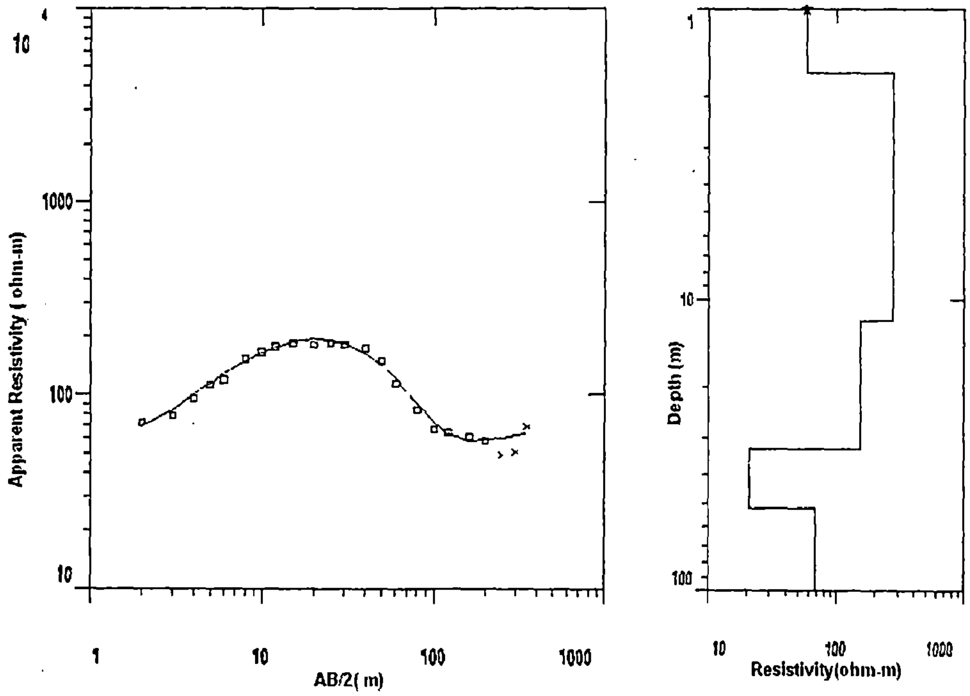

R.M.S.E : 5.81%

Figure .4.5 Interpreted VES curve (Resistivity)- Nagal Site



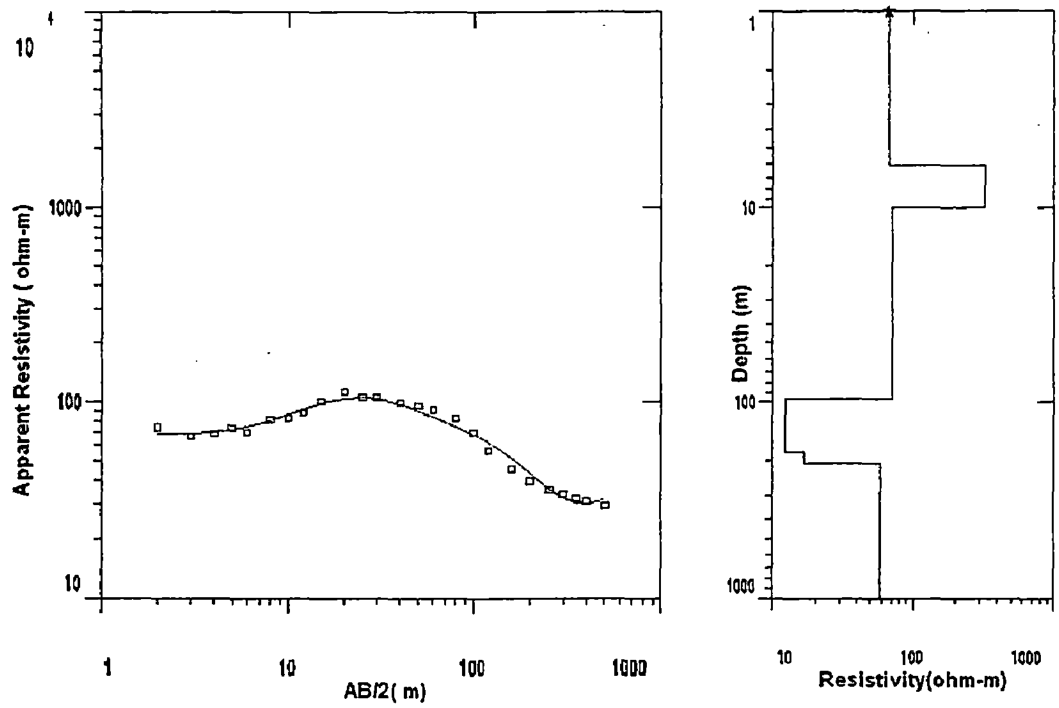

R.M.S.E : 5.12%

Figure 4.6 . Interpreted VES (Resistivity)- Nanauta Site



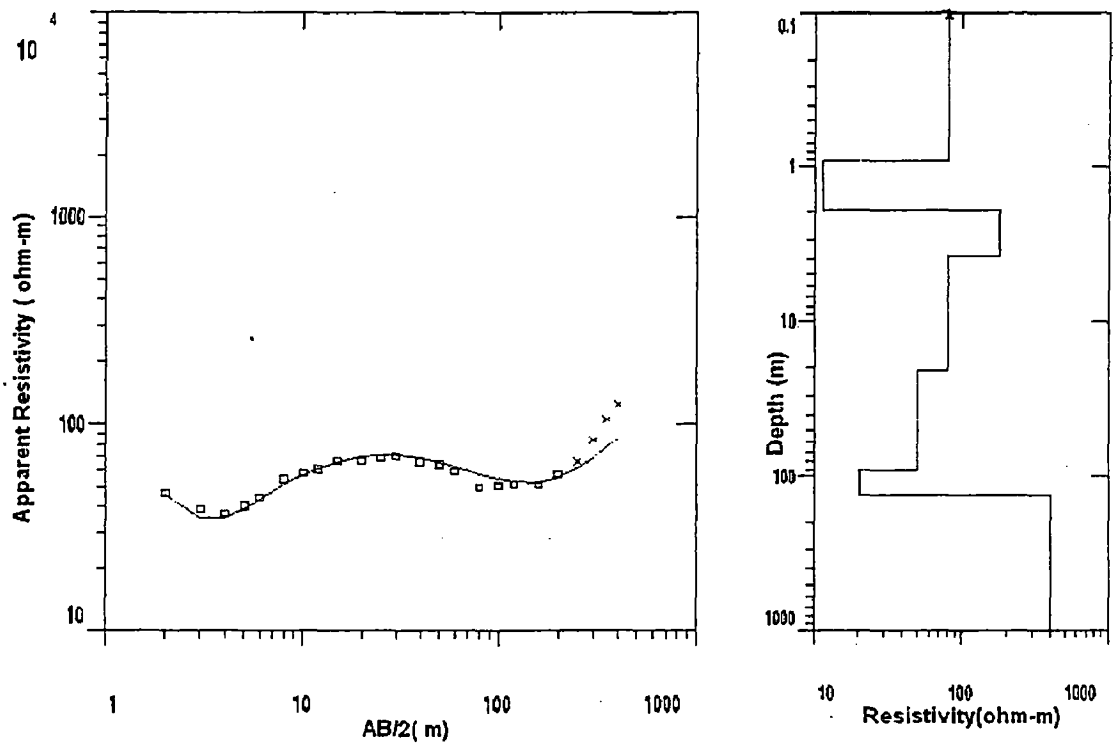

R.M.S.E : 4.98%

Figure 4.7 Interpreted VES curve (Resistivity)- Nakur Site



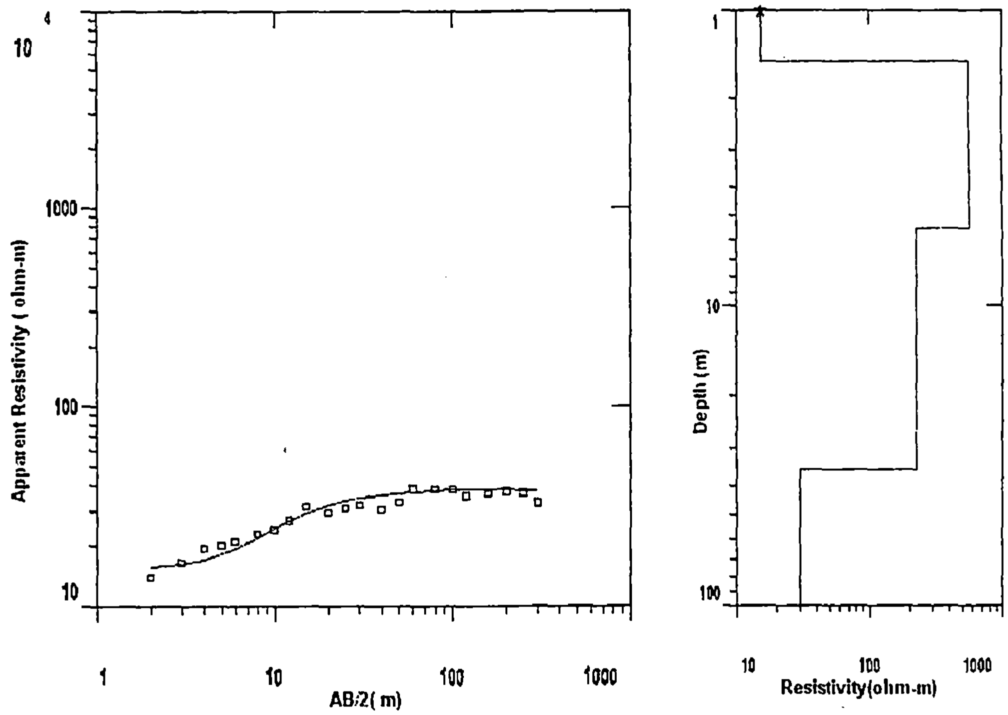

R.M.S.E : 6.09%

Figure 4.8 Interpreted VES curve (Resistivity)- K-Akbarpur Site



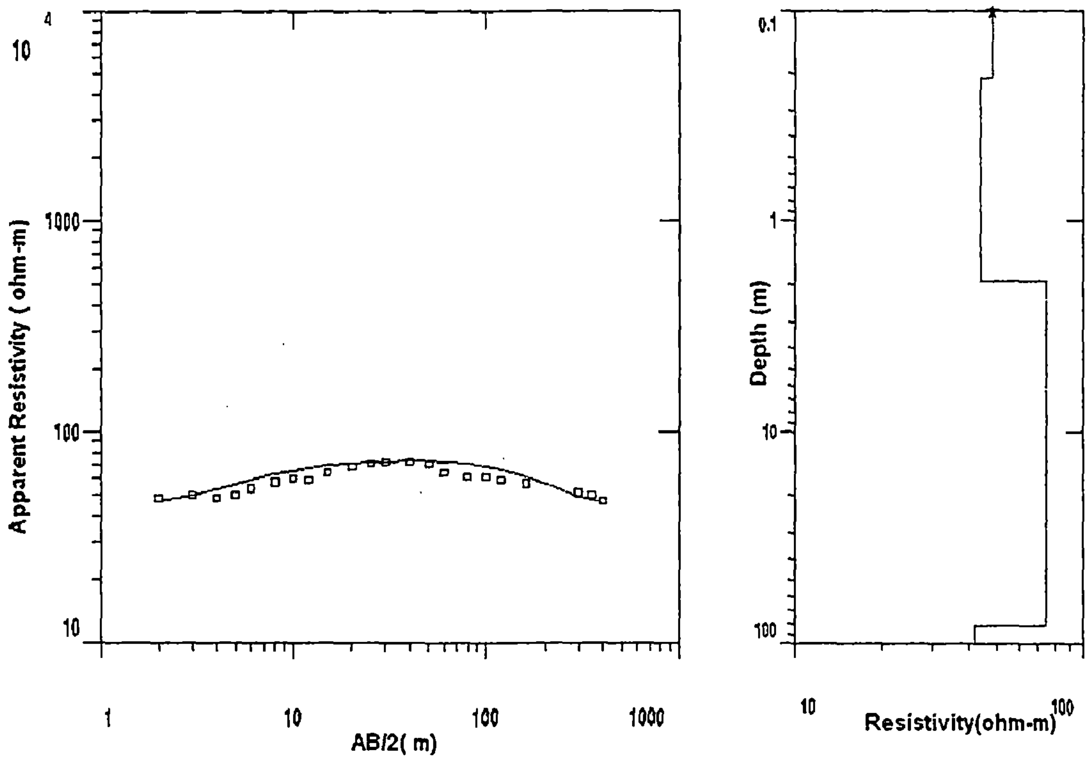

R.M.S.E : 5.7%

Figure 4.9 Interpreted VES curve (Resistivity)- Fatehpur Site



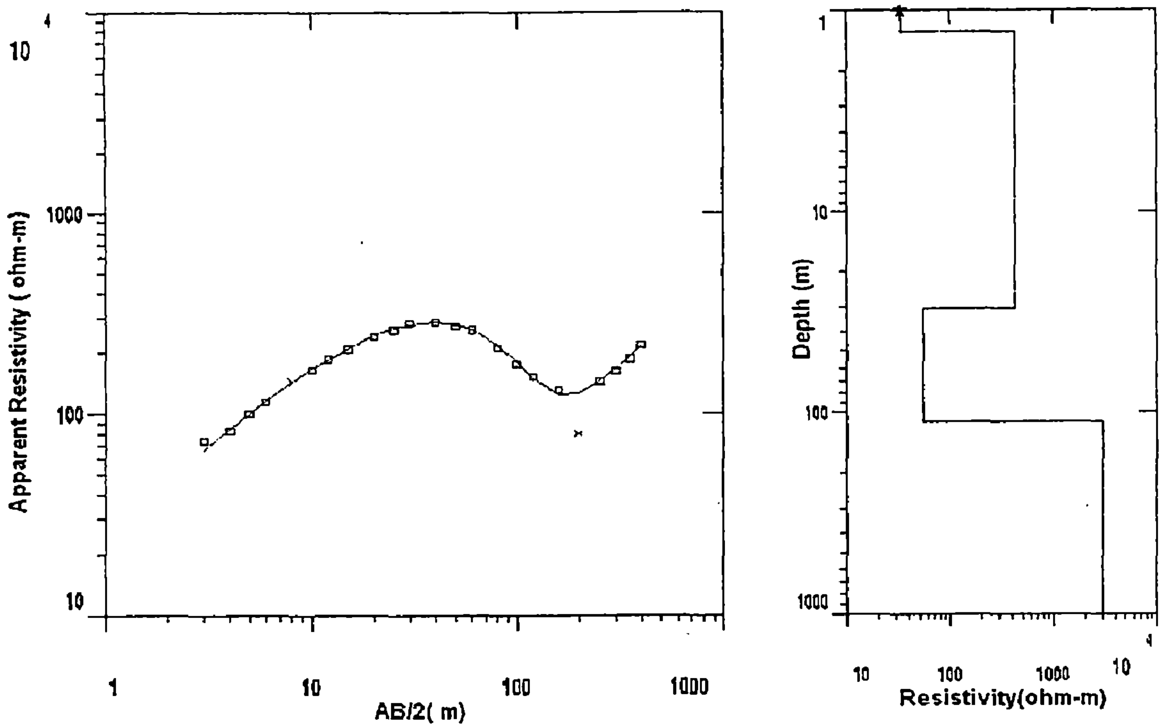

R.M.S.E : 4.39%

Figure 4.10 Interpreted VES curve (Resistivity)- Kashipur Site



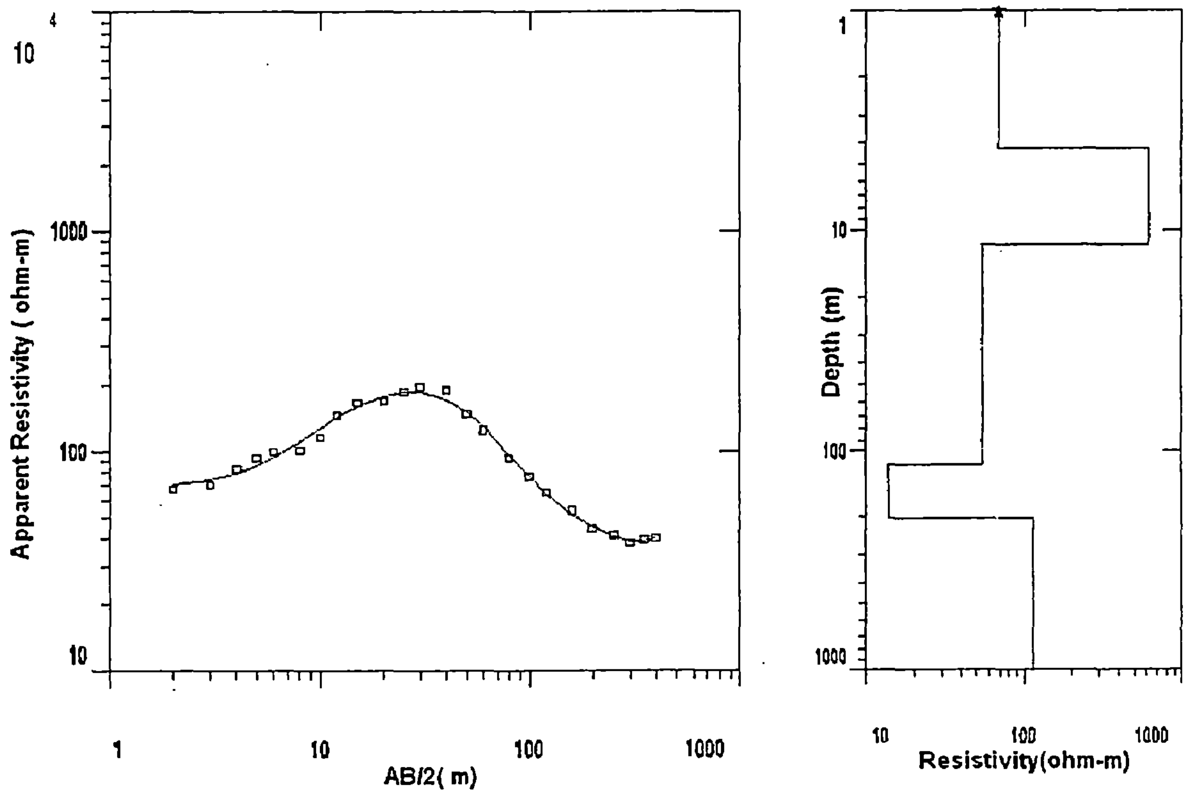

R.M.S.E : 4.10%

Figure 4.11 Interpreted VES curve (Resistivity)- Barthakaith Site



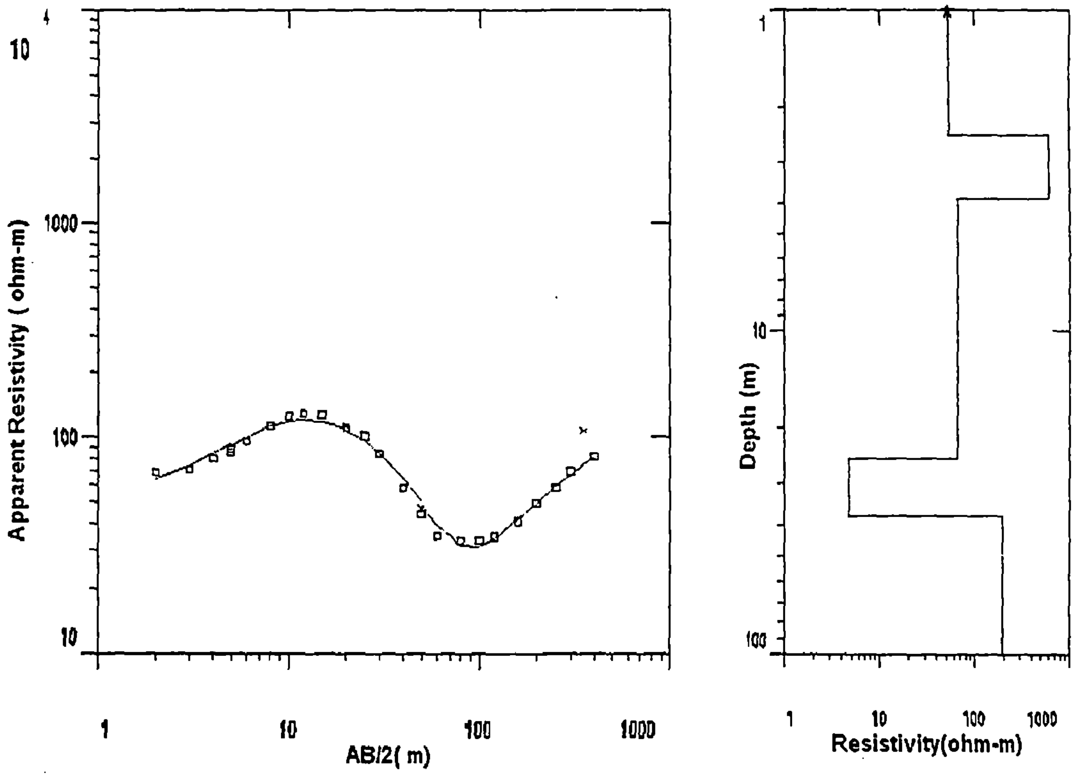

R.M.S.E : 4.39%

Figure 4.12 Interpreted VES curve (Resistivity)- Khera Afghan Site



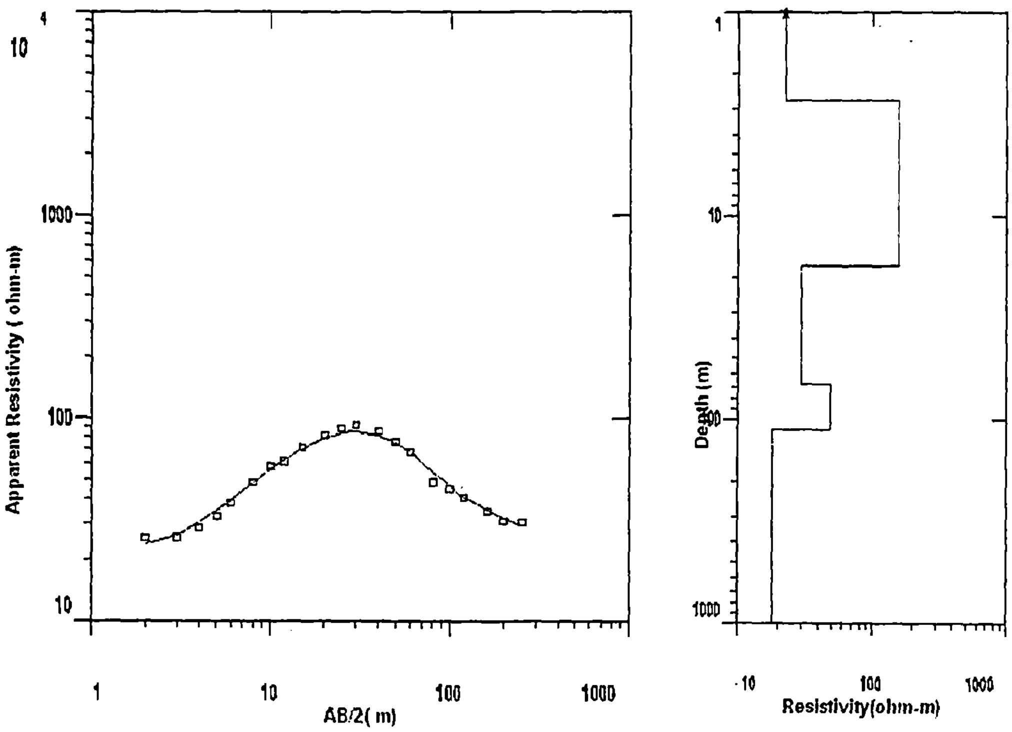

R.M.S.E : 5.11%

Figure 4.13 Interpreted VES curve (Resistivity)- Salehpur Site



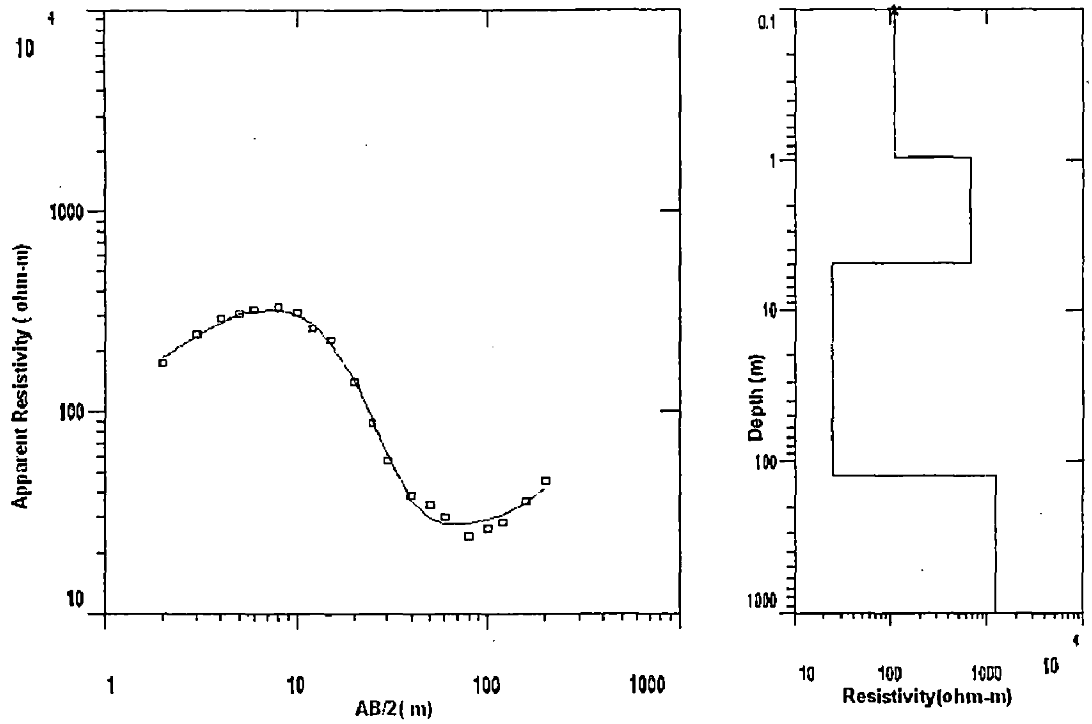

R.M.S.E : 5.51%

Figure 4.14 Interpreted VES curve (Resistivity)- Sarsawan Site



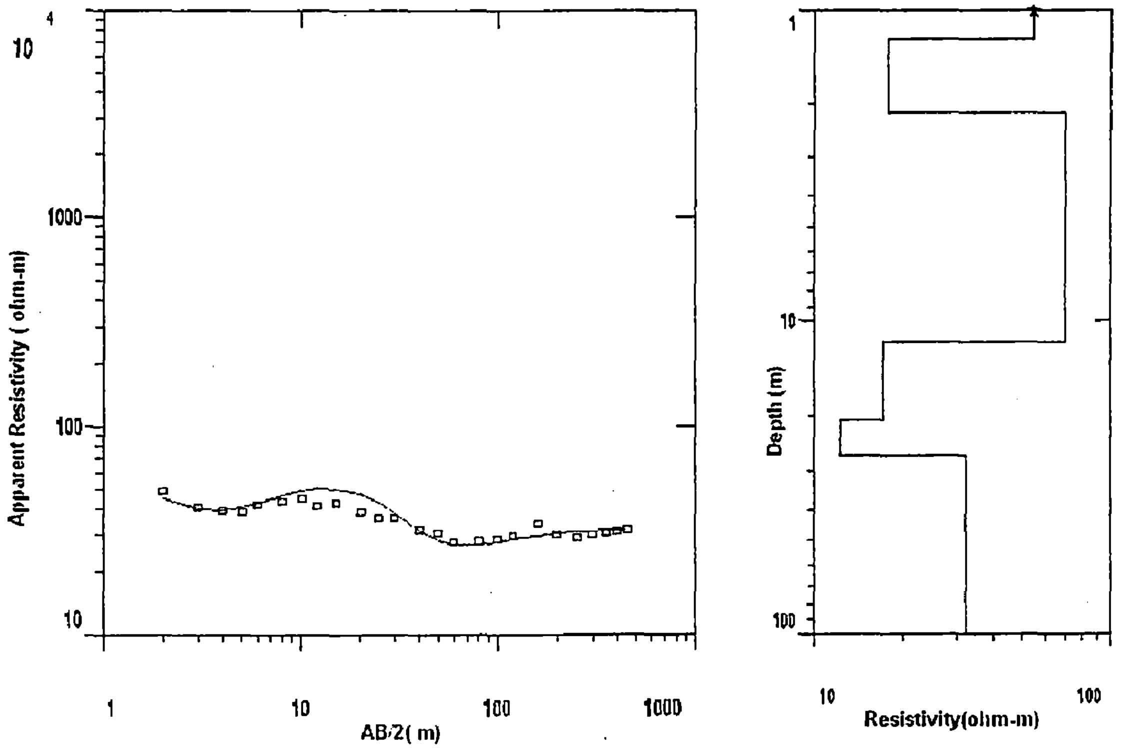

R.M.S.E : 4.93%

Figure 4.15 Interpreted VES curve (Resistivity)- Kailashpur Site



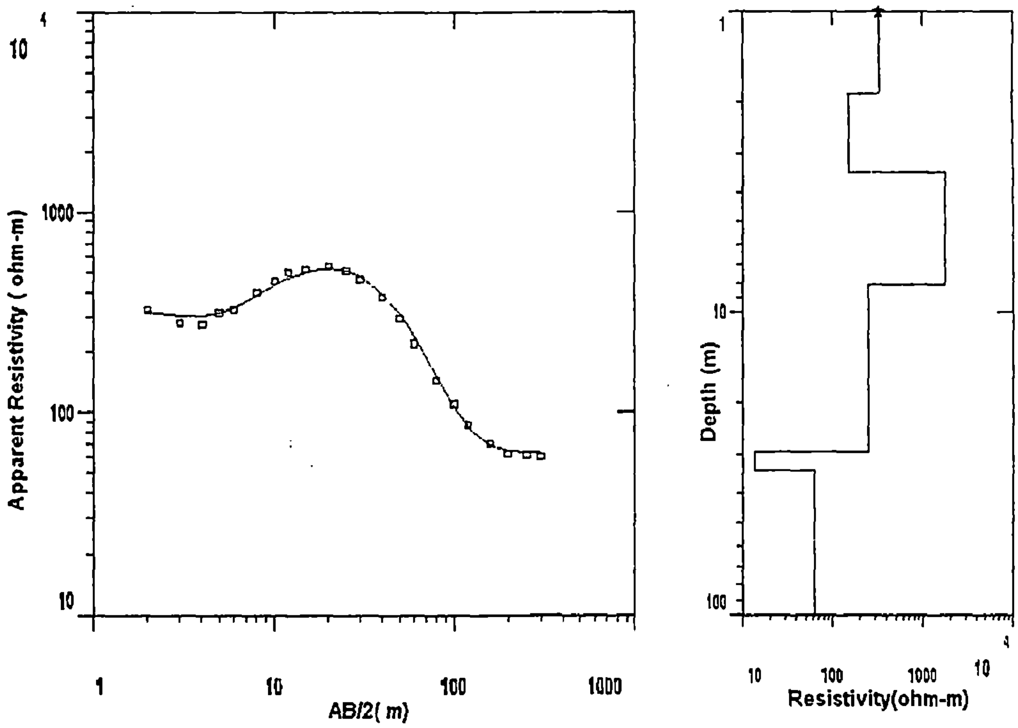

R.M.S.E : 3.39%

Figure 4.16 Interpreted VES curve (Resistivity)- Gudam Site



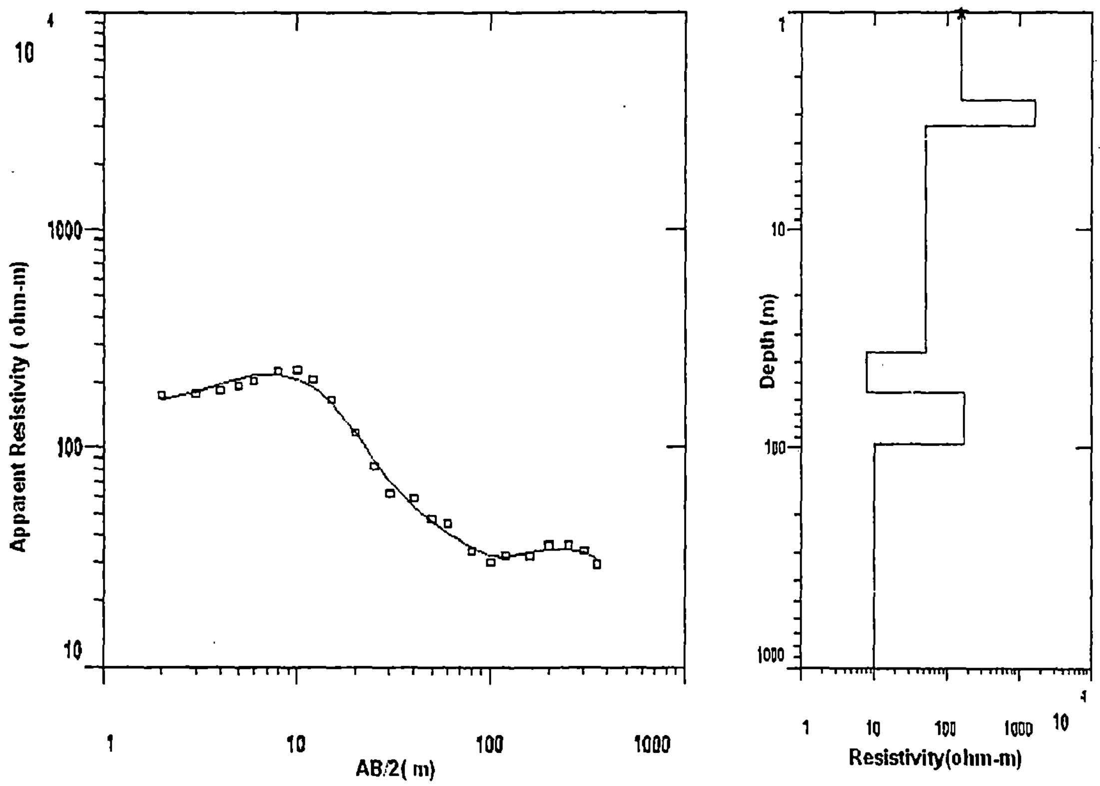

R.M.S.E : 5.51%

Figure 4.17 Interpreted VES curve (Resistivity)- Muzaffarabad Site



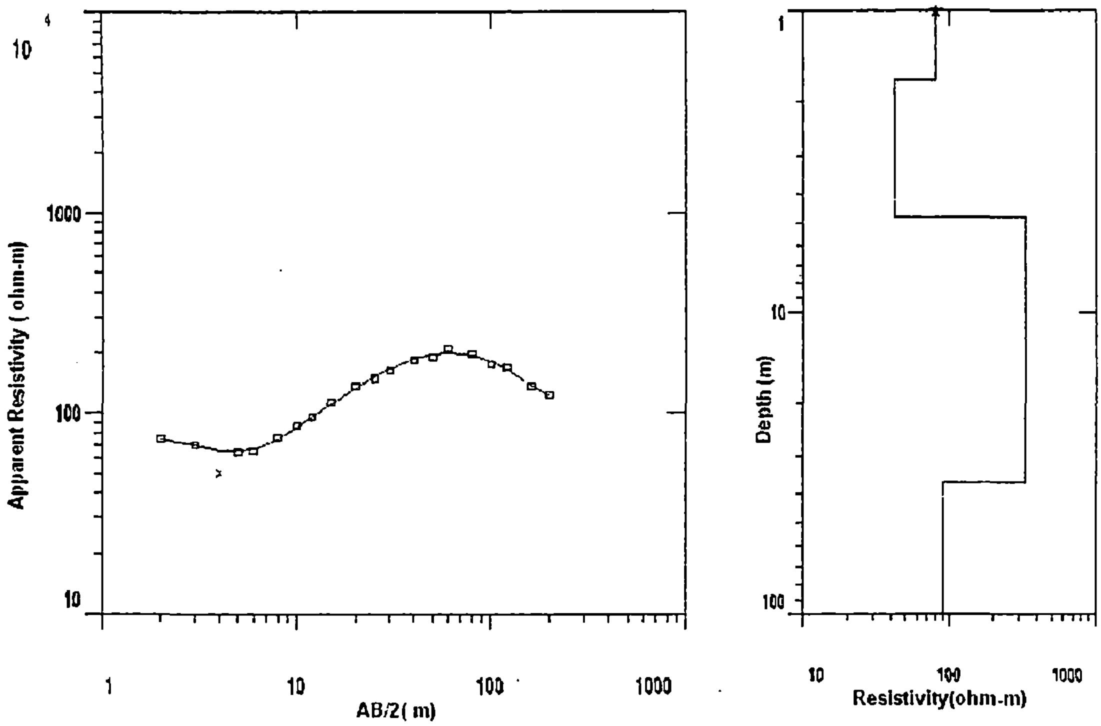

R.M.S.E : 5.1%

Figure 4.18 Interpreted VES curve (Resistivity)- Bhanera Site



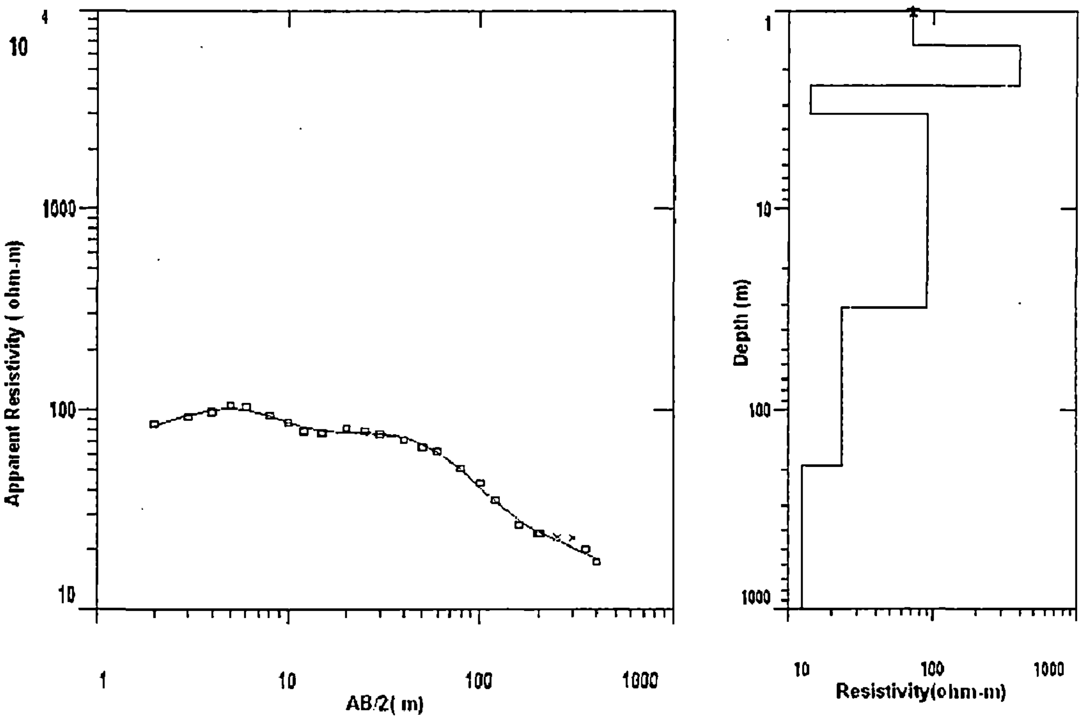

R.M.S.E : 6.55%

Figure 4.19 Interpreted VES curve (Resistivity)- Belda Site



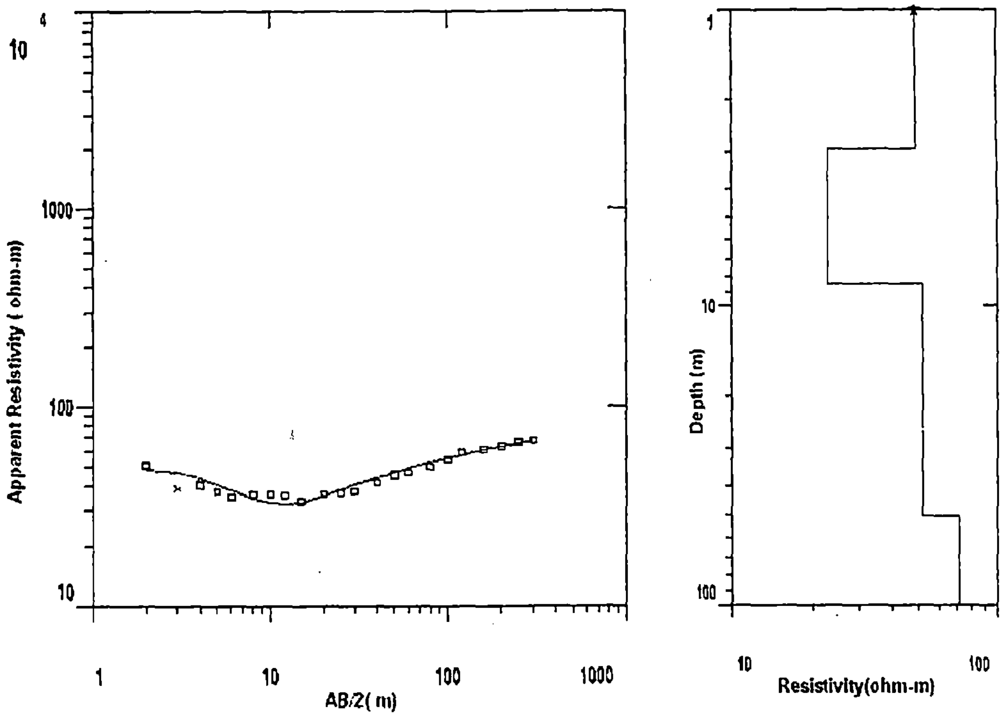

R.M.S.E : 2.19%

Figure 4.20 Interpreted VES curve (Resistivity)- Landhaura Site



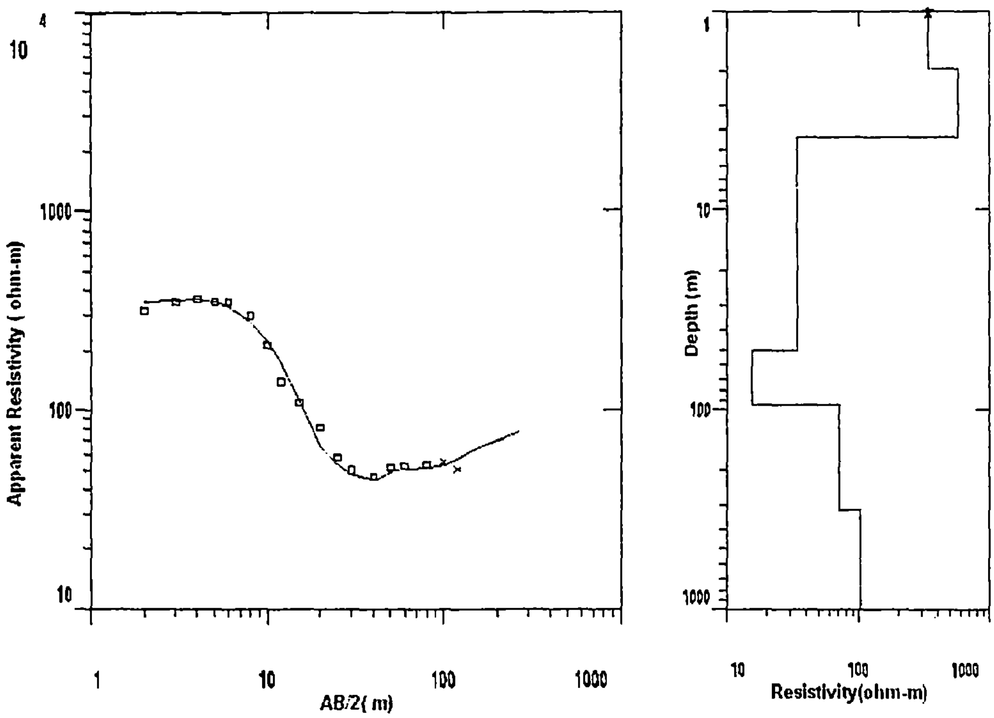

R.M.S.E : 3.4%

Figure 4.21 Interpreted VES curve (Resistivity)- Chutmalpur Site



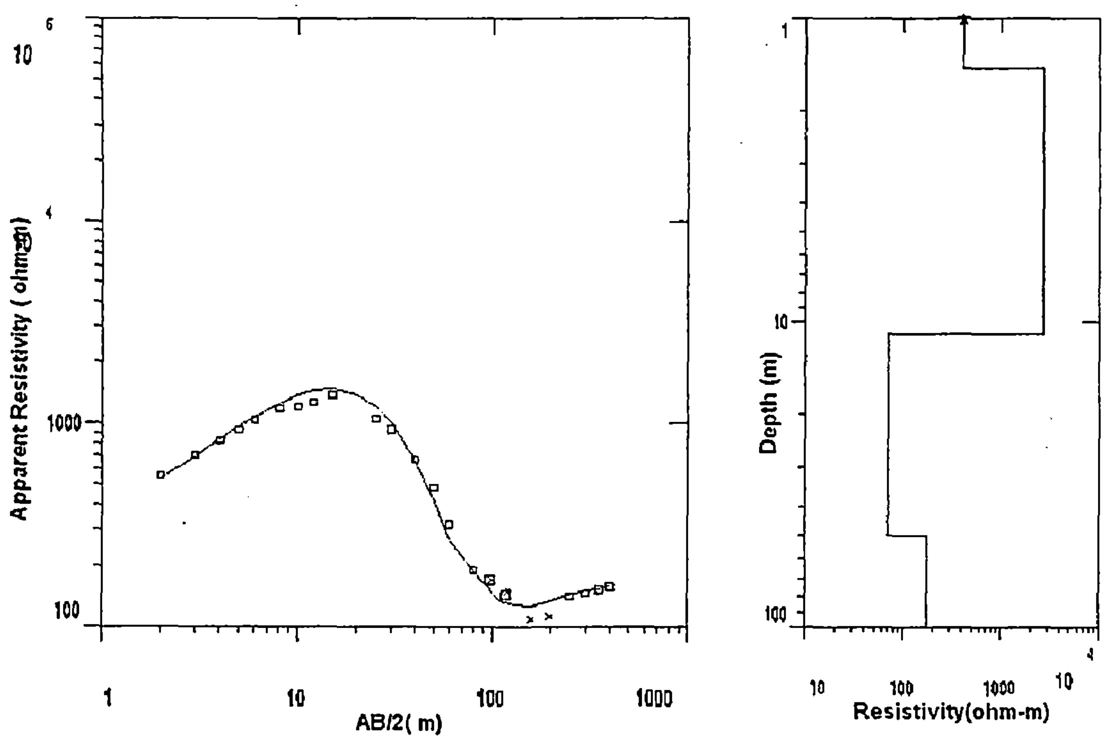

R.M.S.E : 5.5%

Figure 4.22 Interpreted VES curve (Resistivity)- Deoband Site



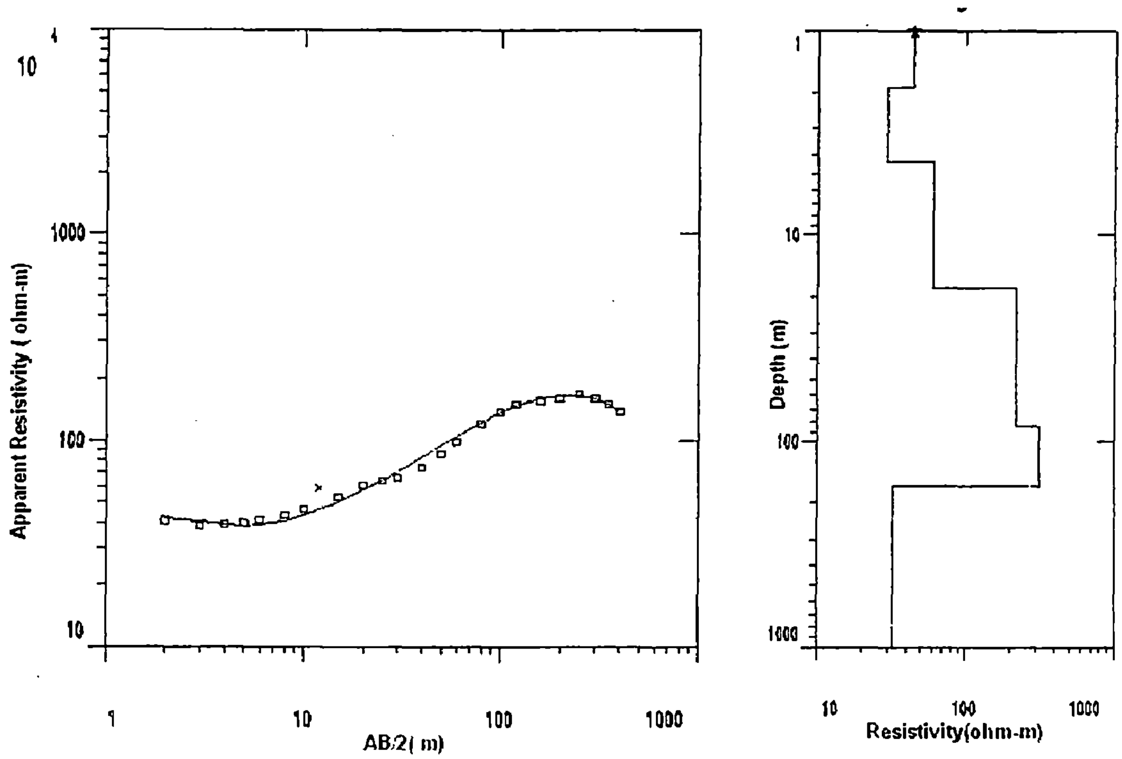

R.M.S.E : 4.39%

Figure 4.23 Interpreted VES curve (Resistivity)- Ismailpur Site



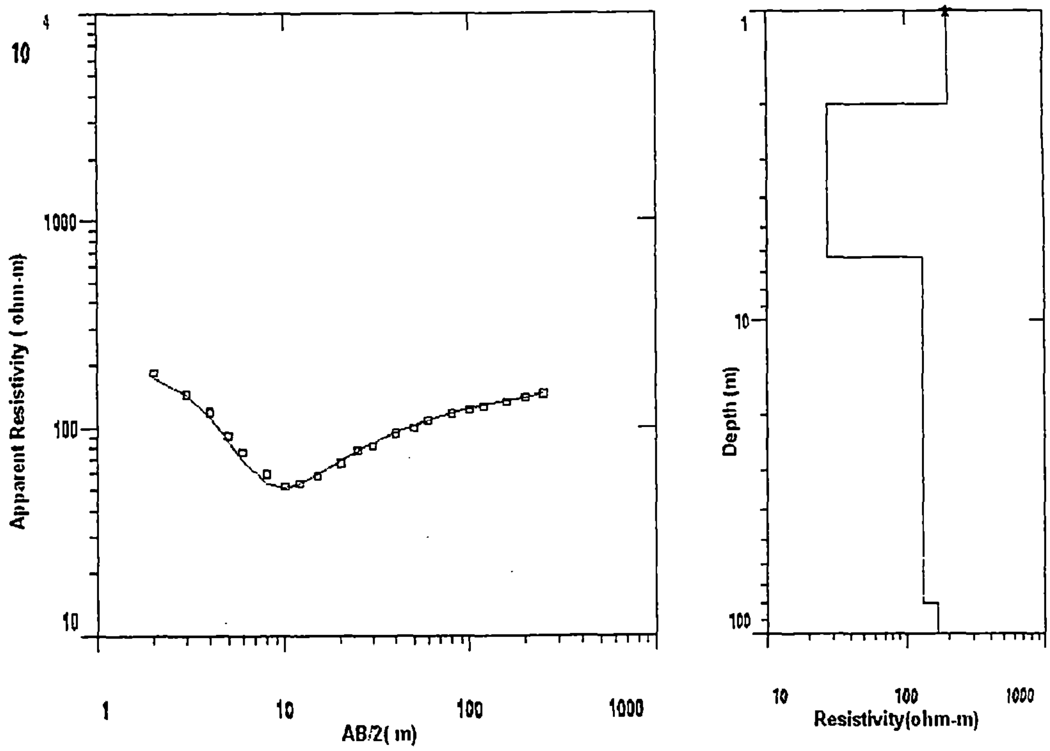

R.M.S.E : 3.49%

Figure 4.24 Interpreted VES curve (Resistivity)- Ganeshpur Site




R.M.S.E : 5.11%

Figure 4.25 Interpreted VES curve (Resistivity)- Jwalapur Site




R.M.S.E : 4.44%

Figure 4.26 Interpreted VES curve (Resistivity)- Roorkee Site

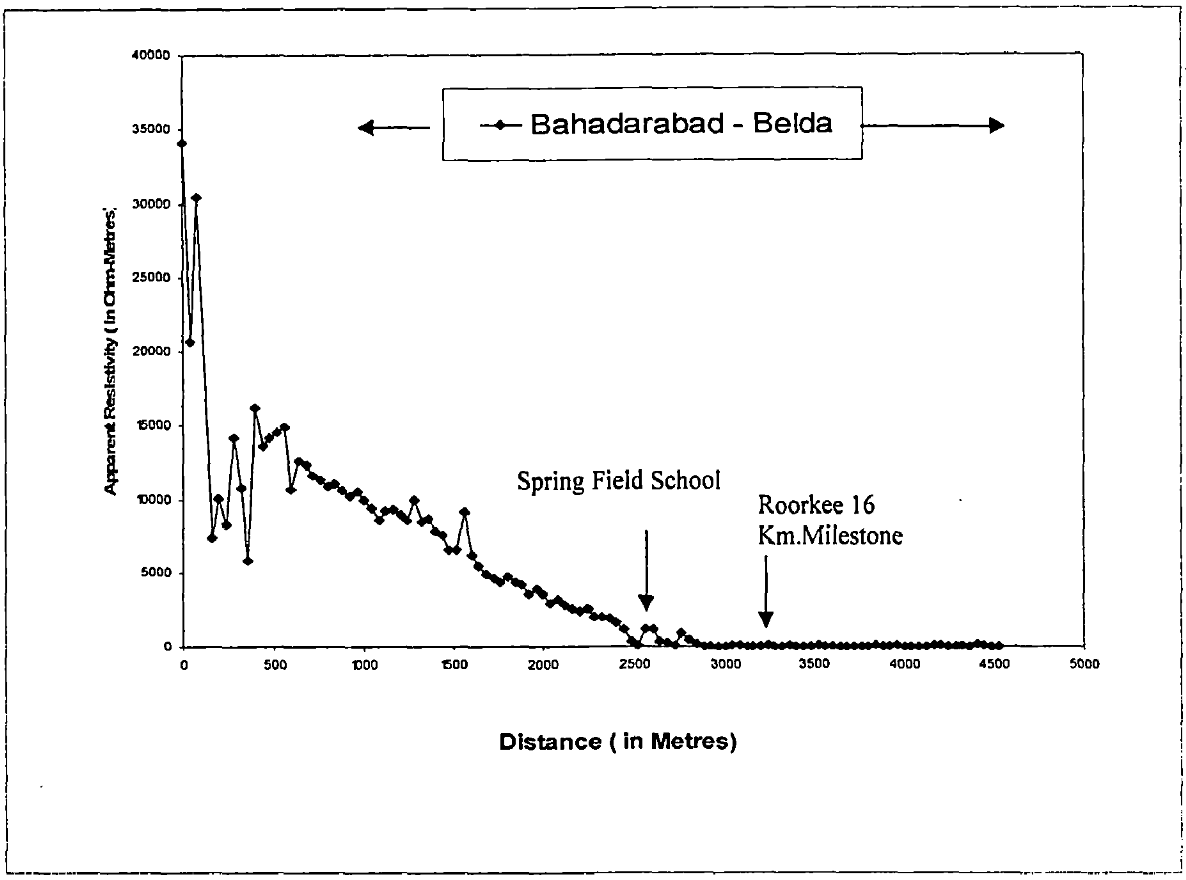



Figure 4.27 Horizontal Resistivity Profiling along Belda-Bahadarabad Section

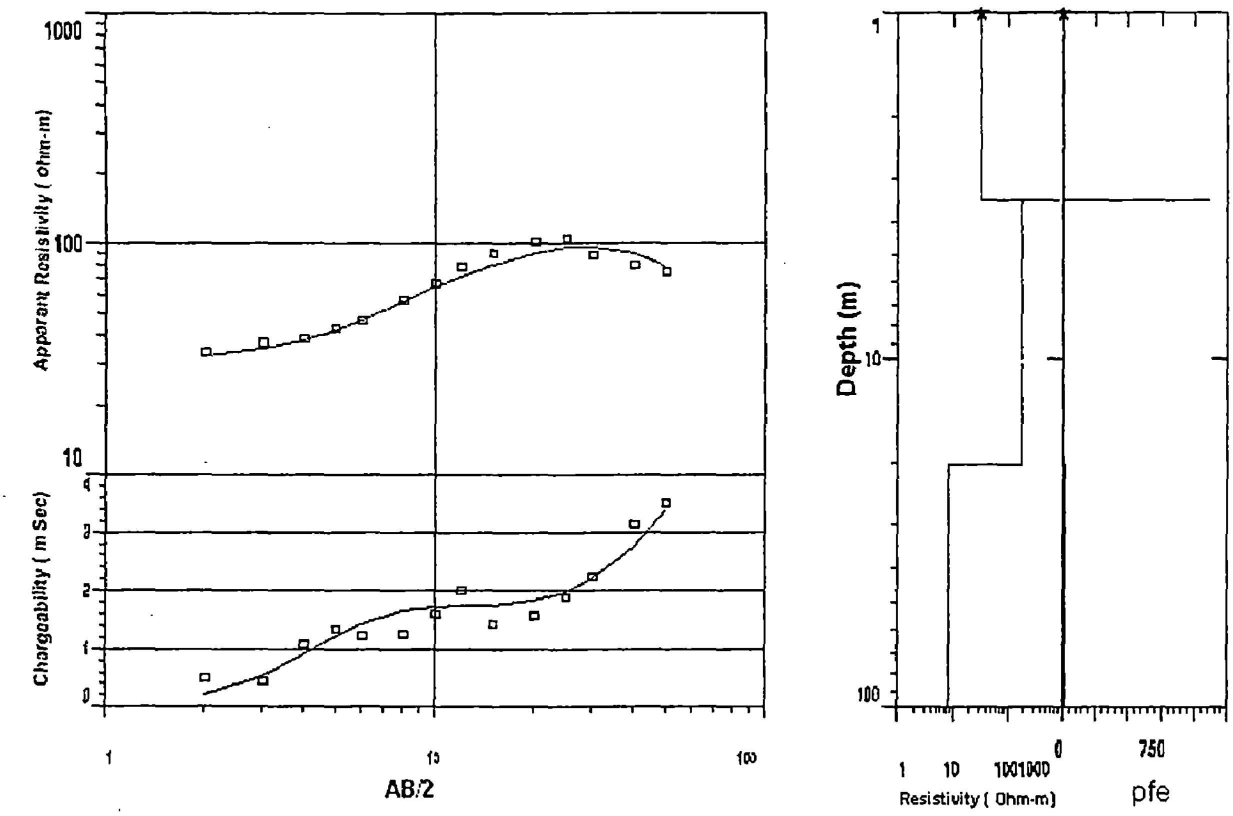



Figure 4.28 Interpreted VES curve ( I.P & Resistivity)- Nagal Site

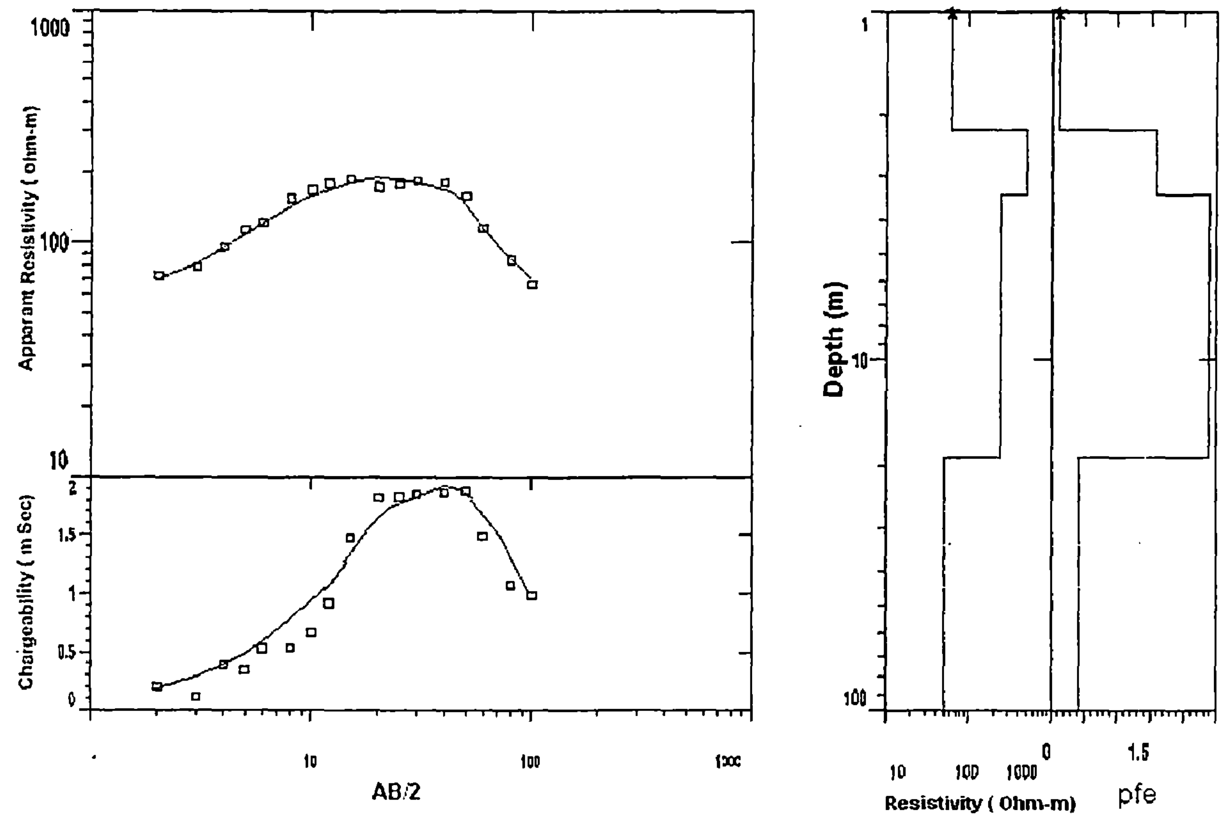



Figure 4.29 Interpreted VES curve ( I.P & Resistivity)- Nakur Site

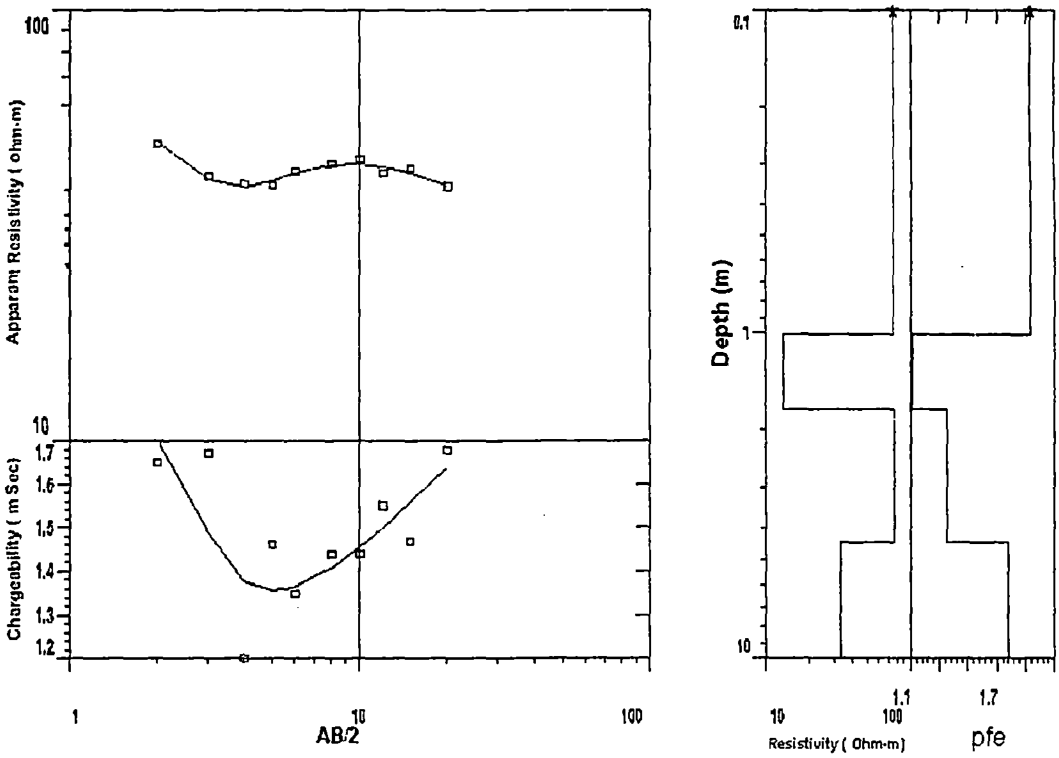



Figure 4.30 Interpreted VES curve ( I.P & Resistivity)- Muzaffarabad Site

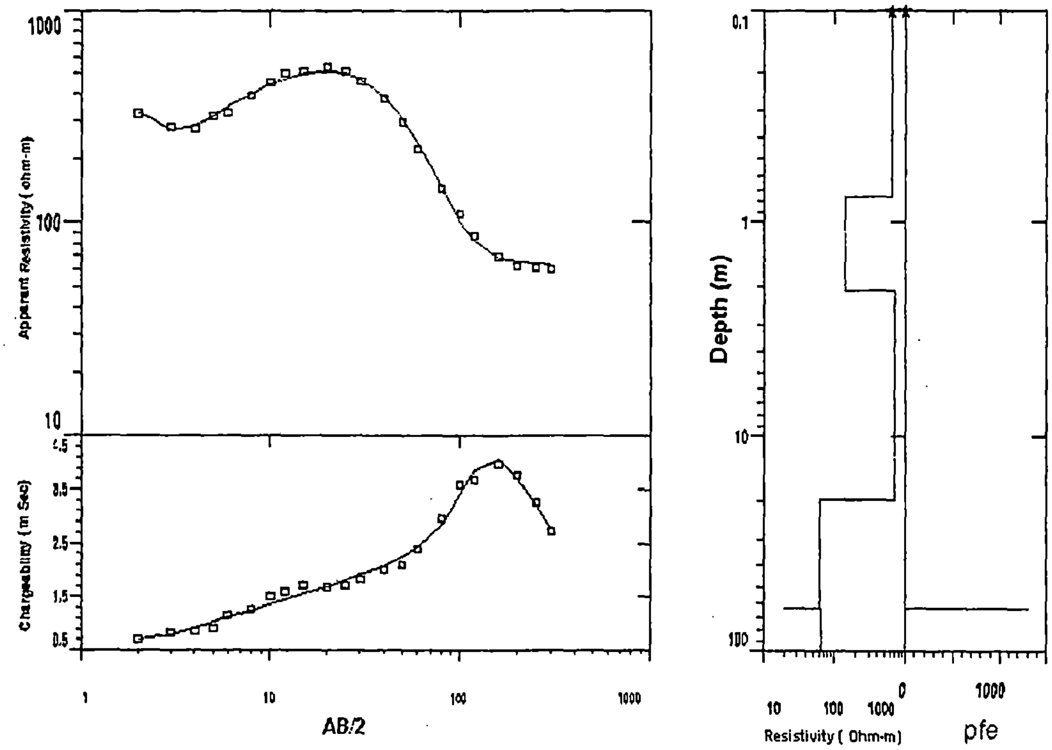



Figure 4.31 Interpreted VES curve ( I.P & Resistivity)- Bhanera Site

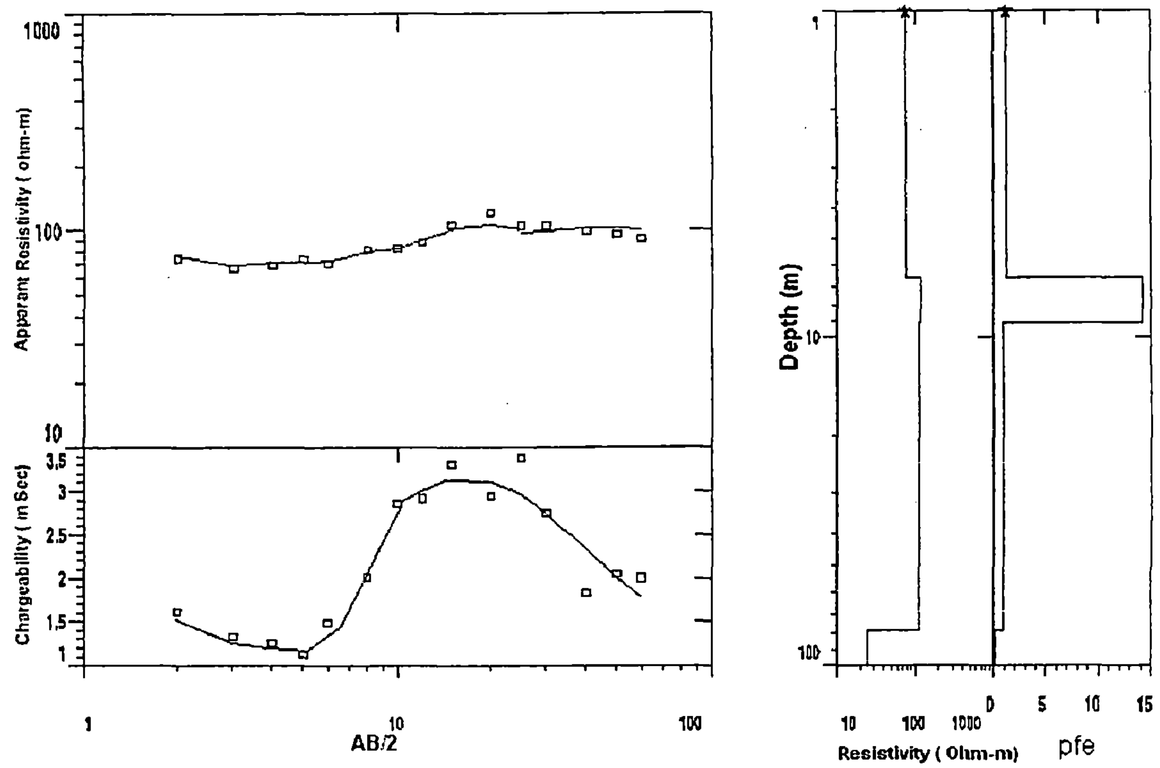



Figure 4.32 Interpreted VES curve ( I.P & Resistivity)- K.Akbarpur Site

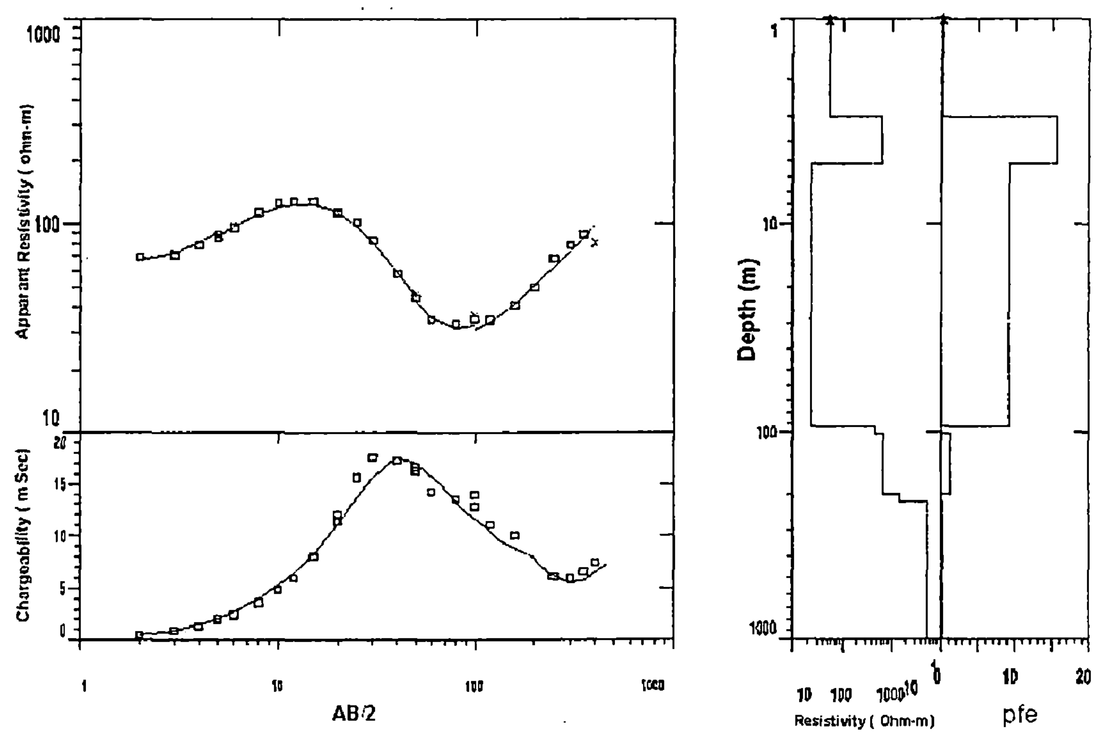



Figure 4.33 Interpreted VES curve ( I.P & Resistivity)- Sarsawan Site

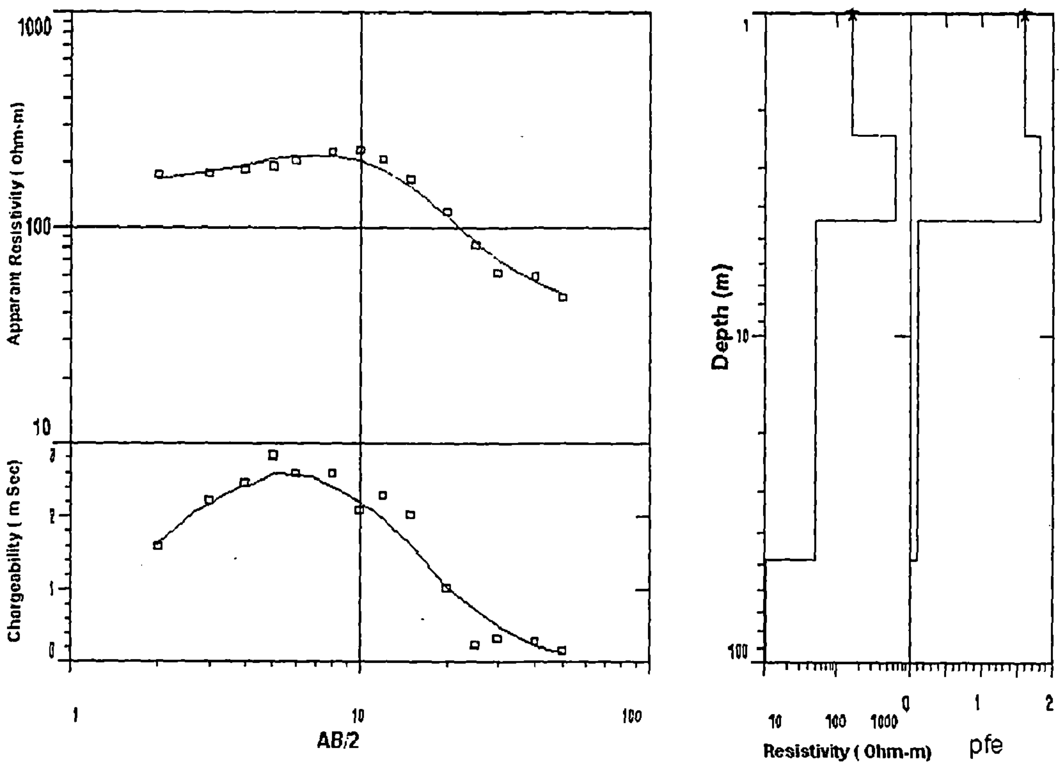



Figure 4.34 Interpreted VES curve ( I.P & Resistivity)- Belda Site

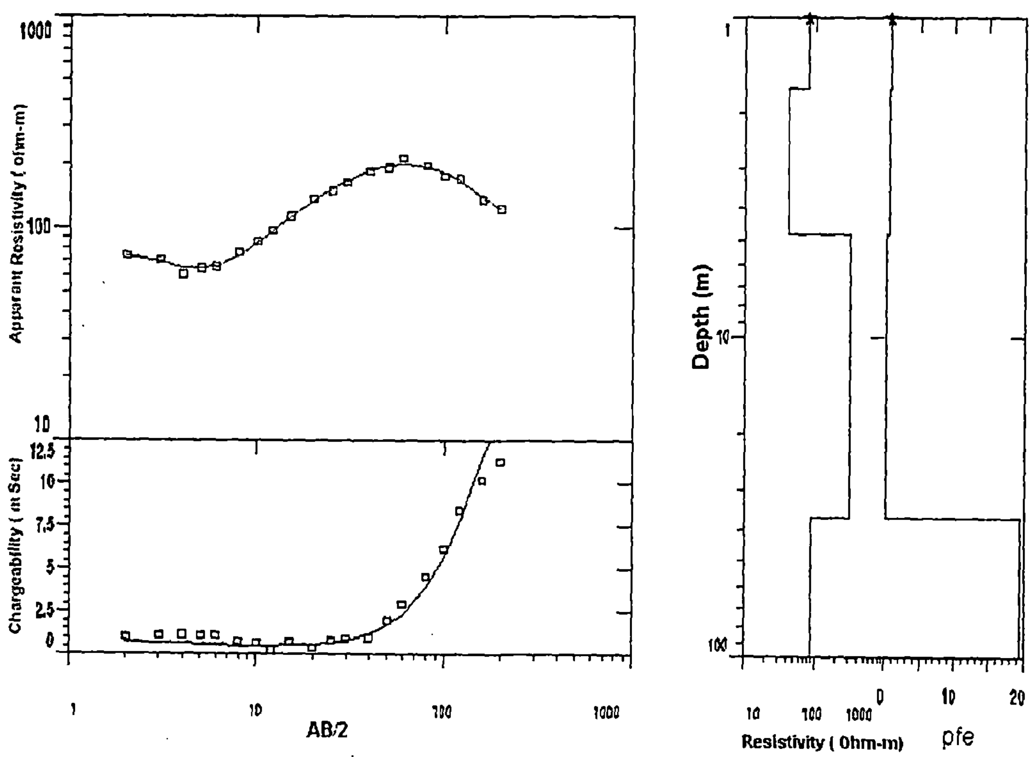



Figure 4.35 Interpreted VES curve (I.P & Resistivity)- Landhaura Site

# CHAPTER-5

## RELATIONS BETWEEN GEOELECTRIC AND HYDRAULIC PARAMETERS

Conceptually, the resistivity method is based on the Equation of conservation of charges and Ohm's law; like wise hydrodynamics is based on the Equation of conservation of mass and Darcy's law. Hence, an interrelationship between resistivity and permeability is expected to exist for porous media.

### 5.1 Analogy Between Electrical Current Flow And Ground Water Flow

Ground water flow through saturated porous media has been found to be analogous to electrical flow through a conducting medium.

According to Darcy's Law the rate of flow of water, Q, through an aquifer of hydraulic conductivity, K, cross sectional area "A" perpendicular to direction of flow, under an hydraulic gradient I is given by

$$Q = K.I.A \tag{5.1}$$

Ohm's Law states that the current density 'J' and the electric field 'E',is related through the electric property ( conductivity) "$\sigma$" of the medium as

$$J = \sigma .E \tag{5.2}$$

Equations( 5.1 & 5.2), indicate that the flow of water & flow of electrical current are analogous to each other and for an isotropic and homogeneous material; the hydraulic conductivity and electrical conductivity are constant. Ground water flows around individual grains of a porous medium and the grains may be regarded as submerged bodies within the fluid. For an incompressible fluid like water, the hydraulic conductivity, which is a measure of the ease of movement of ground water through a medium, depends on both the matrix and l properties. The matrix properties which influence ground water flow include spe ıce, grain size distribution, shape of pores, tortusity and porosity.

Similarly, the electric current flowing through a medium also takes a path of stance. The flow of electric current through a saturated porous medium takes plac c conduction through the liquid electrolyte, electronic conduction through solid pha: urface conduction which is a special form of ionic transport of electric current that t e at the solid-liquid interface by means of exchange mechanism. The matrix due t er composition is usually non-conducting except where it contains a significant portic /shale. Hence, the resistivity of a standard porous media may be considered as b trolled by porosity and water quality rather than resistivity of rock matrix. Therefo pore level the electric path is similar to the hydraulic path and hence the measuremer stivity can be well utilized to predict the hydraulic properties of the medium.

## : Geoelectric Section vs Geohydraulic Section

In a multilayer aquifer system, determination of geoelectrical parameters is icult by the fact that almost all sedimentary aquifers are anisotropic and characterize erent resistivities in longitudinal and transverse direction. In geoelectric sectio ndaries between layers are determined by resistivity contrasts rather than by ıbination of factors (age, composition etc.) used by the geologists in establi: ndaries between beds.

Consider a geoelectric column of unit cross section consisting of n horizontal h having its characteristic resistivity $\rho_i$ and thickness $h_i$. (Figure 5.1)

: parameters of geoelectric section can be defined as:

The transverse resistance is defined when the current is flowing perpendicular t ers, the total transverse resistance R is the sum of the resistances $R_i$ offered by indiv ers.

$$R = \sum_{i=1}^{n} \rho_i h_i \quad (5.3)$$

and the transverse resistivity, $\rho_t$ is defined as

$$\rho_t = \frac{\sum_{i=1}^{n} \rho_i h_i}{\sum_{i}^{n} h_i} \quad (5.4)$$

The longitudinal resistivity $\rho_L$ can be defined as :

$$\rho_L = \frac{\sum_{i}^{n} h_i}{\sum_{i}^{n} \frac{h_i}{\rho_i}} \quad (5.5)$$

The coefficient of electrical anisotropy $\lambda$, and the mean resistivity $\rho_m$, of a geoelectrical section are defined as :

$$\lambda = \sqrt{\rho_t/\rho_l} \quad (5.6)$$

$$\rho_m = \sqrt{\rho_t.\rho_l} = \rho_{VES} \quad (5.7)$$

In a geohydraulic section consisting of n layers having hydraulic conductivity, $K_i$ and thickness $h_i$ of $i^{th}$ layer. The parameter of geohydraulic section are :

Vertical Hydraulic Conductivity = $K_V = \frac{\sum_{i}^{n} h_i}{\sum_{i}^{n} \frac{h_i}{k_i}}$ (5.8)

Horizontal Hydraulic Conductivity $K_h = \frac{\sum_{i}^{n} K_i h_i}{\sum_{i}^{n} h_i}$ (5.9)

And hydraulic anisotropy $B = K_h/K_v$ (5.10)

In view of analogous behavior of electrical nature of electrical current and hydraulic flow, different workers have attempted to correlate the electrical properties with the hydraulic properties so as to predict the aquifer behaviors on the regional aquifer scale.

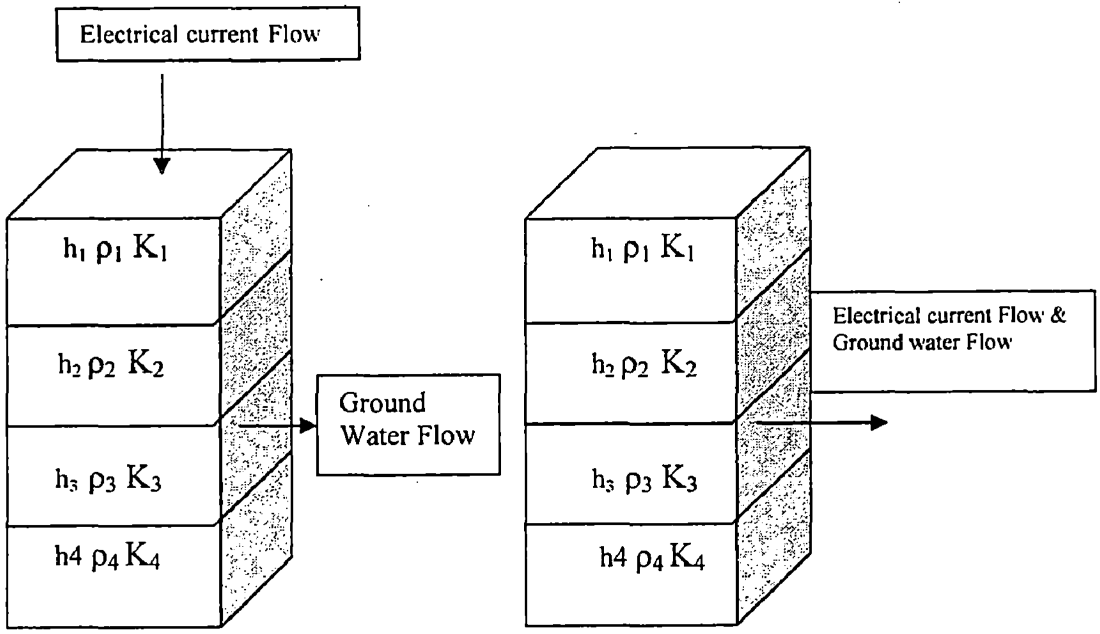



Figure.5.1 (a) Layered Model, Transverse case (b) Layered Model, Longitudinal Case.

## 5.3 Previous Works

Numerous investigators have studied the relationships between electrical and hydraulic parameters of aquifers. In past three decades, several workers have also tried to establish empirical and semi-empirical relations between different aquifer parameters and the parameters obtained by geoelectrical soundings under different geological conditions. The previous works on the subject is summarized as under:

- **Archie ( 1942)** presented an empirical relationship between resistivity and porosity as

$$\rho = a.\ \rho_w\ \Phi^{-m}. \quad (5.11)$$

where $\rho$ = Bulk resistivity of the rock ,

$\rho_w$ = Resistivity of the formation water

$\Phi$ = Porosity

m = Cementation factor

a = Emperically derived constant.

- **Bufford (1951)** extended the use of above Equation to porous media saturated with fresh water and measured the formation factor and intrinsic permeability of some graded sand samples and found that both formation factor and intrinsic permeability are directly related to the aquifer material.

- **Pfannkuch (1969)** discussed the factors that should be considered in developing quantitative relations between electrical parameters and viscous flow parameters. He opined that in clean sands saturated with fresh water, surface conduction becomes the dominant electrical transport mechanism in addition to ionic conduction through the electrolyte and electronic conduction through the solid phase when the matrix is conductive. True formation factor can be measured if the grains in the medium are perfect insulators.
- **Vincenz (1968)** obtained good positive correlation between surface resistivity and well yield.
- **Ungemach et al (1969)** correlated transmissivity determined from the results of six pumping tests in Rhine aquifer with transverse resistance.
- **Worthington (1975)** reported an inverse correlation between a corrected formation factor and intergranular permeability.
- **Kelley (1977)** estimated hydraulic conductivity in glacial aquifers from surface resistivity measurements by developing semi-empirical relations between apparent formation factor of aquifer and hydraulic conductivities from pumping tests. Such correlations are made possible using the best available data. Good water quality data is essential so that correct value of water resistivity is used in computing formation factors.
- **Mazac and Landa (1979)** analyzed data from Czechoslovakia and concluded that relation between aquifer Transmissivity and either transverse resistance (or longitudinal conductance) is possible for both direct and inverse material-level correlations for transverse resistance, longitudinal conductance, transmissivity, and leakance. In general, semiemperical relations between formation factor (FF) and hydraulic conductivity (K) can be represented by :

$K = A \times FF^m$ (5.12)

where A, is a empirically derived constant

- **Sri Niwas and Singhal (1981)** reanalyzed data presented by Kelly (1977) emphasizing the use of transverse resistance rather than resistivity. SriNiwas and Singhal (1981) estimated aquifer transmissivity from Dar-Zarrouk parameters in porous media. They established an analytical relationship between the aquifer parameters for porous media and the Dar-Zarrouk parameters so that the former can best be estimated from surface resistivity measurements.

Taking into account a prism of aquifer material having unit cross sectional area and thickness h, the two fundamental laws (Darcy's law & Ohm's law) can be combined. as:

$T = K\sigma R$ (5.13)

and $T = (K/\sigma)C$ (5.14)

where T is the transmissivity which is obtained by multiplying the aquifer thickness with the hydraulic conductivity of the aquifer and R is the transverse resistance of the aquifer, and is obtained by multiplying the aquifer thickness and resistivity , where C is the longitudinal conductance of the aquifer, and can be calculated by multiplying the aquifer thickness and its conductivity .

Equations (5.13) and (5.14) offer two possibilities of estimating transmissivity and hydraulic conductivity from the values of transverse resistance and longitudinal conductance, once the nature of variation of products ($K\sigma$) and $K/\sigma$ is known.

Equation (5.13) will be useful if $K\sigma$ remains constant for an area. By knowing the value of this constant, the transmissivity and hydraulic conductivity can be calculated once the transverse resistance and conductivity ($\sigma$) of the aquifer are obtained by resistivity measurements. Similarly Equation (5.14) reveals that if $K/\sigma$ remains constant, transmissivity and hydraulic conductivity can be calculated by knowing the electrical conductivity and longitudinal conductance of the aquifer. However, either of the two propositions could be true and only one relation out of Equation (5.13) and (5.14) may be useful in particular case.

They concluded that the relations between transverse resistance and transmissivity are more meaningful than relation between longitudinal conductance and transmissivity.

- **Kosinski & Kelly (1981)** correlated saturated thickness resistivity with hydraulic conductivities obtained from pumping tests in southern Rhode Island. Two bedrock valleys (Pawcatuck river basin), filled with glacial outwash material, were investigated. The Pawcatuck River Basin includes north to south trending preglacial valleys filled with glacial outwash materials which constitute the present-day aquifers. The bed rock valleys are filled with stratified outwash deposits which often grade into and are commonly underlain by till. Outwash deposits consisting of unconsolidated gravel, sand and silt form principle aquifers. The thickest deposits generally occur along the axis of the buried bedrock valleys and often vary abruptly in depth within short distances. Saturated thicknesses of outwash range from 40 feet to 90 feet in the Beaver River study area. In both areas, the deposits generally thicken to the south. Kosinski and Kelly inferred that estimating aquifer Transmissivity; it is necessary only to determine the average aquifer resistivity, water resistivity, and saturated thickness. The use of apparent formation factor, or normalized resistivity, is essential in any hydro-geological investigation. Apparent formation factor, for a saturated material, is defined as the total resistivity of the material divided by the resistivity of the saturating fluid. Similarly, normalized resistivity may be used to maintain units of resistivity. They have shown that useful relations can be developed between aquifer hydraulic and electric properties for water table aquifers where entire saturated thickness comprises the aquifer.

**Urish (1981)** presented an analysis of conditions of Southern Rhode Island which generally support an observed direct relationship between aquifer formation factor and hydraulic conductivity. He used simple layer models to suggest the probable influence of aquifer layering on correlations. The model demonstrates that intergranular surface conductance is an important factor at small grain sizes and high pore water resistivity, operating to lower the apparent formation factor. The model further shows that direct relationships between hydraulic conductivity and formation factor are weak in the normal range of pore water resistivity, being strongly dependent of porosity.

- **Singhal and SriNiwas (1983)** modified the analytical relationship proposed by SriNiwas and Singhal for alluvial aquifers of Southern U.P., India after taking into consideration the spatial variation of quality of water within the area. SriNiwas and Singhal modified Equation (5.13) by taking into consideration a "normalized aquifer resistivity" instead of "aquifer resistivity" (Kosinski and Kelly, 1981). The normalization factor is always the ratio of actual average aquifer water resistivity ($\rho_{wav}$) and the aquifer water resistivity ($\rho_w$) at a particular location. Thus Equation (5.13) can be written as

$$T = K\sigma' R' \qquad (5.15)$$

Where

$\sigma' \left( = \sigma \dfrac{\rho_w}{\rho_{wav}} \right)$ and $R' = R\left( \dfrac{\rho wav}{\rho w} \right)$ are, respectively, normalized conductivity and normalized transverse resistance of the aquifer. Equation (5.15) gives an analytical relation between aquifer transmissivity and the so called "normalized transverse resistance" of the aquifer by taking into consideration the variation of quality of aquifer water at different places. In this Equation, product $K\sigma'$ remains constant.

A natural corollary of Equation (5.15) can be written as,

$$K = \alpha\rho' \qquad (5.16)$$

where, $\alpha$ is equal to product $K\sigma'$ which is always constant in a basin and $\rho'$ is the normalized aquifer resistivity. Equations (5.15) and (5.16) appear to be useful for computing the transmissivity and hydraulic conductivity of the aquifers in porous, homogeneous, and isotropic media where the variation on quality of ground water is of consequence influencing the bulk resistivity of the aquifer.

- **Kelly and Reiter (1984)** examined the theoretical influence of aquifer anisotropy caused by layering on relations between aquifer hydraulic and electrical properties. The basis for such relations appears to be for clay-free aquifers. These authors computed random pairs of average hydraulic conductivity and average longitudinal resistivity. They sorted the values based on hydraulic anisotropy and found that for constant hydraulic anisotropy the points lie approximately along a straight line; shifting from this line increases with increase in anisotropy. If anisotropy is constant, then the slope would be unaffected but the intercept of the line on Y-axis would increase with increasing anisotropy.

An approximate three-parameter model was derived by Kelly & Reiter from the model results assuming a relation of the form:

$$K_h = 5.13 * 10^{-6} B^n r_l^{1.43} \tag{5.17}$$

with

B= $K_h/K_v$

The hydraulic anisotropy, where $K_v$ and $K_h$ are the vertical and horizontal hydraulic conductivities respectively. The constant n varies with anisotropy. In general the Equation (5.17) can be represented in generalized form as:

$$K_h = A.B^n \rho_l^m, \tag{5.18}$$

where A and m are the empirically derived constants from the log-log relation $K = A.(FF)^m$ . Figure 5.2 is a sounding curve presented by Kosinski and Kelly(1981) which is a typical curve obtained in southern Rhode Island. Basically the curve can be represented by a four layer model consisting of topsoil, unsaturated zone, saturated aquifer, and resistive bed. The parameter used to define the aquifer is its longitudinal resistivity.

Figure 5.3 shows the graphically that current flow in the aquifer (layer3) is horizontal. For another contrasting case in which the bottom layer was conducting, the current flow in the aquifer (layer3) is generally perpendicular to the aquifer ( Figure 5.4) and the transverse resistivity of the aquifer is used as electrical parameter.

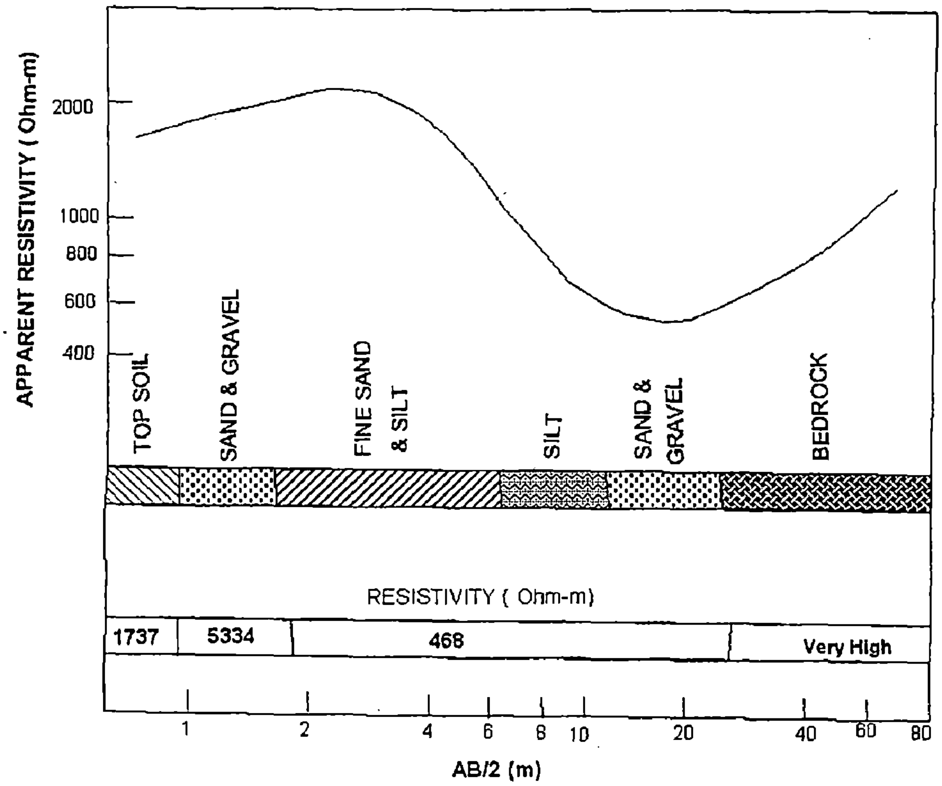



**Figure5.2 Geoelectrical depth sounding with resistivity and depth**

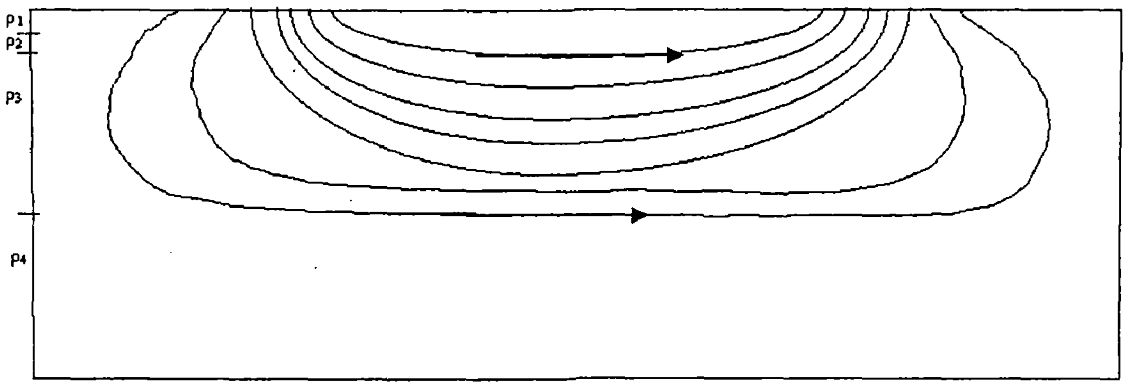



**Figure5.3 Electrical current flow for resistive substratum**

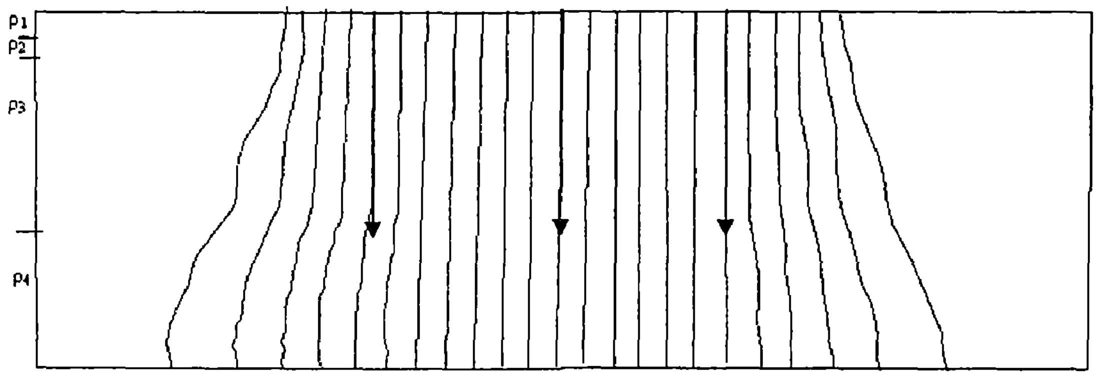



**Figure5.4 Electrical current flow for conductive substratum**

- **Mazac et al (1985)** suggested a general hydrogeophysical model which states that the anisotropic aquifers characterized by alternating sand and clay layers, the choice of the most convenient geophysical parameter to obtain optimum correlation with hydraulic conductivity depends on the direction of groundwater flow relative to the layering. If the flow is parallel to the bedding the best correlation is obtained between the hydraulic conductivity and the average transverse resistivity. If flow is normal to the bedding, then the best correlation is obtained between the hydraulic conductivity normal to the bedding and the average longitudinal resistivity. In situation where aquifer rests on resistive bedrock, the longitudinal conductance of the aquifer layer is the parameter defined by the sounding curve. Conditions where the transverse resistance is measured occur when the aquifer rests on a less-permeable and conducting material rather than directly on bedrock. Under these conditions five layers can often be distinguished on the sounding curve and the transverse resistance and under favorable conditions the thickness and average transverse resistivity of the aquifer layer can be determined. The determination of either parameter depends on hydrogeophysical conditions of the aquifer and the adjacent layers.
- **Sri Niwas et al (1985)** gave case histories of alluvial aquifers establishing the applicability of the relation $T=\alpha R'$ between transmissivity and modified transverse resistance than using $T=R'$. The analytical relation is based on the fact that $K\sigma'=\alpha$ is relatively constant for homogeneous porous formations. The method is quite useful in that if the hydraulic conductivity of the aquifer at a reference point is known, it can be estimated at other locations with the help of surface geo-electrical measurements.
- **Frohlick and Kelly (1985) and Huntley (1986)** generally confirmed the wider applicability of direct relations between apparent formation factor and hydraulic conductivity for granular aquifers and transverse resistance and transmissivity in glacial aquifers in different parts of U.S.A.

- **Shakeel Ahmad et al (1988)** used the method of co-kriging to estimate the Transmissivity, from measurements of specific capacity and electrical transverse resistance.
- **Singhal et al (1998)** proposed a empirical relationship between hydraulic parameters and electrical parameters of alluvial anisotropic aquifers of Saharanpur area, western Uttar pradesh. Three types of empirical relations were established, for estimating the hydraulic parameters from electrical data. They concluded that an estimate of hydraulic conductivity and Transmissivity of aquifers with reasonable accuracy can be made at aquifer level by using relations between hydraulic properties and resistivity parameters.
- **Yadav and Abolfazli (1998)** attempted to relate the hydraulic and geoelectric parameters in semiarid regions of Jalore, Northwestern India in various ways and suggested that hydraulic conductivity is linearly related with the normalized aquifer resistivity and similarly transmissivity is also linearly related with normalized transverse resistance.
- **Lima et al.(2001)** simulated the electrical current density distribution ($j = \hat{r} J_r + \hat{z} J_z$; $\hat{r}$ *and* $\hat{z}$ being unit vectors in the longitudinal and vertical directions, respectively) in aquifer. They found that, in the case of highly resistive substratum, the longitudinal flow is dominant, implying that longitudinal resistivity is the characteristic parameter in the electrical flow system. This physical situation can be linearly modeled by combining the block resistors in parallel. Whereas, in case of a highly conductive substratum, the vertical component is stronger, implying that the characteristic parameter would be the transverse resistance. Obviously, this case can be modeled using block resistors in serial combination.
- **Sri Niwas and Lima (2003)** developed analytical Equations separately for saline and for fresh water saturations. They explained a model in which the aquifer system overlays an impervious substratum, such that the hydraulic flow is dominantly horizontal. Electrically, the substratum may be either more conductive (clay/shales) or more resistive (compact hard

rock) than the aquifer material. In each case, the current flow within the aquifer is greatly influenced by the electrical nature of its substratum. For perfectly insulating or perfectly conducting substratum, the relation between hydraulic parameter and electrical parameter can be written as $K=(T/C_l)\sigma$ and $K=(T/R_t)\rho$. They concluded that in case of highly resistive sub-stratum; the longitudinal flow is dominant, implying that longitudinal resistivity is the characteristic parameter in the electrical flow system. Where as, in case of highly conductive substratum, the horizontal component is still there but the current flow in the characteristic unit column is now dominantly vertical.

Various relationship between the hydraulic & electrical parameters are summarized in Figure 5.5 and 5.6

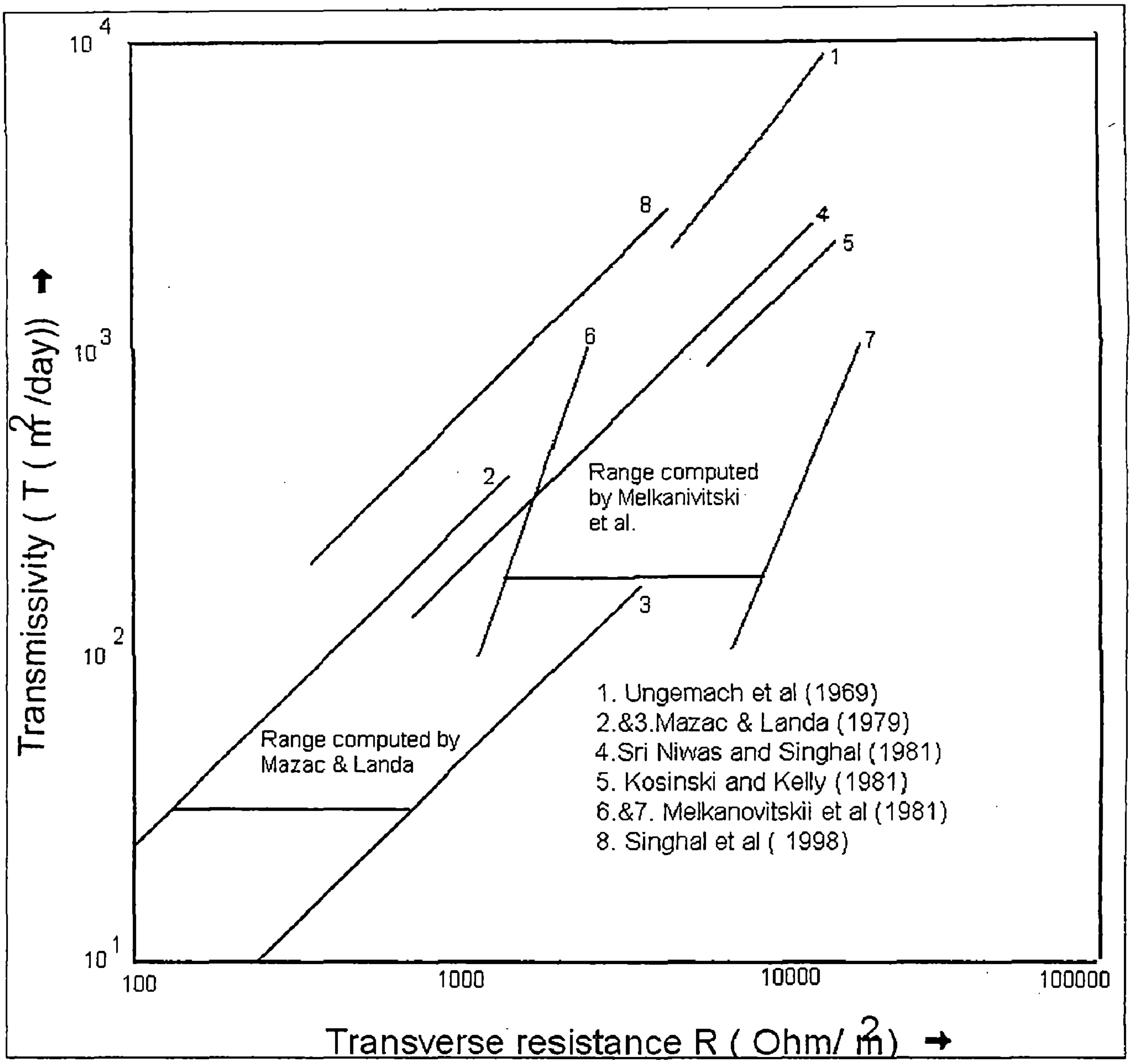



**Figure 5.5 Relation Between Aquifer Transmissivity And Transverse Resistance**

( Modified after Mazac & Landa,1985)

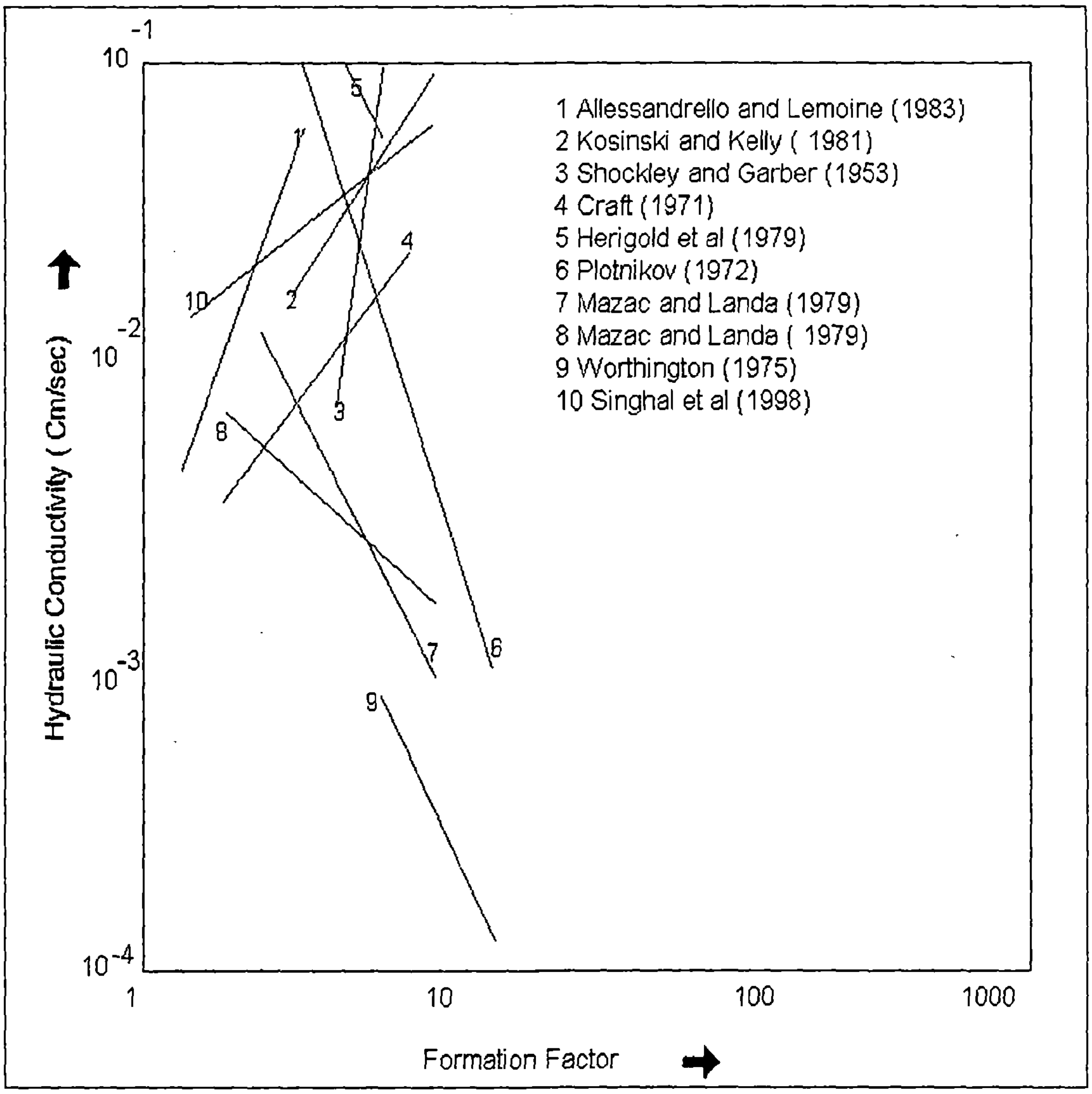



**Figure 5.6 Relation Between Hydraulic Conductivity And Formation Factor**

( Modified after Mazac & Landa,1985)

## 5.4 Relations Between Aquifer Parameters And Geoelectric Parameters In The Study Area

Various hydraulic parameters and geoelectric parameters are calculated for establishing relationships between them. The various parameters used for the study area in respect of electrical soundings and pumping test analysis is given in Table 5.1A,5.1B,5.1C,and 5.1D.

# Table 5.1A Evaluated Electrical and Hydraulic Parameters

| Evaluated Parameters | Name of Site | | | | | |
|---|---|---|---|---|---|---|
| | Gangoh | Nagal | Nanauta | Nakur | K.Akbarpur | Fatehpur |
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Thickness of aquifer ( From Resistivity) | 22.13 | 18.16 | 22.70 | 20.85 | 86.41 | 86.13 |
| Transverse resistance ( C ) ($\sum\rho_i h_i$) | 1847.41 | 1335.48 | 1251.90 | 3185.43 | 6134.24 | 4806.88 |
| Transverse resistivity ($\rho_t = \sum\rho_i h_i / b_r$). | 83.48 | 73.54 | 55.15 | 152.78 | 70.99 | 55.81 |
| Longitudinal conductance ( C ) ($\sum h_i/\rho_i$) | 0.27 | 0.25 | 0.41 | 0.14 | 1.21 | 1.60 |
| Longitudinal resistivity($\rho_l = b_r / \sum h_i/\rho_i$) | 83.51 | 73.54 | 55.10 | 154.44 | 71.41 | 53.83 |
| Average resistivity of aquifer ($\rho_{av}$ ( ohm-m)) | 83.49 | 73.54 | 55.12 | 153.61 | 71.20 | 54.81 |
| Electrical anisotropy($\lambda$=sqrt.$\rho_t/\rho_l$) | 1.000 | 1.00 | 1.00 | 0.99 | 1.00 | 1.02 |
| Average Transmissivity(T) (m2/day) | 595.00 | 674.16 | 472.09 | 1532.29 | 895.00 | 1340.41 |
| Thickness of aquifer(b) | 23.00 | 20.00 | 21.70 | 25.00 | 88.00 | 88.01 |
| Average hydraulic conductivity ($K_h$=T/b) | 25.87 | 33.71 | 21.76 | 61.29 | 10.17 | 15.23 |
| Vertical permeability ($K_v$(m/day)) | 1.667 | 1.773 | 1.34 | 2.87 | 0.106 | 0.287 |
| Hydraulic anisotropy(B=$k_h/k_v$) | 15.52 | 19.01 | 16.24 | 21.36 | 95.94 | 53.07 |
| Resistivity of water($\rho_w$)(At 25$^0$ C) | 21.60 | 11.60 | 17.88 | 9.21 | 22.27 | 14.90 |
| Average resistivity of water( $\rho_w$(avg.)) | 17.11 | 17.11 | 17.11 | 17.11 | 17.11 | 17.11 |
| Modification Factor $\rho_w$(avg.)/$\rho_w$ | 0.79 | 1.48 | 0.96 | 1.86 | 0.77 | 1.15 |
| Modified aquifer resistivity $\rho' = \rho_{av} * \rho_w$(avg.) /$\rho_w$(ohm-m) | 66.14 | 108.47 | 52.75 | 285.37 | 54.70 | 62.94 |
| Modified aquifer conductivity ($\sigma' = 1/\rho'$) | 0.02 | 0.01 | 0.02 | 0.004 | 0.02 | 0.02 |
| $K_h * \sigma'$ (mho/day) | 0.39 | 0.31 | 0.41 | 0.21 | 0.19 | 0.24 |
| Formation Factor (FF=$\rho_{av}/\rho_w$) | 3.87 | 6.34 | 3.08 | 16.68 | 3.20 | 3.68 |
| Modified transverse Resistance (R'=R*$\rho_w$(avg.)/$\rho_w$ | 1463.39 | 1969.83 | 1197.99 | 5917.77 | 4712.93 | 5519.85 |
| Modified Transverse resistivity($\rho'_t$) | 66.13 | 108.47 | 52.77 | 283.83 | 54.54 | 64.09 |
| Modified Longitudinal resistivity($\rho'_l$) | 66.15 | 108.47 | 52.72 | 286.92 | 54.87 | 61.82 |

## Table 5.1B Evaluated Electrical and Hydraulic Parameters

| Evaluated Parameters | Name of Site | | | | | |
|---|---|---|---|---|---|---|
| | Kashipur | Barthakaith | KheraAfghan | Salehpur | Sarsawan | Kailashpur |
| | 7 | 8 | 9 | 10 | 11 | 12 |
| Thickness of aquifer ( From Resistivity) | 31.00 | 79.38 | 109.91 | 105.58 | 26.67 | 112.70 |
| Transverse resistance ( R )($\sum \rho_i h_i$) | 6954.85 | 5894.75 | 18288.88 | 5712.93 | 2898.33 | 6031.95 |
| Transverse resistivity ($\rho_t = \sum \rho_i h_i / b_r$). | 224.35 | 74.26 | 166.40 | 54.11 | 108.67 | 53.52 |
| Longitudinal conductance ( C ) ($\sum h_i / \rho_i$) | 0.14 | 1.07 | 1.57 | 1.95 | 0.39 | 2.69 |
| Longitudinal resistivity ($\rho_l = b_r / \sum h_i / \rho_i$) | 224.48 | 74.26 | 70.23 | 54.11 | 68.31 | 41.96 |
| Average resistivity of aquifer ($\rho_{av}$ ( ohm-m)) | 224.41 | 74.26 | 108.10 | 54.11 | 86.16 | 47.39 |
| Electrical anisotropy($\lambda$=sqrt.$\rho_t / \rho_l$) | 1.00 | 1.00 | 1.54 | 1.00 | 1.26 | 1.13 |
| Average Transmissivity(T) (m2/day) | 1536.72 | 1240.00 | 2420.00 | 1050.00 | 1481.49 | 1874.81 |
| Thickness of aquifer(b) | 30.00 | 79.00 | 102.40 | 98.00 | - | - |
| Average hydraulic conductivity ($K_h$=T/b) | 51.22 | 15.70 | 23.63 | 10.71 | - | - |
| Vertical permeability ($K_v$(m/day)) | 2.135 | 0.589 | 0.359 | 0.116 | - | - |
| Hydraulic anisotropy(B=$k_h / k_v$) | 23.99 | 26.65 | 65.83 | 92.52 | - | - |
| Resistivity of water($\rho_w$)(At 25$^0$ C) | 16.55 | 28.73 | 24.69 | 17.00 | 9.92 | 10.75 |
| Average resistivity of water( $\rho_w$(avg.)) | 17.11 | 17.11 | 17.11 | 17.11 | 17.11 | 17.11 |
| Modification Factor $\rho_w$(avg.)/$\rho_w$ | 1.03 | 0.60 | 0.69 | 1.01 | 1.72 | 1.59 |
| Modified aquifer resistivity $\rho' = \rho_{av}$ *$\rho_w$(avg.)/$\rho_w$(ohm-m) | 232.01 | 44.23 | 74.91 | 54.46 | 148.61 | 75.43 |
| Modified aquifer conductivity ($\sigma'=1/\rho'$) | 0.004 | 0.02 | 0.01 | 0.02 | 0.01 | 0.01 |
| $K_h$*$\sigma'$ (mho/day) | 0.22 | 0.35 | 0.32 | 0.20 | - | - |
| Formation Factor (FF=$\rho_{av} / \rho_w$) | 13.56 | 2.58 | 4.38 | 3.18 | 8.69 | 4.41 |
| Modified transverse Resistance (R'=R*$\rho_w$(avg.)/$\rho_w$ | 7190.18 | 3510.59 | 12674.07 | 5749.90 | 4999.03 | 9600.62 |
| Modified Transverse resistivity($\rho'_t$) | 231.94 | 44.23 | 115.31 | 54.46 | 187.44 | 85.19 |
| Modified Longitudinal resistivity($\rho'_l$) | 232.07 | 44.23 | 48.67 | 54.46 | 117.82 | 66.78 |

# Table 5.1C Evaluated Electrical and Hydraulic Parameters

| Evaluated Parameters | Name of Site | | | | | |
|---|---|---|---|---|---|---|
| | Gudam | M.Bad | Bhanera | Belda | Landhaura | Chutmalpur |
| | 13 | 14 | 15 | 16 | 17 | 18 |
| Thickness of aquifer ( From Resistivity) | 134.01 | 9.40 | 21.23 | 33.15 | 31.86 | 27.78 |
| Transverse resistance (R ) ($\sum \rho_i h_i$) | 3566.07 | 655.65 | 5264.40 | 1704.25 | 10354.50 | 2508.25 |
| Transverse resistivity ($\rho_t = \sum \rho_i h_i / b_r$). | 26.61 | 69.75 | 247.97 | 51.42 | 325.00 | 90.29 |
| Longitudinal conductance (C) ($\sum h_i/\rho_i$) | 5.08 | 0.13 | 0.09 | 0.64 | 0.10 | 0.31 |
| Longitudinal resistivity($\rho_l = b_r / \sum h_i/\rho_i$) | 26.38 | 69.78 | 248.01 | 51.42 | 325.00 | 90.29 |
| Average resistivity of aquifer ($\rho_{av}$ ( ohm-m)) | 26.49 | 69.77 | 247.99 | 51.42 | 325.00 | 90.29 |
| Electrical anisotropy($\lambda$=sqrt.$\rho_t/\rho_l$) | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.0 |
| Average Transmissivity(T) (m2/day) | 920.00 | 95.95 | 1028.56 | 541.58 | 1335.00 | 167.58 |
| Thickness of aquifer(b) | - | 9.15 | 20.00 | 33.00 | 31.00 | 28.50 |
| Average hydraulic conductivity ($K_h$=T/b) | - | 10.49 | 51.43 | 16.41 | 43.06 | 5.88 |
| Vertical permeability ($K_v$(m/day)) | - | 0.1106 | 1.585 | 0.196 | 0.89 | 0.0108 |
| Hydraulic anisotropy(B=$k_h/k_v$) | - | 94.81 | 32.45 | 83.87 | 48.39 | 544.44 |
| Resistivity of water($\rho_w$)(At 25$^0$ C) | 19.45 | 22.32 | 14.97 | 8.09 | 20.16 | 19.88 |
| Average resistivity of water( $\rho_w$(avg.)) | 17.11 | 17.11 | 17.11 | 17.11 | 17.11 | 17.11 |
| Modification Factor $\rho_w$(avg.)/$\rho_w$ | 0.88 | 0.77 | 1.14 | 2.11 | 0.85 | 0.86 |
| Modified aquifer resistivity $\rho' = \rho_{av} * \rho_w$(avg.)/$\rho_w$(ohm-m) | 23.31 | 53.48 | 283.44 | 108.75 | 275.83 | 77.71 |
| Modified aquifer conductivity ($\sigma'=1/\rho'$) | 0.04 | 0.02 | 0.004 | 0.01 | 0.004 | 0.01 |
| $K_h * \sigma'$ (mho/day) | - | 0.20 | 0.18 | 0.15 | 0.16 | 0.08 |
| Formation Factor (FF=$\rho_{av}/\rho_w$) | 1.36 | 3.13 | 16.57 | 6.36 | 16.12 | 4.54 |
| Modified transverse Resistance (R'=R*$\rho_w$(avg.)/$\rho_w$ | 3137.04 | 502.61 | 6016.96 | 3604.42 | 8787.97 | 2158.76 |
| Modified Transverse resistivity($\rho'_t$ ) | 23.41 | 53.47 | 283.42 | 108.75 | 275.83 | 77.71 |
| Modified Longitudinal resistivity($\rho'_l$) | 23.21 | 53.50 | 283.47 | 108.75 | 275.83 | 77.71 |

## Table 5.1D Evaluated Electrical and Hydraulic Parameters

| Evaluated Parameters | Name of Site | | | | | |
|---|---|---|---|---|---|---|
| | Deoband | Ismailpur | Ganeshpur | Jwalapur | Roorkee | Saliyar |
| | 19 | 20 | 21 | 22 | 23 | 24 |
| Thickness of aquifer ( From Resistivity) | 41.97 | 46.39 | 39.00 | 66.25 | 73.50 | 18.26 |
| Transverse resistance (R) ( $\sum\rho_i h_i$) | 2173.62 | 1589.32 | 2674.62 | 14307.31 | 9678.26 | 776.78 |
| Transverse resistivity ($\rho_t = \sum\rho_i h_i / b_r$). | 51.79 | 34.26 | 68.58 | 215.96 | 131.68 | 52.08 |
| Longitudinal conductance (C) ($\sum h_i/\rho_i$) | 0.81 | 1.35 | 0.57 | 0.31 | 0.56 | 0.46 |
| Longitudinal resistivity($\rho_l = b_r/\sum h_i/\rho_i$) | 51.81 | 34.26 | 68.42 | 213.02 | 131.25 | 39.61 |
| Average resistivity of aquifer ($\rho_{av}$ ( ohm-m)) | 51.80 | 34.26 | 68.50 | 214.49 | 131.46 | 41.05 |
| Electrical anisotropy($\lambda$=sqrt.$\rho_t/\rho_l$) | 0.9998 | 0.99998 | 1.00 | 1.01 | 1.00 | 1.036 |
| Average Transmissivity(T) (m2/day) | 439.88 | 338.40 | 542.60 | 1985.00 | 1850.00 | 335.0 |
| Thickness of aquifer(b) | 40.00 | 45.72 | 35.36 | 65.53 | 70.00 | 20.0 |
| Average hydraulic conductivity ($K_h$=T/b) | 11.00 | 7.40 | 15.35 | 30.29 | 26.43 | 16.75 |
| Vertical permeability ($K_v$(m/day)) | 0.18 | - | - | - | - | - |
| Hydraulic anisotropy($B=k_h/k_v$) | 61.09 | - | - | - | - | - |
| Resistivity of water($\rho_w$)(At $25^0$ C) | 20.62 | 13.35 | 12.73 | 19.69 | 17.36 | 15.91 |
| Average resistivity of water( $\rho_w$(avg.)) | 17.11 | 17.11 | 17.11 | 17.11 | 17.11 | 17.11 |
| Modification Factor $\rho_w$(avg.)/$\rho_w$ | 0.83 | 1.28 | 1.34 | 0.87 | 0.99 | 1.07 |
| Modified aquifer resistivity $\rho'=\rho_{av}*\rho_w$(avg.)/$\rho_w$(ohm-m) | 42.98 | 43.91 | 92.07 | 186.38 | 129.57 | 43.92 |
| Modified aquifer conductivity ($\sigma'=1/\rho'$) | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.02 |
| $K_h*\sigma'$ (mho/day) | 0.26 | 0.17 | 0.17 | 0.16 | 0.20 | .0335 |
| Formation Factor (FF=$\rho_{av}/\rho_w$) | 2.51 | 2.57 | 5.38 | 10.89 | 7.57 | 2.58 |
| Modified transverse Resistance (R'=R*$\rho_w$(avg.)/$\rho_w$ | 1803.62 | 2036.95 | 3594.87 | 12432.61 | 9678.26 | 831.15 |
| Modified Transverse resistivity ($\rho'_t$) | 42.97 | 43.91 | 92.18 | 187.66 | 129.78 | 55.73 |
| Modified Longitudinal resistivity ($\rho'_l$) | 42.99 | 43.91 | 91.96 | 185.11 | 129..17 | 42.58 |

### 5.4.1. Relation between Transmissivity and Modified Transverse Resistance

In accordance with the approach suggested by SriNiwas & Singhal (1981 & 1985), the resistivity and transverse resistance of the aquifer for each well were modified by multiplying with the modification factor.

For the present study the spatial variation in the values of the product $K\sigma'$(Table-5.1A, 5.1B, 5.1C, 5.1D) when plotted against the well site numbers (Figure 5.7), showed that within the area, the product (Kσ') is almost constant with a mean value of 0.23. Therefore, the Equation (5.15) becomes,

$$T = 0.23R' \qquad (5.19)$$

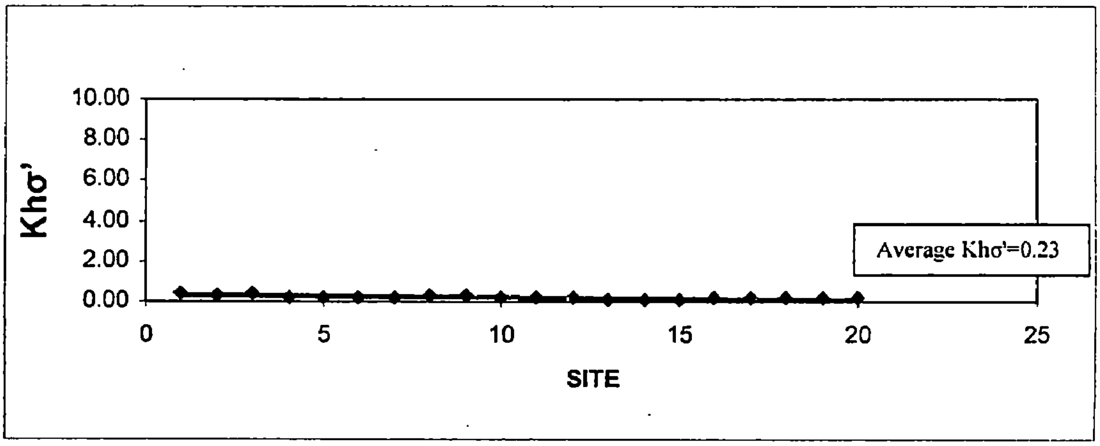



**Figure 5.7 Spatial Variation Of $K\sigma'$ For Different Sites In The Whole Study Area**

The results of the application of Equation (5.19) and the comparison between observed and calculated transmissivity are summarized in Table 5.2 with Root mean square error (r.m.s.e) of 348.

Alternatively, a linear relationship also exists between aquifer Transmissivity and modified transverse resistance (Figure 5.8). The relationship can be expressed as:

$$T = 0.1653R' + 209.02 \qquad (5.20)$$

and correlation coefficient as 0.92

The results of application of this Equation in the study area are summarized in Table5.2, giving value of transmissivity, with r.m.s.e of 238.57.

As has been discussed in chapter2 (Section 2.3.5), the study area can be divided into two hydraulic units based on the general variation in aquifer grain size parameters. Accordingly unit-1 pertaining to Yamuna deposition is comprised of fine grained sand as compared to unit2 pertaining to Ganga river deposits.

A perusal of Figure (5.8) reveals that sites belonging to hydraulic unit-1 i.e. towards river Yamuna generally fall above the best fit line. Where as, the sites plotted below the best fit line belong to hydraulic unit-2 i.e. towards river Ganga. Further, if the study area is considered as one composite unit, the value of transmissivity calculated from modified transverse resistance data differ from the actual field values considerably. Such differences may be attributed to considerable extent of anisotropy in the aquifers.

Aquifer material belonging to hydraulic unit-1 consists of comparatively fine grained material and is better sorted with uniformity coefficient ranging from 2-3.

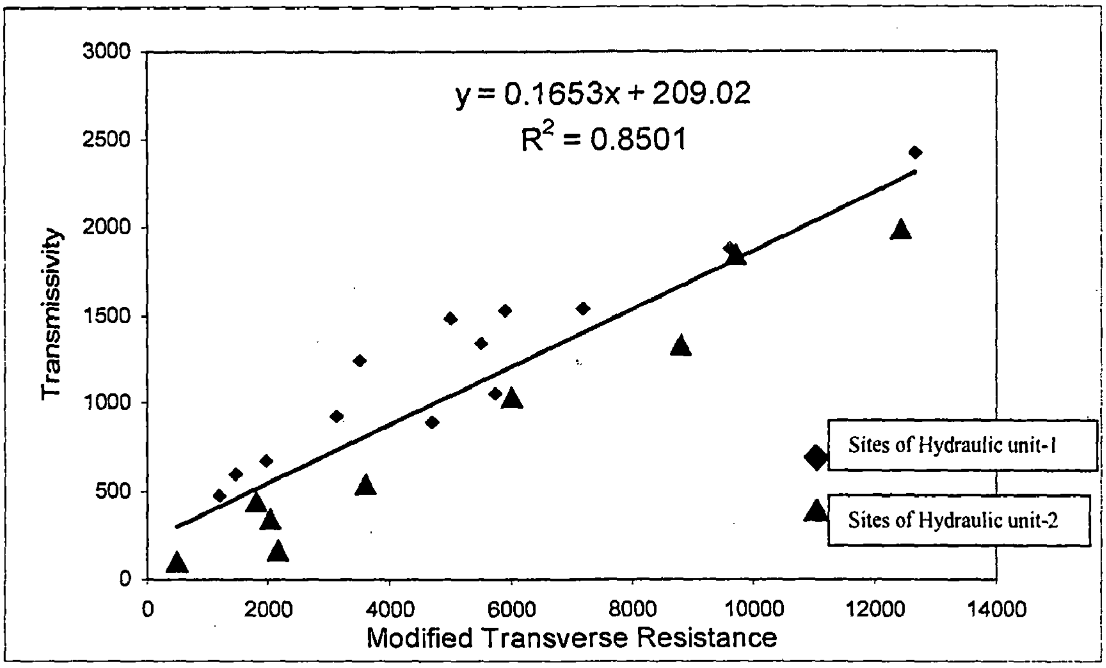



**Figure 5.8 Transmissivity vs. Modified Transverse Resistance of the study area**

On the other hand, aquifer material belonging to hydraulic unit-2 (Ganga deposits) consists of coarse grained and unsorted material with uniformity coefficient more than 4.

In view of this large variation in observed and calculated values a linear regression is preferred separately for the two hydraulic units (having sediments deposited by Yamuna & Ganga rivers).

## Hydraulic Unit-1

Figure (5.9) shows a linear relationship between transmissivity and modified transverse resistance of hydraulic unit-1. The relationship between transmissivity & modified transverse resistance can be expressed as under:

$$T = 0.1597R' + 402.05 \qquad (5.21)$$

with the correlation coefficient as 0.94

The results of application of Equation (5.21) in the study area are summarized in Table5.2. Results of the calculated Transmissivity are much closer to the observed field values with r.m.s.e of 165.55, which is lower than that found in case of composite hydraulic unit.

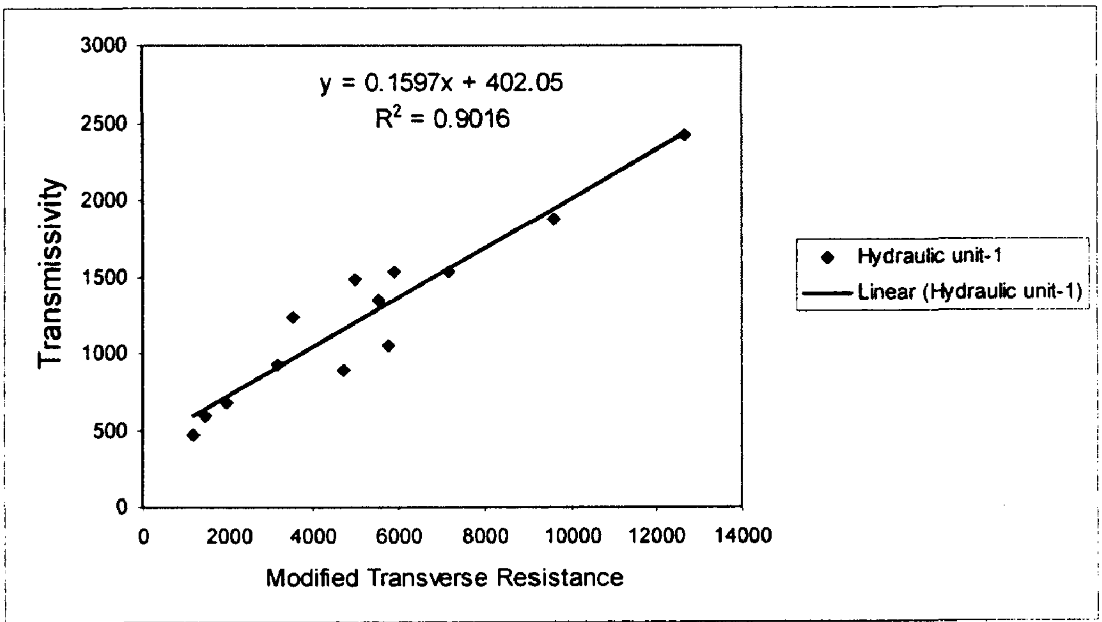



**Figure 5.9 Transmissivity vs. Modified Transverse Resistance of Hydraulic unit-1**

### Hydraulic Unit-2

Figure (5.10) shows a linear relationship between transmissivity and modified transverse resistance of hydraulic unit-2 for sediments deposited by river Ganga. The relationship can be expressed as:

$$T = 0.1682R' - 18.716 \quad (5.22)$$

Here the correlation coefficient is 0.98 which is quite high.

The results of application of Equation (5.22) in the study area are summarized in Table5.2. Again, results of the calculated transmissivity are much closer to the observed values with r.m.s.e of 119.51, which is lower than that for composite study area.

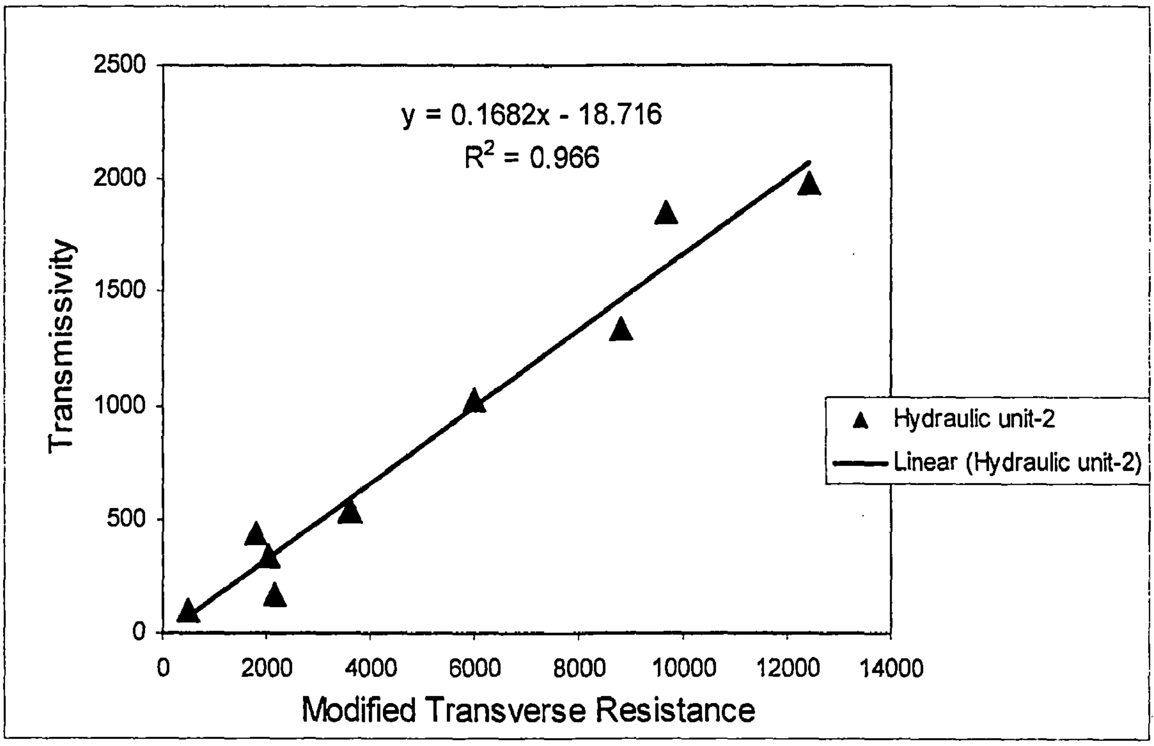



**Figure 5.10 Transmissivity vs. Modified Transverse Resistance of Hydraulic unit-2**

Here it may be relevant to point out that the slopes of the Equation (5.20), (5.21), & (5.22) are approximately the same i.e. the lines are parallel to the initial straight line (Figure 5.11) with a greater shift from this line with increasing anisotropy (Kelly & Reiter 1984). In case of constant anisotropy, the slope of the line would be unaffected but the intercept will vary with changing anisotropy. Figure 5.8 shows more scatter. However when values are sorted on the basis of hydraulic unit (Figure 5.9 & Figure 5.10), the plots show a lesser scatter.

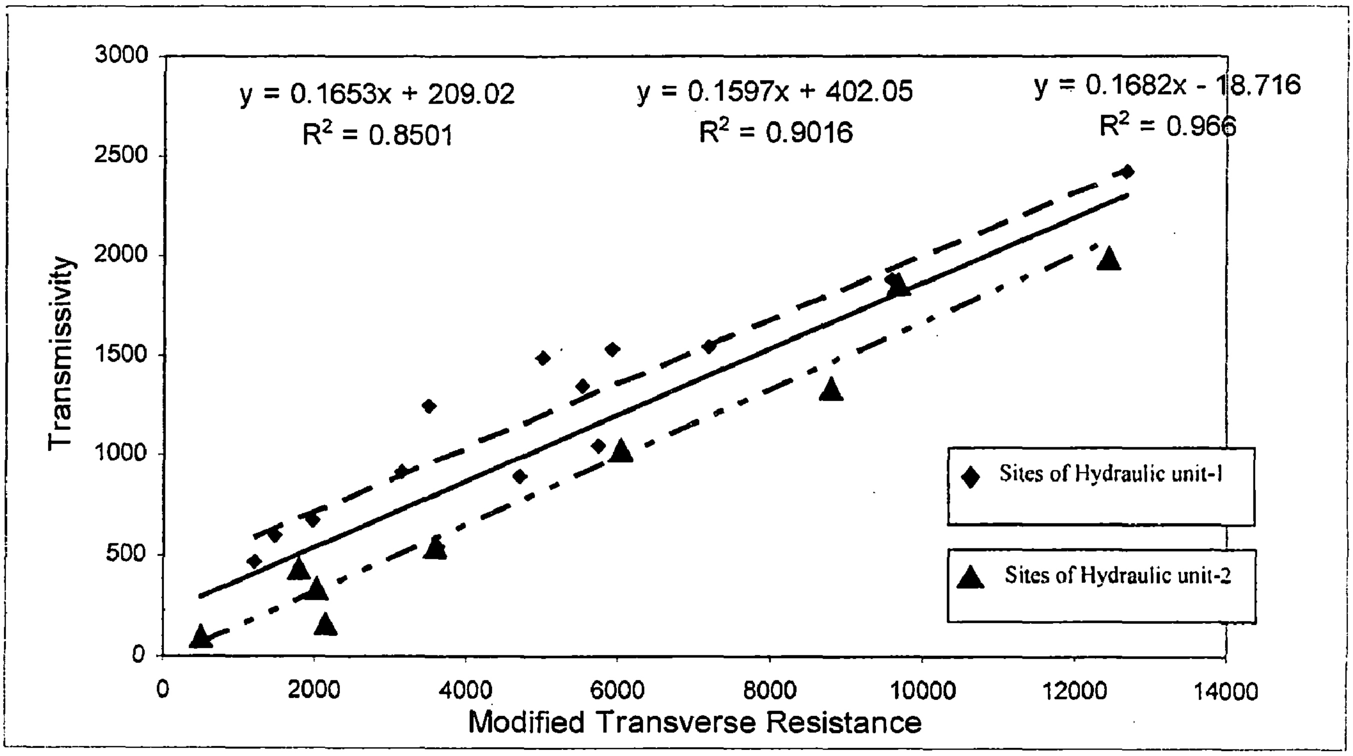



**Figure 5.11 Transmissivity vs. Modified Transverse Resistance of Different Hydraulic units**

Figure 5.11 shows a linear relationship between transmissivity and modified transverse resistance of study area for different hydraulic units. The plot shows a series of parallel lines with different intercepts, which changes with change in grain sizes.

**Table 5.2: Observed & Computed Transmissivity Values using Different Equations in Parts of the Study Area.**

| Name of Site | Observed Transmissivity | Calculated Transmissivity Equ. 5.19 T =0.23 R" | Calculated Transmissivity Equ. 5.20 T =0.1653 R' + 209.02 | Calculated Transmissivity Equ. 5.21 T =0.1597 R' + 402.05 | Calculated Transmissivity Equ. 5.22 T =0.1682 R' - 18.716 |
|---|---|---|---|---|---|
| Gangoh | 595 | 336.58 | 450.92 | 635.75 | |
| Nagal | 674.16 | 453.06 | 534.63 | 716.63 | |
| Nanauta | 472.09 | 275.54 | 407.05 | 593.37 | |
| Nakur | 1532.29 | 1361.09 | 1187.23 | 1347.12 | |
| K.Akbarpur | 895 | 1083.97 | 988.07 | 1154.70 | |
| Fatehpur | 1340.41 | 1269.56 | 1121.45 | 1283.57 | |
| Kashipur | 1536.72 | 1653.74 | 1397.56 | 1550.32 | |
| Barthakaith | 1240 | 807.44 | 789.32 | 962.69 | |
| KheraAfghan | 2420 | 2915.04 | 2304.04 | 2426.10 | |
| Salehpur | 1050 | 1322.48 | 1159.48 | 1320.31 | |
| Sarsawan | 1481.49 | 1149.78 | 1035.36 | 1200.40 | |
| Kailashpur | 1874.81 | 2208.14 | 1796.00 | 1935.27 | |
| Gudam | 920 | 721.52 | 727.57 | 903.04 | |
| M.Bad | 95.95 | 115.60 | 292.10 | | 65.82 |
| Bhanera | 1028.56 | 1383.90 | 1203.62 | | 993.33 |
| Belda | 541.58 | 829.02 | 804.83 | | 587.54 |
| Landhaura | 1335 | 2021.23 | 1661.67 | | 1459.42 |
| Chutmalpur | 167.58 | 496.51 | 565.86 | | 344.38 |
| Deoband | 439.88 | 414.83 | 507.16 | | 284.65 |
| Ismailpur | 338.4 | 468.50 | 545.73 | | 323.89 |
| Ganeshpur | 542.6 | 826.82 | 803.25 | | 585.94 |
| Jwalapur | 1985 | 2859.50 | 2264.13 | | 2072.44 |
| Roorkee | 1850 | 2226.00 | 1808.84 | | 1609.16 |

### 5.4.2. Relation Between Hydraulic Conductivity And Formation Factor

It may be mentioned that for establishing the relations between geoelectrical and hydraulic parameters, the whole study area has been considered together.

For finding the degree of correlation between hydraulic conductivity (K) and formation factor (FF), data of twenty sites . Using regression (Figure 5.12), the Equation of straight line is found to be as under:

$$K=2.9398\ FF + 4.3404 \quad (5.23)$$

This Equation has a correlation coefficient of 0.91

The values hydraulic conductivity (K) computed from this Equation are summarized in Table 5.3. It is obvious that values of the calculated hydraulic conductivity are much closer to the observed values with r.m.s.e of 6.43

An empirical relation between formation factor (FF) and hydraulic conductivity (K) can also be represented by a power relation (Mazac and Landa, 1985) in the following form:

$$K = A.(FF)^{m} \qquad (5.24)$$

where, A and m are empirically derived constants. For the present study area, the values of the coefficient (A) & the exponent (m) are found to be 4.18 and 0.84 respectively to give the following Equation:

$$K = 4.81.(FF)^{0.84} \qquad (5.25)$$

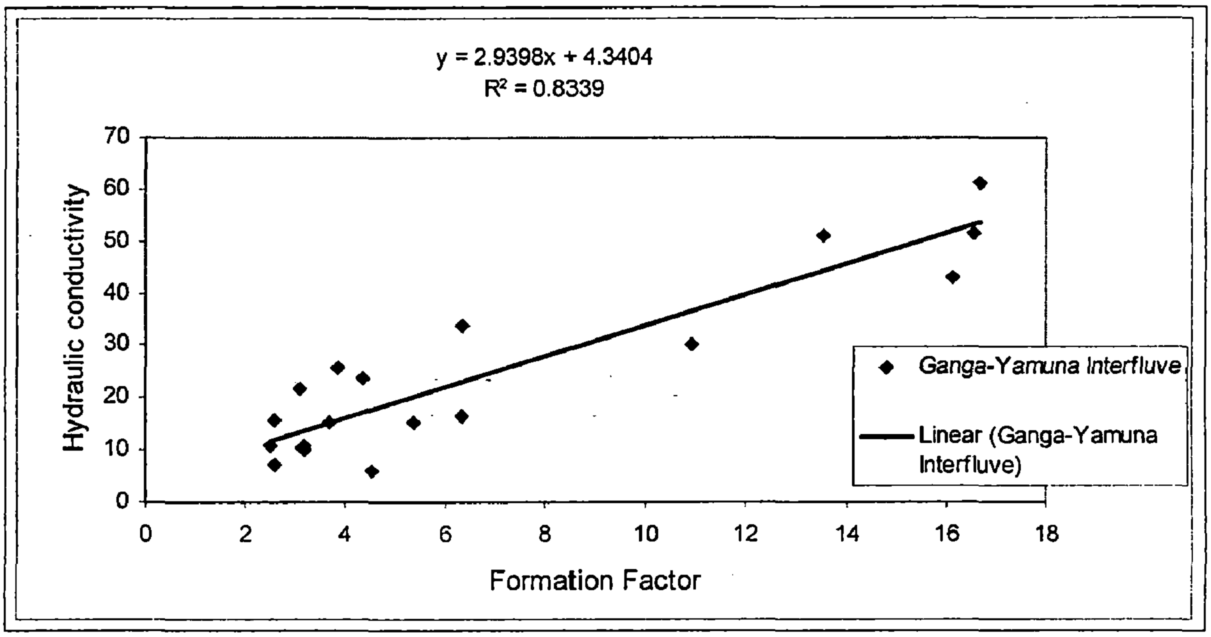



**Figure 5.12 Hydraulic conductivity vs. Formation factor**

### 5.4.3. Relation Between Hydraulic Conductivity And Modified Aquifer Resistivity

Sri Niwas & Singhal (1983) has suggested a corollary of Equation (5.15) as

$$K = \alpha\rho' \qquad (5.26)$$

where, ρ' is the modified aquifer resistivity.

The above technique is applied to the present study area and the data of K and ρ' were plotted as a linear graph (Figure 5.13) and using regression the Equation of straight line is found to be,

$$K = 0.1718\rho' + 4.34 \qquad (5.27)$$

The results of application of Equation (5.27) in the study area are summarized in Table 5.3 with r.m.s.e of 6.4 is obtained between observed hydraulic conductivity and calculated hydraulic conductivity.

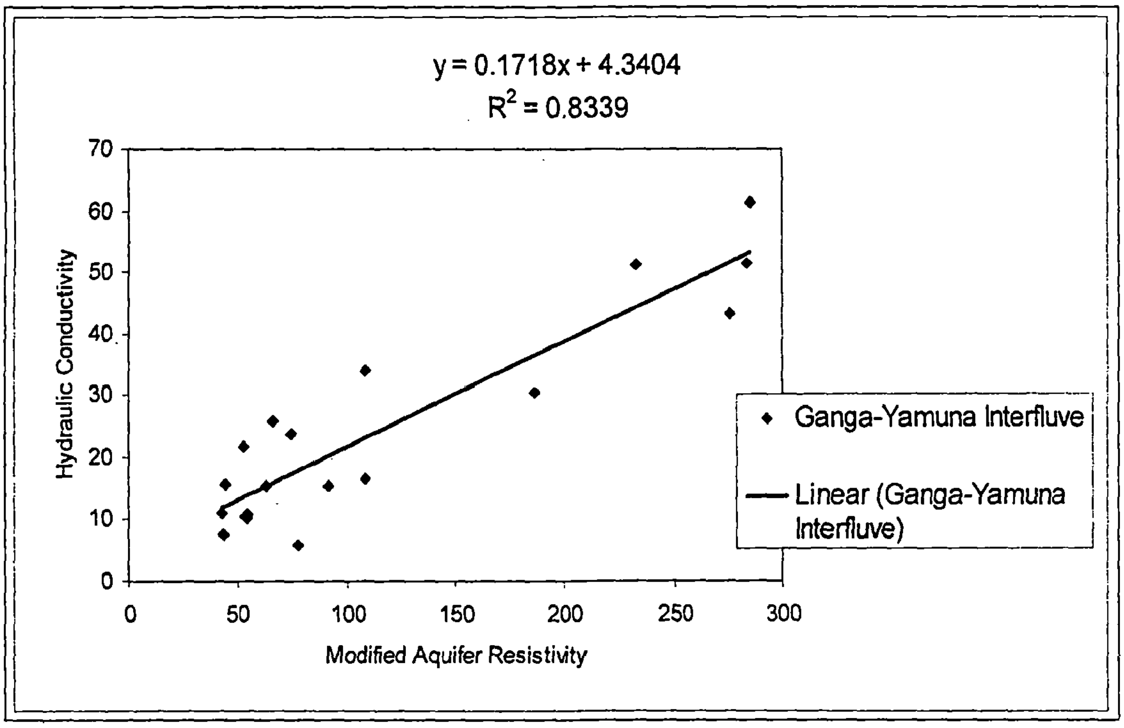



**Figure 5.13 Hydraulic conductivity vs. Modified Aquifer Resistivity**

### 5.4.4. Relation Between Hydraulic Conductivity And Modified Longitudinal Resistivity In Anisotropic Aquifers

In light of work done by Kelly & Reiter (1984) and sri Niwas and Olivar ( 2003), attempts have been made to ascertain the nature of relationship between hydraulic conductivity and resistivity of the anisotropic aquifers . As shown in Figure 5.1b the flow of electricity is assumed parallel to the layering along the direction of ground water flow. The horizontal hydraulic conductivity is given by the Equation (5.9) and the longitudinal resistivity is given by Equation (5.5). Assuming that the current flow is parallel to the strata, hydraulic conductivity was plotted against modified longitudinal resistivity (Figure 5.14).

Regression Equation of straight line is found to be,

$$K = 0.1684\rho_l' + 4.97 \qquad (5.28)$$

With a correlation coefficient of 0.90

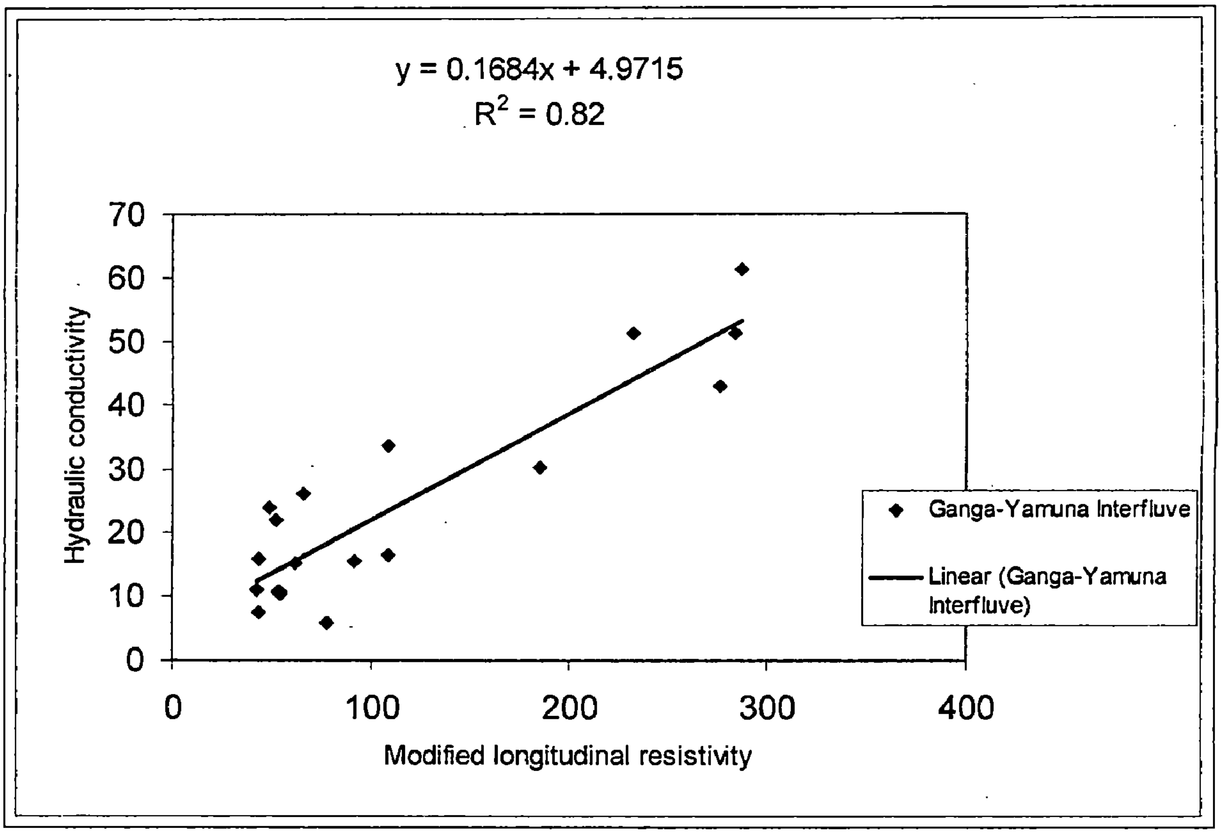



**Figure 5.14 Hydraulic Conductivity vs. Modified Longitudinal Resistivity**

The values of hydraulic conductivity found from this Equation are summarized in Table 5.3. RMSE of 6.97 is obtained between observed and calculated hydraulic conductivity and the degree of correlation is good (0.90).

5.4.5. Relation Between Hydraulic Conductivity And Modified Transverse Resistivity In Anisotropic Aquifers.

Assuming that the current flow is perpendicular to the layering with the ground water flow parallel to layers, hydraulic conductivity was plotted against modified transverse resistivity (Figure 5.15).

In this case, the regression Equation of straight line is found to be,

$$K = 0.174\rho_t' + 3.713 \quad (5.29)$$

with a correlation coefficient of 0.92

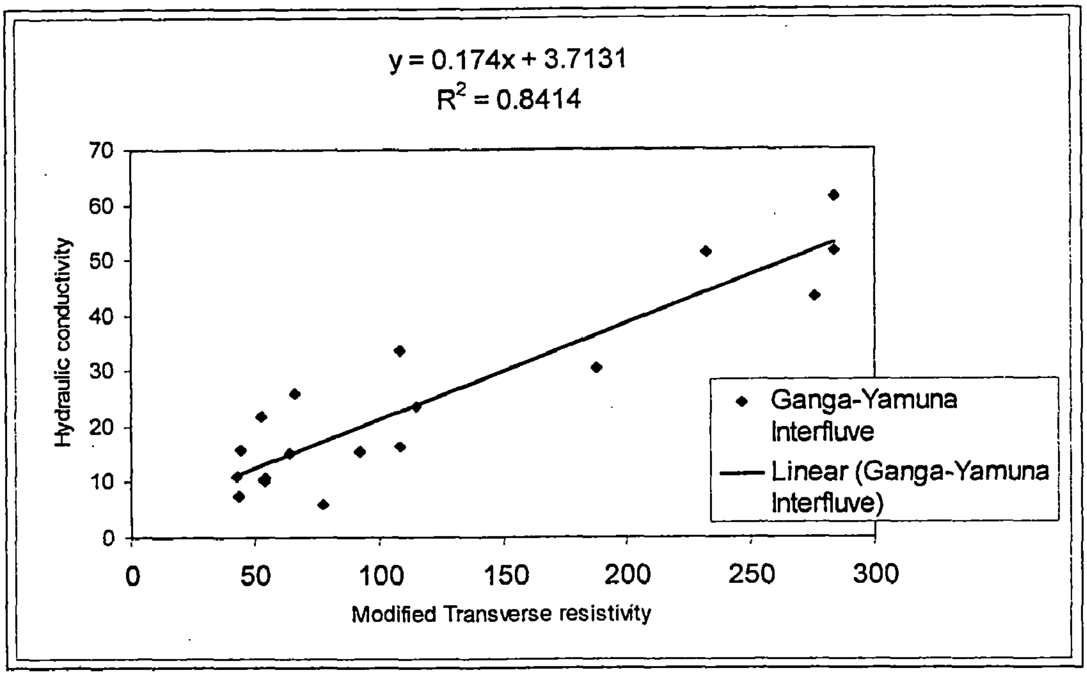



**Figure 5.15 Hydraulic Conductivity vs. Modified Transverse Resistivity**

The values of hydraulic conductivity calculated from the Equation (5.29) are summarized in Table 5.3. The error (r.m.s.e) of 6.28 is obtained between observed hydraulic conductivity and calculated hydraulic conductivity, with the correlation coefficient being 0.92, which gives a better estimate of horizontal hydraulic conductivity amongst all the tried alternatives. This corroborates the findings of Sri Niwas & Singhal (1981) and Kelly & Reiter (1984).

**Table 5.3: Observed & Computed Hydraulic Conductivity Values Using Different Equations In Parts Of The Study Area**

| Name of Site | Observed Hydraulic Conductivity | Calculated Kh Equationn.(5.23) Kh=2.9398 FF +4.3418 | Calculated Kh Equationn.(5.27) Kh=0.1718 ρ'(avg) +4.3418 | Calculated Kh Equationn.(5.28) Kh=0.1684 ρl ' +4.9588 | Calculated Kh Equationn.(5.29) Kh=0.174 ρt' +3.7131 |
|---|---|---|---|---|---|
| Gangoh | 25.87 | 15.71 | 15.70 | 16.10 | 15.22 |
| Nagal | 33.71 | 22.98 | 22.98 | 23.23 | 22.59 |
| Nanauta | 21.76 | 13.41 | 13.40 | 13.84 | 12.90 |
| Nakur | 61.29 | 53.37 | 53.37 | 53.28 | 53.10 |
| K.Akbarpur | 10.17 | 13.74 | 13.74 | 14.20 | 13.20 |
| Fatehpur | 15.23 | 15.16 | 15.16 | 15.37 | 14.86 |
| Kashipur | 51.22 | 44.20 | 44.20 | 44.04 | 44.07 |
| Barthakaith | 15.70 | 11.94 | 11.94 | 12.41 | 11.41 |
| KheraAfghan | 23.63 | 17.21 | 17.21 | 13.15 | 23.78 |
| Salehpur | 10.71 | 13.70 | 13.70 | 14.13 | 13.19 |
| M.Bad | 10.49 | 13.53 | 13.53 | 13.97 | 13.02 |
| Bhanera | 51.43 | 53.04 | 53.04 | 52.69 | 53.03 |
| Belda | 16.41 | 23.03 | 23.02 | 23.27 | 22.64 |
| Landhaura | 43.06 | 51.73 | 51.73 | 51.41 | 51.71 |
| Chutmalpur | 5.88 | 17.69 | 17.69 | 18.05 | 17.23 |
| Deoband | 11.00 | 11.73 | 11.73 | 12.20 | 11.19 |
| Ismailpur | 7.40 | 11.89 | 11.89 | 12.35 | 11.35 |
| Ganeshpur | 15.35 | 20.16 | 20.16 | 20.45 | 19.75 |
| Jwalapur | 30.29 | 36.37 | 36.36 | 36.13 | 36.37 |
| Roorkee | 26.43 | 26.60 | 26.60 | 26.74 | 26.29 |

## 5.5 Evaluation of Anisotropy

Keeping in view the influence of longitudinal resistivity in case of aquifers underlain by basement of infinite resistivity and that of transverse resistivity in case of aquifers underlain by conductive bottom layer, attempts are made to derive a suitable model for estimation of horizontal hydraulic conductivity using parameters like hydraulic anisotropy, modified longitudinal resistivity and modified transverse resistivity.-

## 5.5.1 Three Parameter Model

Kelly & Reiter (1984) have suggested a three parameter model for calculating hydraulic conductivity for anisotropic aquifers. The model is described by the following Equation:

$$K_h = AB^n \rho_l^m \tag{5.30}$$

where n is the exponent varying with anisotropy. A is empirically derived constant and m is the cementation factor derived from Equation (5.24).

$\rho_l$ : Longitudinal resistivity

B : Hydraulic anisotropy ( $K_h/K_v$)

### 5.5.1.1 Three Parameter Model Using Modified Longitudinal Resistivity

As it is clear from previous discussion that modified form of resistivity is much relevant in estimating hydraulic parameters, hence a three parameter regression is done amongst hydraulic conductivity, hydraulic anisotropy and modified longitudinal resistivity of 15 sites of the study area. Here the geoelectric parameters of Chutmalpur were omitted as the hydraulic anisotropy at this location is too high (544). The regression analysis is done by taking the value of "A" as 4.81 from Equation (5.25).

The three parameter relation takes the form:

$$K_h = 4.81 B^{-0.38} \rho_l'^{0.65} \tag{5.31}$$

The value of exponent m (0.65) does not match with m as derived from Equation (5.25) which is 0.84.

Hence modified longitudinal resistivity does not represent the parameter in aquifers which are underlain by conductive matrix, supporting the statement made by Kelly and Reiter (1984).

#### 5.5.1.2 Three Parameter Model Using Modified Transverse Resistivity

A regression between hydraulic conductivity, hydraulic anisotropy and modified transverse resistivity of 15 sites of the study area by taking the value of "**A**" as 4.81 from Equation (5.25) is obtained as:

$$K_h = 4.81 B^{-0.43} \rho'^{0.68}_t \qquad (5.32)$$

Again the value 0.68 does not match with m as derived from Equation (5.25) which is 0.84. Hence, modified transverse resistivity alone does not sum to be the parameter for anisotropic aquifers which are underlain by conductive matrix corroborating the contention given by Sri Niwas and Lima (2003). Thus there is a need to examine and introduce additional parameters, as necessary.

### 5.5.2 Four Parameter Model

A four parameter hydrogeophysical model has been tried by considering modified transverse resistivity, modified longitudinal resistivity, and hydraulic anisotropy.

A regression analysis is attempted between hydraulic conductivity, hydraulic anisotropy, modified transverse resistivity, and modified longitude resistivity by taking the value of "**A**" as 4.81 from Equation (5.25).

The four parameter relation takes the form:

$$K_h = 4.81 B^{-0.43} (\rho'_t)^{0.85} (\rho'_l)^{-0.17} \qquad (5.33)$$

The value of m is equal to (0.85) which is close to the value of **m** (0.84) as derived from Equation (5.25).

The approximate four parameter model can be written as:

$$K_h = AB^n(\rho'_t)^m(\rho'_t)^\lambda \qquad (5.34)$$

with $B = {K_h}/{K_v}$, the hydraulic anisotropy.

where A and m are the empirically derived constants from Equation (5.24). The value of n varies with anisotropy and ($\lambda$) will depend upon the percentage of dispersed clay present in the aquifer.

In case of anisotropic aquifers where the aquifer is not perfectly clean sand and there is presence of clay which is underlain by conducting matrix, the dominant current flow is vertical and there is a component of electric current flow in lateral direction as well ( Sri Niwas & Lima, 2003). This can be explained by the fact that if the resistivity of the aquifer is much larger than that of the lower layer, the electric current flow will tend to avoid the resistive layer and take the shortest route to the lower conducting layer. So the lines of current flow will be almost perpendicular to the layer. However if the aquifer is anisotropic and there is presence of some dispersed clay along with the sand, the horizontal component of current may be significant due to presence of conducting clay.

Figure 5.16 is a typical sounding curve obtained in the study area. Basically the curve can be represented by a four layer model consisting of top soil, unsaturated aquifer, saturated aquifer, and conductive clay. The Figure shows the vertical and horizontal components of the current lines through the anisotropic aquifer underlain by clay.

The results of application of Equation (5.33) in the study area are summarized in Table 5.4. In this case a nominal error (r.m.s.e) of 2.71 is obtained between observed hydraulic conductivity and calculated hydraulic conductivity and is quite in acceptable range. A perusal of computed and observed hydraulic conductivity values (Table 5.4) indicates that the former values are more realistic and compare well with the field hydraulic conductivity of the aquifer as compared to results from other Equation ( No.5.23, 5.27,5.28 & 5.29).

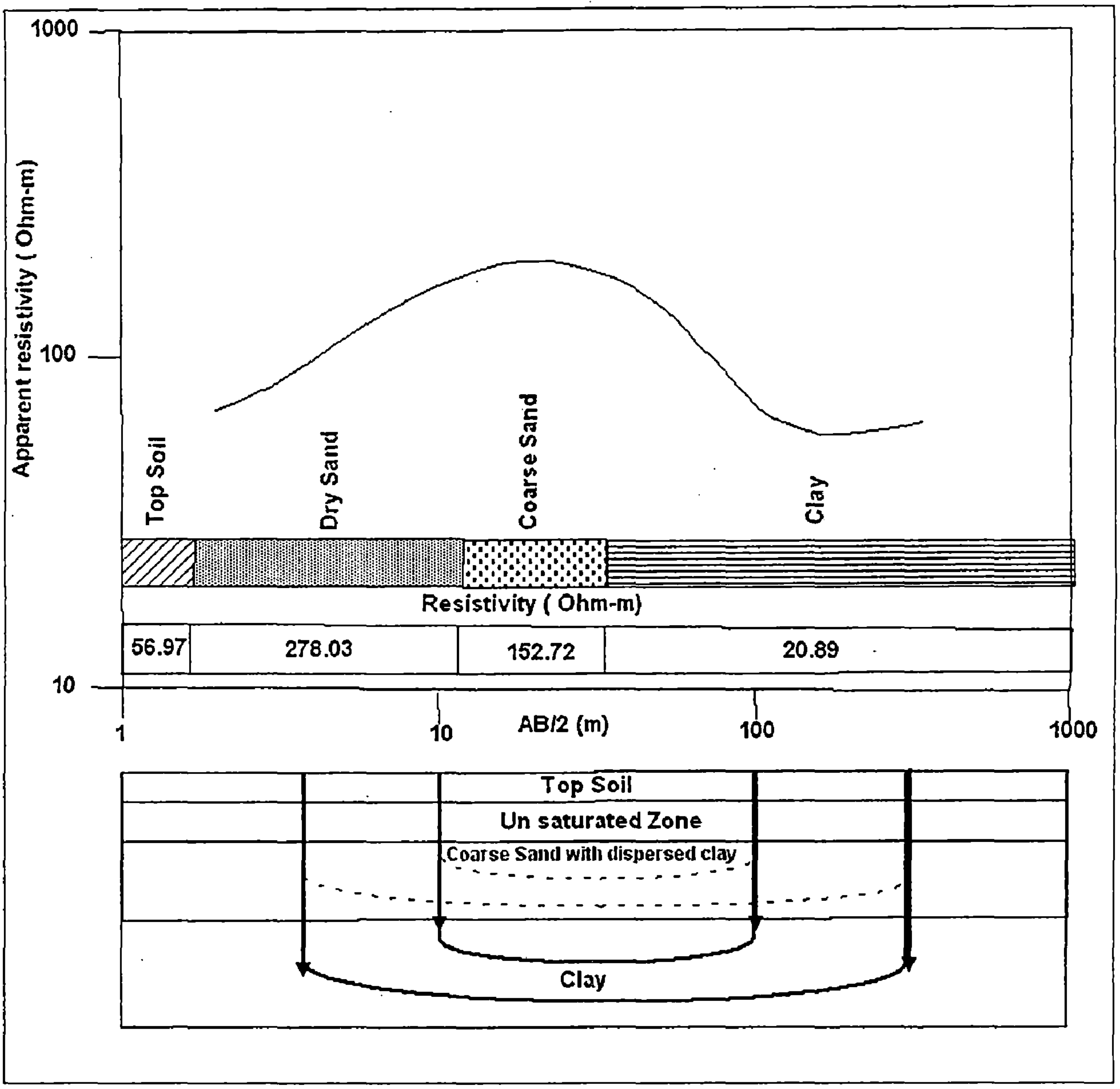



**Figure 5.16 Typical Sounding Curve & Electrical current flow in anisotropic aquifers underlain by conductive substratum.**

**Table 5.4: Observed & Computed Hydraulic Conductivity Values Using Four Parameter model**

| Name of Site | Observed Hydraulic Conductivity (m/day) | Calculated Hydraulic Conductivity (m/day) |
|---|---|---|
| Gangoh | 25.87 | 24.23 |
| Nagal | 33.71 | 30.90 |
| Nanauta | 21.76 | 20.43 |
| Nakur | 61.29 | 55.78 |
| K.Akbarpur | 10.17 | 9.68 |
| Fatehpur | 15.23 | 14.03 |
| Kashipur | 51.22 | 46.44 |
| Barthakaith | 15.7 | 14.65 |
| KheraAfghan | 23.63 | 21.80 |
| Salehpur | 10.71 | 9.83 |
| M.Bad | 10.49 | 9.61 |
| Bhanera | 51.43 | 46.63 |
| Belda | 16.41 | 16.29 |
| Landhaura | 43.06 | 38.50 |
| Deoband | 11 | 10.04 |

## 5.6 Validation of Four Parameter Model

The four parameter relation (Equation 5.33) have been used to compute hydraulic conductivity of aquifer in locations ( Roorkee, Ismailpur, Ganeshpur and Saliyar) which were not used in regression analysis. An average value of anisotropy ( B) is taken as 50.05 The results of application of this Equation in the study area are summarized in Table 5.5

**Table 5.5: Observed & Computed Hydraulic Conductivity Values Using Four Parameter model at different locations**

| Name of Site | Observed Hydraulic Conductivity(m/day) | Calculated Hydraulic Conductivity(m/day) |
|---|---|---|
| Ismailpur | 7.4 | 12.45 |
| Ganeshpur | 15.35 | 20.71 |
| Jwalapur | 30.29 | 33.76 |
| Roorkee ( NIH) | 26.43 | 26.19 |
| Saliyar | 16.75 | 15.28 |

## 5.7 Performance Evaluation

Several statistical measures are available for evaluating the performance of a model. The Nash and Sutcliffe (1970) efficiency is one of the most frequently used criteria and is employed in this study. The criterion is analogous to the coefficient of determination and is expressed in percentage form as:

$$\text{Efficiency} = (1 - D_1/D_0) * 100 \tag{5.35}$$

Where $D_1$ is the sum of the squares of deviations between computed and observed data:

$$D_1 = \sum\left(Y_0 - \hat{Y}\right)^2 \tag{5.36}$$

and $D_0$ is the initial variance which is the sum of the squares of deviations of the observed data about observed mean, expressed as :

$$D_0 = \sum\left(Y_0 - \bar{Y}\right)^2 \tag{5.37}$$

where $Y_0$ is the observed data, $\hat{Y}$ is computed data $\bar{Y}$ stands for mean of observed data. The efficiency varies in a scale of 0 to 100. It can also be assume a negative value if $D_1>D_0$, implying that variance in the observed and computed values is greater than the model variance. In such a case mean of the observed data fits better than the model. The efficiency of 100 implies that the computed values are in perfect agreement with the observed data.

For evaluation of model performance, hydraulic conductivity was computed for each site using Equation (5.35) and efficiency value is computed, which is estimated to be 97.16%.

# CHAPTER-6

## SUMMARY AND CONCLUSION

One of the most renewable resources of the Earth is ground water. Due to regional imbalances in the supply and demand of water and man's interference, over-exploitation of ground water is manifested by the lowering of water table and deteriorating quality of ground water. Although, this resource has account with vast magnitude, its potential resource is subject to wide spatio-temporal variations. It is renewable but not inexhaustible. Accordingly, utmost care has to be exercised in its exploitation and management. Thus, in order to evolve pragmatic and scientific planning for the management of ground water resources, one needs to quantify the characteristic hydrogeologic parameters. This requires knowledge of aquifer properties,viz. hydraulic conductivity & transmissivity. Low cost surface geophysical methods have developed in order to narrow down areas of potential water supplies.

The present work discusses a modified approach for evaluation of aquifer parameters using surface electrical resistivity techniques. The applicability of the approach has been demonstrated in the interfluvial parts of Ganga and Yamuna, Northern India. The study area is located between latitude 29$^0$54'N to 30$^0$8'12"N and longitude 77$^0$14'5"E to 77$^0$57'35" E constituting approximately 5500 km$^2$ area.

It has been found that existing methodology require modification to evaluate hydrgeological framework in the Ganga-Yamuna Interfluve under anisotropic conditions.

In the study area 12 numbers of borehole geophysical and 25 lithological logs were used to delineate aquifer disposition. 46 numbers of electrical resistivity and 11 numbers of I.P soundings were conducted .Out of 23 pumping test site, data for 20 tube wells in the dy area was interpreted by various methods, and interpreted data of 3 sites have been ısidered directly.

For geological interpretation of resistivity data, the layer parameters obtained from ınual interpretation were reinterpreted by using 1D inversion technique. For this purpose a nputer software viz. Interprex.exe is used. Preliminary values of model parameters as tained by manually matching the VES field curves with the theoretical master curves and kiliary point charts are subsequently used as input (starting model) in Interprex.exe for ther refinement of results. The degree of uncertainty of the computed model parameters d the goodness of fit in the curve are expressed in terms of RMS error. The resistivity and cknesses of different layers are iteratively refined and final best fit model is obtained from ch VES data set.

Following conclusions were drawn on the basis of detailed analysis of data:

- The study area is characterized by alluvial aquifers composed of sand of varying grain sizes, having at places admixtures of clay, silt and Kankar.
- The study area consists of two types of hydraulic units. The one which is mainly due to river Yamuna deposition consists of fine grained well sorted sediments. The other is due to river Ganga deposition consists of coarse grained poorly sorted sediments.
- The values of transmissivities and hydraulic conductivities obtained from the analysis of pumping test data ranges from 95.95 to 2420.00 $m^2$/day and 5.88 to 51.43m/day respectively in the two units.
- The Vertical hydraulic conductivity value ranges from 0.108 to 2.87 m/day.
- The hydraulic anisotropy of the aquifer ranges from 15.51 to 542.29.
- The resistivity of aquifer in the study area ranges from 25.46 Ω-m to325 Ω-m.

- The resistivity and transverse resistance of the aquifer for each well were modified by multiplying with the modification factor, which is the ratio of average water resistivity ($\rho_{avw}$) of the area and aquifer water resistivity ($\rho_w$) at a particular location.
- The following relations have been worked out from the field data.

➢ *Relation Between Transmissivity And Modified Transverse Resistance* : In this case the product $K_h\sigma'$ was found to be generally constant in the study area and equals to 0.23, which gives a comparison of observed and computed values of transmissivities with RMSE=348.

Alternatively a linear relation exists directly between aquifer transmissivity(T) and modified transverse resistance ,giving calculated values of T close to field values with RMS errors= 238.57.

A better correlation is obtained between transmissivity and modified transverse resistance when values are sorted separately for the two hydraulic units.

➢ *Relation Between Hydraulic Conductivity And Formation factor*: A linear relationship between hydraulic conductivity and formation factor is obtained for the study area.

➢ *Relation Between Hydraulic Conductivity And Modified Aquifer Resistivity*: A linear relationship between hydraulic conductivity and modified aquifer resistivity is obtained with RMSE= 6.40.

➢ *Relation Between Hydraulic Conductivity And Modified* Longitudinal Resistivity: A linear relationship between hydraulic conductivity and modified longitudinal resistivity with RMSE= 6.97 is also obtained.

➢ *Relation Between Hydraulic Conductivity And Modified* Transverse Resistivity: A linear relationship between hydraulic conductivity and modified transverse resistivity with RMSE= 6.28 is also obtained.

- It has been demonstrated that *the three parameter model* accounts for anisotropic aquifers underlain by bed rock, may not be applied in anisotropic alluvial aquifers underlain by clayey matrix.
- *Formulation Of Four Parameter Model*: A four parameter hydro geophysical model is presented by considering modified transverse resistivity, modified longitudinal resistivity, hydraulic conductivity and hydraulic anisotropy. The equation gives the value of $K_h$ very close to field values with RMSE = 2.71.

It has been demonstrated that surface geoelectric measurements can be used to predict of hydraulic conductivity and transmissivity of aquifers without significant additional expenditure. However, these estimates are reasonably valid for aquifer scale correlations only and more data from diverse geological environments is required to test the universality of the three relations.

A comparative analysis for few different sités in the study area show that the values of hydraulic conductivity estimated using four parameter model is close to the observed value of hydraulic conductivity in comparison to all other existing relations.

The technique is also validated.

However the values obtained by indirect methods needs verification of these parameters at some control points by a more direct method like pumping test which would enhance the reliability of the quantitative evaluation of aquifer parameters.

## SUGGESTIONS FOR FURTHER STUDY

The technique proposed in the present work need generalization in various geological environments. Their validation needs more data from various geological setting.

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# APPENDIX-1

## TIME DRAWDOWN DATA OF PUMPING TEST SITES OF THE STUDY AREA

# APPENDIX-1

| Site:Gangoh | | | | | |
|---|---|---|---|---|---|
| Discharge: 1570.9m$^3$/day | | | | | |
| Distance from pumped well: | | r=30.0m | r=32m | r=38m | r=20m |
| | | Observation Well -1 | Observation Well -2 | Observation Well -4 | 0.31 |
| Sn | Time(min) | Draw down(m) | Draw down(m) | Draw down(m) | 0.48 |
| 1 | 1.0 | 0.205 | 0.18 | 0.31 | 0.53 |
| 2 | 1.5 | 0.325 | 0.3 | 0.48 | 0.605 |
| 3 | 2.0 | 0.365 | 0.325 | 0.53 | 0.64 |
| 4 | 2.5 | 0.415 | 0.38 | 0.605 | 0.715 |
| 5 | 3.0 | 0.435 | 0.4 | 0.64 | 0.74 |
| 6 | 3.5 | 0.485 | 0.425 | 0.715 | 0.775 |
| 7 | 4.0 | 0.5 | 0.455 | 0.74 | 0.795 |
| 8 | 4.5 | 0.52 | 0.47 | 0.775 | 0.82 |
| 9 | 5.0 | 0.535 | 0.485 | 0.795 | 0.825 |
| 10 | 5.5 | 0.555 | 0.5 | 0.82 | 0.825 |
| 11 | 6.0 | 0.575 | 0.515 | 0.825 | 0.98 |
| 12 | 6.5 | 0.585 | 0.535 | 0.825 | 0.94 |
| 13 | 7.0 | 0.615 | 0.565 | 0.98 | 0.955 |
| 14 | 7.5 | 0.62 | 0.58 | 0.94 | 0.98 |
| 15 | 8.0 | 0.635 | 0.605 | 0.955 | 1.01 |
| 16 | 8.5 | 0.645 | 0.625 | 0.98 | 1.035 |
| 17 | 9.0 | 0.67 | 0.64 | 1.01 | 1.05 |
| 18 | 9.5 | 0.685 | 0.655 | 1.035 | 1.065 |
| 19 | 10.0 | 0.695 | 0.665 | 1.05 | 1.08 |
| 20 | 11 | 0.705 | 0.685 | 1.065 | 1.105 |
| 21 | 12.0 | 0.725 | 0.685 | 1.08 | 1.125 |
| 22 | 13 | 0.74 | 0.715 | 1.105 | 1.15 |
| 23 | 14.0 | 0.755 | 0.73 | 1.125 | 1.175 |
| 24 | 15 | 0.765 | 0.745 | 1.15 | 1.19 |
| 25 | 16.0 | 0.78 | 0.755 | 1.175 | 1.205 |
| 26 | 17 | 0.795 | 0.775 | 1.19 | 1.22 |
| 27 | 18.0 | 0.805 | 0.785 | 1.205 | 1.235 |
| 28 | 19 | 0.815 | 0.795 | 1.22 | 1.25 |
| 29 | 20.0 | 0.825 | 0.805 | 1.235 | 1.3 |
| 30 | 22 | 0.845 | 0.82 | 1.25 | 1.325 |
| 31 | 24.0 | 0.87 | 0.825 | 1.3 | 1.35 |
| 32 | 26 | 0.885 | 0.845 | 1.325 | 1.36 |
| 33 | 28.0 | 0.895 | 0.865 | 1.35 | 1.375 |
| 34 | 30 | 0.915 | 0.885 | 1.36 | 1.41 |
| 35 | 32.0 | 0.925 | 0.895 | 1.375 | 1.43 |
| 36 | 34 | 0.94 | 0.91 | 1.41 | 1.445 |
| 37 | 36.0 | 0.955 | 0.925 | 1.43 | 1.46 |
| 38 | 38 | 0.96 | 0.935 | 1.445 | 1.485 |
| 39 | 40.0 | 0.975 | 0.945 | 1.46 | 1.49 |
| 40 | 42 | 0.985 | 0.95 | 1.485 | 1.495 |
| 41 | 44.0 | 0.995 | 0.96 | 1.49 | 1.495 |
| 42 | 46 | 0.995 | 0.965 | 1.495 | 1.5 |
| 43 | 48.0 | 1 | 0.975 | 1.495 | 1.54 |
| | | | | | Continued |

| | | | | | |
|---|---|---|---|---|---|
| 44 | 50 | 1.01 | 0.985 | 1.5 | 1.565 |
| 45 | 55 | 1.02 | 1.015 | 1.54 | 1.59 |
| 46 | 60 | 1.045 | 1.025 | 1.565 | 1.615 |
| 47 | 65 | 1.065 | 1.045 | 1.59 | 1.64 |
| 48 | 70 | 1.095 | 1.065 | 1.615 | 1.68 |
| 49 | 75 | 1.115 | 1.075 | 1.64 | 1.715 |
| 50 | 80 | 1.135 | 1.095 | 1.68 | 1.75 |
| 51 | 85 | 1.16 | 1.125 | 1.715 | 1.785 |
| 52 | 90 | 1.175 | 1.145 | 1.75 | 1.8 |
| 53 | 95 | 1.195 | 1.165 | 1.785 | 1.86 |
| 54 | 100 | 1.21 | 1.185 | 1.8 | 1.9 |
| 55 | 110 | 1.245 | 1.225 | 1.86 | 1.95 |
| 56 | 120 | 1.275 | 1.255 | 1.9 | 1.975 |
| 57 | 130 | 1.3 | 1.265 | 1.95 | 1.995 |
| 58 | 140 | 1.32 | 1.285 | 1.975 | 2.01 |
| 59 | 150 | 1.34 | 1.295 | 1.995 | 2.03 |
| 60 | 160 | 1.355 | 1.325 | 2.01 | 2.04 |
| 61 | 170 | 1.37 | 1.345 | 2.03 | 2.085 |
| 62 | 180 | 1.38 | 1.355 | 2.04 | 2.07 |
| 63 | 190 | 1.395 | 1.36 | 2.085 | 2.085 |
| 64 | 200 | 1.405 | 1.365 | 2.07 | 2.095 |
| 65 | 210 | 1.415 | 1.375 | 2.085 | 2.12 |
| 66 | 220 | 1.425 | 1.385 | 2.095 | 2.135 |
| 67 | 230 | 1.425 | 1.385 | 2.12 | 2.15 |
| 68 | 240 | 1.435 | 1.405 | 2.135 | 2.155 |
| 69 | 250 | 1.445 | 1.415 | 2.15 | 2.16 |
| 70 | 260 | 1.445 | 1.425 | 2.155 | 2.175 |
| 71 | 270 | 1.45 | 1.43 | 2.16 | 2.18 |
| 72 | 280 | 1.455 | 1.435 | 2.175 | 2.185 |
| 73 | 290 | 1.455 | 1.44 | 2.18 | 2.195 |
| 74 | 300 | 1.46 | 1.445 | 2.185 | 2.2 |
| 75 | 320 | 1.47 | 1.455 | 2.195 | 2.205 |
| 76 | 340 | 1.48 | 1.455 | 2.2 | 2.21 |
| 77 | 360 | 1.48 | 1.465 | 2.205 | 2.225 |
| 78 | 380 | 1.49 | 1.465 | 2.21 | 2.23 |
| 79 | 400 | 1.5 | 1.47 | 2.225 | 2.235 |
| 80 | 450 | 1.51 | 1.475 | 2.23 | 2.24 |
| 81 | 500 | 1.515 | 1.48 | 2.235 | 2.25 |
| 82 | 550 | 1.52 | 1.485 | 2.24 | 2.26 |
| 83 | 600 | 1.525 | 1.5 | 2.25 | 2.265 |
| 84 | 650 | 1.53 | 1.505 | 2.26 | 2.27 |
| 85 | 700 | 1.53 | 1.505 | 2.265 | 2.285 |
| 86 | 750 | 1.535 | 1.505 | 2.27 | 2.285 |
| 87 | 800 | 1.535 | 1.51 | 2.285 | 2.29 |
| 88 | 900 | 1.54 | 1.51 | 2.285 | 2.295 |
| 89 | 1000 | 1.54 | 1.515 | 2.29 | 2.3 |
| 90 | 1100 | 1.545 | 1.515 | 2.295 | 2.3 |
| 91 | 1200 | 1.55 | 1.515 | 2.3 | 2.305 |
| 92 | 1300 | 1.55 | 1.515 | 2.3 | 2.305 |
| 93 | 1400 | 1.555 | 1.52 | 2.305 | |
| 94 | 1500 | 1.555 | 1.52 | 2.305 | |

Continued

| Site:Nagal | | | | | |
|---|---|---|---|---|---|
| Discharge: 822.0m³/day | | | | | |
| Distance from pumped well: | | r=31.5 | r=35 | r=40 | r=20 |
| | | Observation Well -1 | Observation Well - 2 | Observation Well -3 | Observation Well -4 |
| Sn | Time(min) | Draw down(m) | Draw down(m) | Draw down(m) | Draw down(m) |
| 1 | 1.0 | 0.015 | 0.001 | 0.001 | .0.025 |
| 2 | 1.5 | 0.065 | 0.001 | 0.001 | 0.07 |
| 3 | 2 | 0.08 | 0.002 | 0.001 | 0.1 |
| 4 | 2.5 | 0.11 | 0.003 | 0.001 | 0.15 |
| 5 | 3 | 0.13 | 0.004 | 0.002 | 0.175 |
| 6 | 3.5 | 0.14 | 0.005 | 0.003 | 0.205 |
| 7 | 4 | 0.15 | 0.005 | 0.003 | 0.225 |
| 8 | 4.5 | 0.16 | 0.005 | 0.005 | 0.245 |
| 9 | 5 | 0.175 | 0.005 | 0.008 | 0.27 |
| 10 | 6 | 0.185 | 0.01 | 0.01 | 0.285 |
| 11 | 7 | 0.2 | 0.01 | 0.01 | 0.305 |
| 12 | 8 | 0.21 | 0.015 | 0.01 | 0.315 |
| 13 | 9 | 0.215 | 0.015 | 0.01 | 0.325 |
| 14 | 10 | 0.22 | 0.02 | 0.015 | 0.335 |
| 15 | 12 | 0.23 | 0.03 | 0.015 | 0.34 |
| 16 | 14 | 0.24 | 0.035 | 0.02 | 0.355 |
| 17 | 16 | 0.25 | 0.04 | 0.03 | 0.37 |
| 18 | 18 | 0.265 | 0.045 | 0.035 | 0.4 |
| 19 | 20 | 0.285 | 0.06 | 0.045 | 0.43 |
| 20 | 25 | 0.29 | 0.06 | 0.05 | 0.44 |
| 21 | 30 | 0.295 | 0.065 | 0.05 | 0.445 |
| 22 | 35 | 0.305 | 0.07 | 0.06 | 0.455 |
| 23 | 40 | 0.315 | 0.07 | 0.065 | 0.46 |
| 24 | 45 | 0.315 | 0.075 | 0.065 | 0.46 |
| 25 | 50 | 0.32 | 0.075 | 0.07 | 0.47 |
| 26 | 55 | 0.325 | 0.08 | 0.07 | 0.485 |
| 27 | 60 | 0.325 | 0.08 | 0.075 | 0.49 |
| 28 | 65 | 0.33 | 0.08 | 0.075 | 0.505 |
| 29 | 70 | 0.33 | 0.085 | 0.08 | 0.51 |
| 30 | 75 | 0.335 | 0.085 | 0.08 | 0.515 |
| 31 | 80 | 0.335 | 0.085 | 0.08 | 0.52 |
| 32 | 85 | 0.34 | 0.09 | 0.085 | 0.525 |
| 33 | 90 | 0.34 | 0.09 | 0.085 | 0.53 |
| 34 | 95 | 0.345 | 0.09 | 0.085 | 0.545 |
| 35 | 100 | 0.345 | 0.095 | 0.085 | 0.55 |
| 36 | 110 | 0.345 | 0.095 | 0.09 | 0.555 |
| 37 | 120 | 0.35 | 0.095 | 0.09 | 0.57 |
| 38 | 130 | 0.35 | 0.095 | 0.09 | 0.58 |
| 39 | 140 | 0.355 | 0.095 | 0.09 | 0.59 |
| 40 | 150 | 0.355 | 0.1 | 0.09 | 0.595 |
| 41 | 160 | 0.36 | 0.1 | 0.09 | 0.595 |
| 42 | 170 | 0.36 | 0.1 | 0.09 | 0.6 |
| 43 | 180 | 0.365 | 0.1 | 0.095 | 0.605 |
| | | | | | Continued |

| | | | | | |
|---|---|---|---|---|---|
| 44 | 190 | 0.365 | 0.1 | 0.095 | 0.61 |
| 45 | 200 | 0.37 | 0.1 | 0.095 | 0.615 |
| 46 | 220 | 0.37 | 0.105 | 0.095 | 0.625 |
| 47 | 240 | 0.38 | 0.105 | 0.095 | 0.63 |
| 48 | 260 | 0.385 | 0.105 | 0.095 | 0.635 |
| 49 | 280 | 0.395 | 0.105 | 0.095 | 0.645 |
| 50 | 300 | 0.4 | 0.105 | 0.095 | 0.655 |
| 51 | 350 | 0.4 | 0.11 | 0.095 | 0.665 |
| 52 | 400 | 0.4 | 0.11 | 0.1 | 0.67 |
| 53 | 450 | 0.4 | 0.11 | 0.1 | 0.68 |
| 54 | 500 | 0.405 | 0.115 | 0.1 | 0.69 |
| 55 | 550 | 0.41 | 0.115 | 0.1 | 0.69 |
| 56 | 600 | 0.41 | 0.115 | 0.1 | 0.705 |
| 57 | 700 | 0.415 | 0.12 | 0.105 | 0.71 |
| 58 | 800 | 0.415 | 0.12 | 0.105 | 0.715 |
| 59 | 900 | 0.42 | 0.125 | 0.105 | 0.72 |
| 60 | 1000 | 0.42 | 0.125 | 0.105 | 0.73 |
| 61 | 1100 | 0.425 | 0.125 | 0.105 | 0.73 |
| 62 | 1200 | 0.425 | 0.125 | 0.105 | 0.73 |

| **Site:Nakur** | | | | |
|---|---|---|---|---|
| Discharge: 1265m³/day | | | | |
| Distance from pumped well: | | r=26.4 | r=35.10m | r=50.04m |
| | | Observation Well -1 | Observation Well -2 | Observation Well -3 |
| Sn | Time(min) | Draw down(m) | Draw down(m) | Draw down(m) |
| 1 | 1.0 | 0.06 | 0.04 | 0.01 |
| 2 | 1.2 | 0.08 | 0.05 | 0.02 |
| 3 | 1.5 | 0.09 | 0.055 | 0.03 |
| 4 | 2 | 0.1 | 0.06 | 0.03 |
| 5 | 2.5 | 0.1 | 0.06 | 0.035 |
| 6 | 3 | 0.105 | 0.065 | 0.04 |
| 7 | 4 | 0.11 | 0.07 | 0.04 |
| 8 | 5 | 0.115 | 0.07 | 0.04 |
| 9 | 6 | 0.115 | 0.075 | 0.045 |
| 10 | 7 | 0.12 | 0.075 | 0.045 |
| 11 | 8 | 0.12 | 0.075 | 0.05 |
| 12 | 9 | 0.12 | 0.075 | 0.05 |
| 13 | 10 | 0.12 | 0.075 | 0.05 |
| 14 | 12 | 0.125 | 0.08 | 0.05 |
| 15 | 15 | 0.125 | 0.08 | 0.05 |
| 16 | 20 | 0.13 | 0.085 | 0.055 |
| 17 | 25 | 0.135 | 0.09 | 0.055 |
| 18 | 30 | 0.135 | 0.095 | 0.06 |
| 19 | 40 | 0.14 | 0.105 | 0.06 |
| 20 | 50 | 0.155 | 0.11 | 0.065 |
| 21 | 60 | 0.16 | 0.115 | 0.075 |
| 22 | 70 | 0.165 | 0.12 | 0.08 |
| 23 | 80 | 0.17 | 0.12 | 0.085 |
| 24 | 90 | 0.175 | 0.125 | 0.085 |
| 25 | 100 | 0.175 | 0.13 | 0.09 |
| 26 | 120 | 0.18 | 0.135 | 0.1 |

| Continued | | | | |
|---|---|---|---|---|
| 27 | 150 | 0.185 | 0.14 | 0.105 |
| 28 | 200 | 0.2 | 0.155 | 0.115 |
| 29 | 250 | 0.21 | 0.155 | 0.12 |
| 30 | 300 | 0.22 | 0.175 | 0.125 |
| 31 | 400 | 0.23 | 0.19 | 0.15 |
| 32 | 500 | 0.24 | 0.2 | 0.16 |
| 33 | 600 | 0.25 | 0.215 | 0.17 |
| 34 | 700 | 0.255 | 0.215 | 0.18 |
| 35 | 800 | 0.265 | 0.23 | 0.19 |
| 36 | 900 | 0.27 | 0.24 | 0.2 |
| 37 | 1000 | 0.28 | 0.25 | 0.22 |
| 38 | 1100 | 0.285 | 0.255 | 0.21 |
| 39 | 1200 | 0.29 | 0.26 | 0.21 |
| 40 | 1300 | 0.29 | 0.26 | 0.23 |

| Site:Khajuri-Akbarpur | | | | | |
|---|---|---|---|---|---|
| Discharge: 1073.45$m^3$/day | | | | | |
| Distance from pumped well: | | r=24.08 | r=25 | r=98.8 | r=404 |
| | | Observation Well -1 | Observation Well -2 | Observation Well -3 | Observation Well -4 |
| Sn | Time(min) | Draw down(m) | Draw down(m) | Draw down(m) | Draw down(m) |
| 1 | 1.0 | 0.335 | 0.25 | 0.105 | 0.005 |
| 2 | 1.2 | 0.35 | 0.28 | 0.111 | 0.005 |
| 3 | 5 | 0.43 | 0.45 | 0.265 | 0.025 |
| 4 | 6 | 0.44 | 0.46 | 0.285 | 0.015 |
| 5 | 7 | 0.455 | 0.475 | 0.295 | 0.015 |
| 6 | 8 | 0.45 | 0.48 | 0.32 | 0.02 |
| 7 | 10 | 0.46 | 0.495 | 0.325 | 0.02 |
| 8 | 12 | 0.47 | 0.51 | 0.33 | 0.025 |
| 9 | 15 | 0.48 | 0.52 | 0.345 | 0.025 |
| 10 | 20 | 0.495 | 0.535 | 0.355 | 0.03 |
| 11 | 25 | 0.51 | 0.54 | 0.37 | 0.04 |
| 12 | 30 | 0.52 | 0.56 | 0.38 | 0.04 |
| 13 | 40 | 0.53 | 0.57 | 0.39 | 0.05 |
| 14 | 50 | 0.54 | 0.58 | 0.4 | 0.055 |
| 15 | 60 | 0.545 | 0.59 | 0.41 | 0.06 |
| 16 | 70 | 0.55 | 0.59 | 0.415 | 0.065 |
| 17 | 80 | 0.535 | 0.6 | 0.42 | 0.07 |
| 18 | 90 | 0.56 | 0.605 | 0.425 | 0.075 |
| 19 | 100 | 0.56 | 0.61 | 0.43 | 0.08 |
| 20 | 130 | 0.565 | 0.62 | 0.43 | 0.085 |
| 21 | 150 | 0.57 | 0.61 | 0.435 | 0.085 |
| 22 | 200 | 0.575 | 0.61 | 0.43 | 0.09 |
| 23 | 250 | 0.58 | 0.57 | 0.37 | 0.1 |
| 24 | 300 | 0.59 | 0.58 | 0.395 | 0.17 |
| 25 | 350 | 0.595 | 0.59 | 0.37 | 0.17 |
| 26 | 500 | 0.61 | 0.59 | 0.38 | 0.118 |
| 27 | 600 | 0.61 | 0.59 | 0.38 | 0.23 |
| 28 | 700 | 0.63 | 0.6 | 0.5 | 0.26 |
| 29 | 800 | 0.65 | 0.695 | 0.535 | 0.26 |
| 30 | 900 | 0.666 | 0.74 | 0.57 | 0.26 |

| | | | | | Continued |
|---|---|---|---|---|---|
| 31 | 1000 | 0.68 | 0.75 | 0.57 | 0.27 |
| 32 | 1200 | 0.695 | 0.75 | 0.57 | 0.29 |
| 33 | 1500 | 0.715 | 0.75 | 0.59 | 0.29 |
| 34 | 1600 | 0.725 | 0.765 | 0.62 | 0.29 |
| 35 | 1800 | 0.75 | 0.8 | 0.655 | 0.29 |
| 36 | 2000 | 0.755 | 0.72 | 0.54 | 0.28 |
| 37 | 2500 | 0.77 | 0.84 | 0.68 | 0.28 |
| 38 | 3000 | 0.78 | 0.795 | 0.635 | 0.25 |
| 39 | 3500 | 0.76 | 0.74 | 0.57 | 0.25 |
| 40 | 3800 | 0.77 | 0.74 | 0.58 | 0.25 |
| 41 | 4000 | 0.78 | 0.79 | 0.6 | 0.25 |
| 42 | 4200 | 0.79 | 0.87 | 0.63 | 0.25 |
| 43 | 4500 | 0.78 | 0.725 | 0.55 | 0.26 |
| 44 | 5000 | 0.76 | 0.666 | 0.51 | |
| 45 | 5500 | 0.75 | 0.685 | 0.505 | |
| 46 | 6000 | 0.75 | 0.76 | 0.55 | |
| 47 | 6500 | 0.775 | 0.74 | 0.57 | |
| 48 | 6600 | 0.78 | 0.79 | 0.62 | |
| 49 | 6700 | 0.79 | 0.82 | 0.65 | |
| 50 | 6800 | 0.81 | 0.825 | 0.66 | |
| 51 | 6900 | 0.805 | 0.835 | 0.675 | |
| 52 | 7000 | 0.805 | 0.85 | 0.85 | |

| | | | |
|---|---|---|---|
| Site:Kashipur | | | |
| Discharge: 860.2$m^3$/day | | | |
| Distance from pumped well: | | r=15.15 | r=50.78 |
| | | Observation Well -1 | Observation Well -2 |
| Sn | Time(min) | Draw down(m) | Draw down(m) |
| 1 | 1.0 | 0.1 | 0.001 |
| 2 | 2 | 0.03 | 0.002 |
| 3 | 3 | 0.045 | 0.003 |
| 4 | 4 | 0.055 | 0.004 |
| 5 | 5 | 0.07 | 0.005 |
| 6 | 6 | 0.08 | 0.01 |
| 7 | 7 | 0.1 | 0.01 |
| 8 | 8 | 0.11 | 0.01 |
| 9 | 9 | 0.12 | 0.01 |
| 10 | 10 | 0.12 | 0.015 |
| 11 | 12 | 0.14 | 0.02 |
| 12 | 15 | 0.16 | 0.025 |
| 13 | 20 | 0.18 | 0.03 |
| 14 | 30 | 0.22 | 0.045 |
| 15 | 40 | 0.24 | 0.055 |
| 16 | 50 | 0.24 | 0.055 |
| 17 | 60 | 0.25 | 0.065 |
| 18 | 70 | 0.26 | 0.07 |
| 19 | 80 | 0.265 | 0.07 |
| 20 | 90 | 0.27 | 0.075 |
| 21 | 100 | 0.27 | 0.08 |
| 22 | 120 | 0.275 | 0.085 |
| 23 | 150 | 0.28 | 0.09 |
| 24 | 200 | 0.29 | 0.09 |
| 25 | 300 | 0.3 | 0.11 |

| | | | |
|---|---|---|---|
| | | | Continued |
| 26 | 400 | 0.33 | 0.125 |
| 27 | 500 | 0.325 | 0.13 |
| 28 | 600 | 0.32 | 0.13 |
| 29 | 700 | 0.325 | 0.135 |
| 30 | 800 | 0.325 | 0.14 |
| 31 | 900 | 0.33 | 0.15 |
| 32 | 1000 | 0.33 | 0.15 |
| 33 | 1200 | 0.335 | 0.155 |
| 34 | 1300 | 0.335 | 0.155 |
| 35 | 1400 | 0.335 | 0.155 |
| 36 | 1500 | 0.335 | 0.155 |
| 37 | 1600 | 0.335 | 0.155 |
| 38 | 1700 | 0.335 | 0.155 |
| 39 | 1800 | 0.335 | 0.155 |

| | | |
|---|---|---|
| Site:Barthakaith | | |
| Discharge: 5455m$^3$/day | | |
| Distance from pumped well: | | r=62.0m |
| | | Observation Well -1 |
| Sn | Time(min) | Draw down(m) |
| 1 | 1.0 | 0.014 |
| 2 | 2 | 0.07 |
| 3 | 3 | 0.12 |
| 4 | 4 | 0.18 |
| 5 | 4.5 | 0.21 |
| 6 | 5 | 0.21 |
| 7 | 6 | 0.28 |
| 8 | 7 | 0.32 |
| 9 | 8 | 0.38 |
| 10 | 9 | 0.4 |
| 11 | 10 | 0.42 |
| 12 | 11 | 0.43 |
| 13 | 12 | 0.44 |
| 14 | 14 | 0.54 |
| 15 | 16 | 0.58 |
| 16 | 18 | 0.62 |
| 17 | 20 | 0.66 |
| 18 | 22 | 0.67 |
| 19 | 24 | 0.69 |
| 20 | 26 | 0.72 |
| 21 | 28 | 0.74 |
| 22 | 30 | 0.76 |
| 23 | 32 | 0.82 |
| 24 | 35 | 0.85 |
| 25 | 40 | 0.9 |
| 26 | 45 | 0.91 |
| 27 | 50 | 0.95 |
| 28 | 60 | 1 |
| 29 | 70 | 1.1 |
| 30 | 80 | 1.15 |
| 31 | 90 | 1.2 |
| 32 | 100 | 1.21 |
| 33 | 110 | 1.21 |

| | | |
|---|---|---|
| Continued4 | 120 | 1.22 |
| 35 | 130 | 1.28 |
| 36 | 140 | 1.3 |
| 37 | 150 | 1.32 |
| 38 | 200 | 1.4 |
| 39 | 250 | 1.45 |
| 40 | 300 | 1.5 |
| 41 | 350 | 1.52 |
| 42 | 400 | 1.54 |
| 43 | 450 | 1.55 |
| 44 | 500 | 1.56 |
| 45 | 550 | 1.56 |
| 46 | 600 | 1.6 |
| 47 | 650 | 1.65 |
| 48 | 700 | 1.7 |
| 49 | 750 | 1.71 |
| 50 | 800 | 1.72 |
| 51 | 900 | 1.75 |
| 52 | 1000 | 1.76 |
| 53 | 1500 | 1.8 |
| 54 | 2000 | 1.82 |
| 55 | 3000 | 1.83 |
| 56 | 4000 | 1.85 |
| 57 | 5000 | 1.87 |
| 58 | 6000 | 1.88 |
| 59 | 7000 | 1.89 |
| 60 | 8000 | 1.9 |
| 61 | 10000 | 1.91 |
| Site:Khera Afghan | | |

| Discharge: 6540.0m$^3$/day | | | |
|---|---|---|---|
| Distance from pumped well: | | r=10m | r=30m |
| | | Observation Well -1 | Observation Well -2 |
| Sn | Time(min) | Draw down(m) | Draw down(m) |
| 1 | 2.0 | 0.068 | 0.36 |
| 2 | 3 | 0.078 | 0.46 |
| 3 | 4 | 0.09 | 0.52 |
| 4 | 5 | 0.09 | 0.52 |
| 5 | 6 | 0.095 | 0.56 |
| 6 | 7 | 0.1 | 0.57 |
| 7 | 8 | 0.11 | 0.6 |
| 8 | 9 | 0.105 | 0.65 |
| 9 | 10 | 0.108 | 0.68 |
| 10 | 11 | 0.11 | 0.69 |
| 11 | 12 | 0.115 | 0.7 |
| 12 | 13 | 0.116 | 0.74 |
| 13 | 14 | 0.117 | 0.76 |
| 14 | 15 | 0.118 | 0.77 |
| 15 | 16 | 0.119 | 0.78 |
| 16 | 20 | 0.12 | 0.8 |
| 17 | 25 | 0.125 | 0.81 |
| 18 | 30 | 0.13 | 0.9 |
| 19 | 35 | 0.1325 | 0.95 |

| | | | |
|---|---|---|---|
| | | | Continued |
| 20 | 40 | 0.135 | 1 |
| 21 | 45 | 0.136 | 1 |
| 22 | 50 | 0.14 | 1.05 |
| 23 | 55 | 0.145 | 1.05 |
| 24 | 60 | 0.15 | 1.1 |
| 25 | 70 | 0.155 | 1.1 |
| 26 | 80 | 0.16 | 1.11 |
| 27 | 90 | 0.16 | 1.15 |
| 28 | 100 | 0.165 | 1.2 |
| 29 | 110 | 0.167 | 1.2 |
| 30 | 120 | 0.168 | 1.21 |
| 31 | 130 | 0.168 | 1.21 |
| 32 | 140 | 0.169 | 1.22 |
| 33 | 150 | 0.168 | 1.23 |
| 34 | 160 | 0.167 | 1.26 |
| 35 | 170 | 0.167 | 1.27 |
| 36 | 180 | 0.167 | 1.28 |
| 37 | 190 | 0.166 | 1.29 |
| 38 | 200 | 0.166 | 1.3 |
| 39 | 210 | 0.167 | 1.31 |
| 40 | 220 | 0.168 | 1.32 |
| 41 | 230 | 0.169 | 1.33 |
| 42 | 240 | 0.169 | 1.34 |
| 43 | 250 | 0.17 | 1.35 |
| 44 | 260 | 0.172 | 1.36 |
| 45 | 280 | 0.173 | 1.38 |
| 46 | 300 | 0.175 | 1.4 |
| 47 | 320 | 0.176 | 1.4 |
| 48 | 340 | 0.177 | 1.4 |
| 49 | 360 | 0.178 | 1.41 |
| 50 | 380 | 0.179 | 1.41 |
| 51 | 400 | 0.18 | 1.41 |
| 52 | 450 | 0.18 | 1.42 |
| 53 | 500 | 0.179 | 1.42 |
| 54 | 550 | 0.178 | 1.45 |
| 55 | 600 | 0.18 | 1.46 |
| 56 | 650 | 0.18 | 1.48 |
| 57 | 700 | 0.18 | 1.5 |
| 58 | 800 | 0.182 | 1.51 |
| 59 | 900 | 0.183 | 1.52 |
| 60 | 1000 | 0.183 | 1.54 |
| 61 | 1200 | 0.184 | 1.55 |
| 62 | 1400 | 0.186 | 1.56 |
| 63 | 1600 | 0.188 | 1.58 |
| 64 | 1800 | 0.189 | 1.59 |
| 65 | 2000 | 0.19 | 1.6 |
| 66 | 2500 | 0.195 | 1.61 |
| 67 | 3000 | 0.195 | 1.62 |
| 68 | 3100 | 0.192 | 1.62 |
| 69 | 3200 | 0.193 | 1.61 |
| 70 | 3300 | 0.194 | 1.62 |
| 71 | 3500 | 0.195 | 1.61 |

| | | | Continued |
|---|---|---|---|
| 72 | 3600 | 0.194 | 1.61 |
| 73 | 3800 | 0.195 | 1.62 |
| 74 | 4000 | 0.196 | 1.63 |
| 75 | 4200 | 0.195 | 1.62 |
| 76 | 5000 | 0.194 | 1.62 |
| 77 | 5500 | 0.195 | 1.65 |
| 78 | 6000 | 0.196 | 1.7 |
| 79 | 6500 | 0.197 | 1.71 |
| 80 | 7000 | 0.198 | 1.72 |
| 81 | 8000 | 0.198 | 1.73 |
| 82 | 8500 | 0.198 | 1.73 |
| 83 | 9000 | 0.199 | 1.74 |
| 84 | 10000 | 0.2 | 1.75 |
| | | | |
| Site:Salehpur | | | |
| Discharge: 3270m$^3$/day | | | |
| Distance from pumped well: | | r=70.6m | r=208.5m |
| | | Observation Well -1 | Observation Well -2 |
| Sn | Time(min) | Draw down(m) | Draw down(m) |
| 1 | 2.0 | 0.16 | 0.01 |
| 2 | 2.5 | 0.18 | 0.01 |
| 3 | 3 | 0.21 | 0.011 |
| 4 | 3.5 | 0.25 | 0.011 |
| 5 | 4 | 0.26 | 0.011 |
| 6 | 4.5 | 0.28 | 0.011 |
| 7 | 5 | 0.3 | 0.012 |
| 8 | 6 | 0.34 | 0.019 |
| 9 | 7 | 0.38 | 0.028 |
| 10 | 8 | 0.4 | 0.032 |
| 11 | 10 | 0.5 | 0.048 |
| 12 | 14 | 0.56 | 0.091 |
| 13 | 16 | 0.58 | 0.125 |
| 14 | 18 | 0.59 | 0.135 |
| 15 | 20 | 0.68 | 0.15 |
| 16 | 25 | 0.7 | 0.18 |
| 17 | 32 | 0.78 | 0.22 |
| 18 | 40 | 0.85 | 0.28 |
| 19 | 45 | 0.85 | 0.31 |
| 20 | 50 | 0.9 | 0.33 |
| 21 | 60 | 0.95 | 0.38 |
| 22 | 70 | 1 | 0.4 |
| 23 | 80 | 1.05 | 0.45 |
| 24 | 90 | 1.06 | 0.48 |
| 25 | 100 | 1.2 | 0.49 |
| 26 | 130 | 1.25 | 0.58 |
| 27 | 140 | 1.3 | 0.59 |
| 28 | 200 | 1.31 | 0.7 |
| 29 | 250 | 1.35 | 0.72 |
| 30 | 300 | 1.4 | 0.78 |
| 31 | 350 | 1.45 | 0.8 |
| 32 | 400 | 1.5 | 0.85 |

| | | | |
|---|---|---|---|
| 33 | 450 | 1.52 | 0.87 |
| 34 | 500 | 1.6 | 0.9 |
| 35 | 600 | 1.62 | 0.96 |
| 36 | 700 | 1.65 | 1 |
| 37 | 800 | 1.7 | 1.05 |
| 38 | 900 | 1.75 | 1.1 |
| 39 | 1000 | 1.8 | 1.11 |
| 40 | 1200 | 1.82 | 1.15 |
| 41 | 1400 | 1.84 | 1.2 |
| 42 | 1600 | 1.86 | 1.21 |
| 43 | 1800 | 1.9 | 1.25 |
| 44 | 2000 | 2 | 1.26 |
| 45 | 2500 | 2.05 | 1.3 |
| 46 | 3000 | 2.07 | 1.38 |
| 47 | 4000 | 2.15 | 1.4 |
| 48 | 5000 | 2.2 | 1.42 |
| 49 | 6000 | 2.25 | 1.44 |
| 50 | 7000 | 2.3 | 1.46 |
| 51 | 8000 | 2.4 | 1.47 |
| 52 | 9000 | 2.6 | 1.48 |
| 53 | 10000 | 2.62 | 1.5 |

| Site:Kailashpur | | | | |
|---|---|---|---|---|
| Discharge: 5457.89$m^3$/day | | | | |
| Distance from pumped well: | | r=24.08m | r=25m | r=98.8m |
| | | Observation Well -1 | Observation Well -2 | Observation Well -3 |
| Sn | Time(min) | Draw down(m) | Draw down(m) | Draw down(m) |
| 1 | 1.0 | 0.03 | 0.35 | 0.022 |
| 2 | 1.2 | 0.032 | 0.44 | 0.035 |
| 3 | 5 | 0.45 | 0.6 | 0.19 |
| 4 | 6 | 0.5 | 0.7 | 0.23 |
| 5 | 7 | 0.52 | 0.8 | 0.27 |
| 6 | 8 | 0.62 | 0.9 | 0.31 |
| 7 | 10 | 0.64 | 1 | 0.38 |
| 8 | 12 | 0.74 | 1.05 | 0.43 |
| 9 | 15 | 0.8 | 1.15 | 0.32 |
| 10 | 20 | 0.9 | 1.2 | 0.36 |
| 11 | 25 | 0.95 | 1.21 | 0.42 |
| 12 | 30 | 1.1 | 1.22 | 0.46 |
| 13 | 40 | 1.15 | 1.5 | 0.53 |
| 14 | 50 | 1.3 | 1.6 | 0.58 |
| 15 | 60 | 1.4 | 1.65 | 0.6 |
| 16 | 70 | 1.43 | 1.7 | 0.64 |
| 17 | 80 | 1.44 | 1.75 | 0.65 |
| 18 | 90 | 1.5 | 1.8 | 0.66 |
| 19 | 100 | 1.55 | 1.85 | 0.71 |
| 20 | 130 | 1.6 | 1.9 | 0.75 |
| 21 | 150 | 1.65 | 2 | 0.78 |
| 22 | 200 | 1.7 | 2.1 | 0.85 |
| 23 | 250 | 1.75 | 2.15 | 0.9 |
| 24 | 300 | 1.78 | 2.22 | 0.9 |

| | | | | |
|---|---|---|---|---|
| 25 | 350 | 1.79 | 2.22 | 0.9 |
| 26 | 500 | 1.85 | 2.4 | 1 |
| 27 | 600 | 2 | 2.5 | 1.1 |
| 28 | 700 | 2.1 | 2.55 | 1.2 |
| 29 | 800 | 2.1 | 2.6 | 1.25 |
| 30 | 900 | 2.1 | 2.7 | 1.3 |
| 31 | 1000 | 2.2 | 2.75 | 1.35 |
| 32 | 1200 | 2.23 | 2.78 | 1.4 |
| 33 | 1500 | 2.24 | 2.8 | 1.5 |
| 34 | 1600 | 2.26 | 2.85 | 1.65 |
| 35 | 1800 | 2.76 | 2.9 | 1.78 |
| 36 | 2000 | 2.8 | 3.1 | 1.8 |

| **Site:Muzaffarabad** | | | | | |
|---|---|---|---|---|---|
| Discharge: 822.8m$^3$/day | | | | | |
| Distance from pumped well: | | r=31.5m | r=35m | r=40m | r=20.0m |
| | | Observation Well -1 | Observation Well -2 | Observation Well -3 | Observation Well -4 |
| Sn | Time(min) | Draw down(m) | Draw down(m) | Draw down(m) | Draw down(m) |
| 2 | 1 | 0.015 | 0.001 | 0.001 | 0.025 |
| 3 | 1.5 | 0.065 | 0.002 | 0.0011 | 0.07 |
| 4 | 2 | 0.08 | 0.002 | 0.0012 | 0.1 |
| 5 | 2.5 | 0.11 | 0.003 | 0.002 | 0.15 |
| 6 | 3 | 0.13 | 0.004 | 0.005 | 0.175 |
| 7 | 3.5 | 0.14 | 0.005 | 0.006 | 0.205 |
| 8 | 4 | 0.15 | 0.005 | 0.007 | 0.225 |
| 9 | 4.5 | 0.16 | 0.005 | 0.008 | 0.245 |
| 10 | 5 | 0.175 | 0.005 | 0.01 | 0.27 |
| 11 | 6 | 0.185 | 0.01 | 0.01 | 0.285 |
| 12 | 7 | 0.2 | 0.01 | 0.01 | 0.305 |
| 13 | 8 | 0.21 | 0.015 | 0.01 | 0.315 |
| 14 | 9 | 0.215 | 0.015 | 0.01 | 0.325 |
| 15 | 10 | 0.22 | 0.02 | 0.015 | 0.335 |
| 16 | 12 | 0.23 | 0.03 | 0.015 | 0.34 |
| 17 | 14 | 0.24 | 0.035 | 0.02 | 0.355 |
| 18 | 16 | 0.25 | 0.04 | 0.03 | 0.37 |
| 19 | 18 | 0.265 | 0.045 | 0.035 | 0.4 |
| 20 | 20 | 0.285 | 0.06 | 0.045 | 0.43 |
| 21 | 25 | 0.29 | 0.06 | 0.05 | 0.44 |
| 22 | 30 | 0.295 | 0.065 | 0.05 | 0.445 |
| 23 | 35 | 0.305 | 0.07 | 0.06 | 0.455 |
| 24 | 40 | 0.315 | 0.07 | 0.065 | 0.46 |
| 25 | 45 | 0.315 | 0.075 | 0.065 | 0.46 |
| 26 | 50 | 0.32 | 0.075 | 0.07 | 0.47 |
| 27 | 55 | 0.325 | 0.08 | 0.07 | 0.485 |
| 28 | 60 | 0.325 | 0.08 | 0.075 | 0.49 |
| 29 | 65 | 0.33 | 0.08 | 0.075 | 0.585 |
| 30 | 70 | 0.33 | 0.085 | 0.08 | 0.51 |
| 31 | 75 | 0.335 | 0.085 | 0.08 | 0.515 |
| 32 | 80 | 0.335 | 0.085 | 0.08 | 0.52 |
| 33 | 85 | 0.34 | 0.09 | 0.085 | 0.525 |
| 34 | 90 | 0.34 | 0.09 | 0.085 | 0.53 |

| | | | | | |
|---|---|---|---|---|---|
| 35 | 95 | 0.345 | 0.09 | 0.085 | 0.545 |
| 36 | 100 | 0.345 | 0.095 | 0.085 | 0.55 |
| 37 | 110 | 0.345 | 0.095 | 0.09 | 0.555 |
| 38 | 120 | 0.35 | 0.095 | 0.09 | 0.57 |
| 39 | 130 | 0.35 | 0.095 | 0.09 | 0. 58 |
| 40 | 140 | 0.355 | 0.095 | 0.09 | 0.59 |
| 41 | 150 | 0.355 | 0.1 | 0.09 | 0.595 |
| 42 | 160 | 0.36 | 0.1 | 0.09 | 0.595 |
| 43 | 170 | 0.36 | 0.1 | 0.09 | 0.6 |
| 44 | 180 | 0.365 | 0.1 | 0.095 | 0.605 |
| 45 | 190 | 0.365 | 0.1 | 0.095 | 0.61 |
| 46 | 200 | 0.37 | 0.1 | 0.095 | 0.615 |
| 47 | 220 | 0.37 | 0.105 | 0.095 | 0.625 |
| 48 | 240 | 0.38 | 0.105 | 0.095 | 0.63 |
| 49 | 260 | 0.385 | 0.105 | 0.095 | 0.635 |
| 50 | 280 | 0.395 | 0.105 | 0.095 | 0.645 |
| 51 | 300 | 0.4 | 0.105 | 0.095 | 0.655 |
| 52 | 350 | 0.4 | 0.11 | 0.1 | 0.665 |
| 53 | 400 | 0.4 | 0.11 | 0.1 | 0.67 |
| 54 | 450 | 0.405 | 0.11 | 0.1 | 0.68 |
| 55 | 500 | 0.41 | 0.115 | 0.1 | 0.69 |
| 56 | 550 | 0.41 | 0.115 | 0.1 | 0.69 |
| 57 | 600 | 0.415 | 0.115 | 0.1 | 0.705 |
| 58 | 700 | 0.415 | 0.12 | 0.105 | 0.71 |
| 59 | 800 | 0.42 | 0.12 | 0.105 | 0.715 |
| 60 | 900 | 0.42 | 0.125 | 0.105 | 0.72 |
| 61 | 1000 | 0.425 | 0.125 | 0.105 | 0.73 |
| 62 | 1100 | 0.425 | 0.125 | 0.105 | 0.73 |
| 63 | 1200 | 0.425 | 0.125 | 0.105 | 0.73 |

| Site:Bhanera-Tanda | | | |
|---|---|---|---|
| Discharge: 2658.46m$^3$/day | | | |
| Distance from pumped well: | | r=31.0 m | r=35m |
| | | Observation Well -1 | Observation Well -2 |
| Sn | Time(min) | Draw down(m) | Draw down(m) |
| 1 | 1.0 | 0.17 | 0.29 |
| 2 | 1.5 | 0.22 | 0.35 |
| 3 | 2 | 0.3 | 0.41 |
| 4 | 2.5 | 0.33 | 0.43 |
| 5 | 3 | 0.375 | 0.45 |
| 6 | 3.5 | 0.4 | 0.52 |
| 7 | 4 | 0.43 | 0.52 |
| 8 | 4.5 | 0.475 | 0.54 |
| 9 | 5 | 0.5 | 0.55 |
| 10 | 6 | 0.52 | 0.58 |
| 11 | 7 | 0.525 | 0.6 |
| 12 | 8 | 0.57 | 0.63 |
| 13 | 9 | 0.59 | 0.64 |

| | | | |
|---|---|---|---|
| 14 | 10 | 0.62 | 0.65 |
| 15 | 11 | 0.63 | 0.69 |
| 16 | 12 | 0.65 | 0.71 |
| 17 | 13 | 0.665 | 0.72 |
| 18 | 14 | 0.68 | 0.73 |
| 19 | 15 | 0.69 | 0.74 |
| 20 | 16 | 0.7 | 0.755 |
| 21 | 17 | 0.71 | 0.77 |
| 22 | 18 | 0.725 | 0.77 |
| 23 | 19 | 0.73 | 0.78 |
| 24 | 20 | 0.74 | 0.795 |
| 25 | 22 | 0.75 | 0.815 |
| 26 | 24 | 0.77 | 0.83 |
| 27 | 26 | 0.78 | 0.835 |
| 28 | 28 | 0.785 | 0.84 |
| 29 | 30 | 0.79 | 0.845 |
| 30 | 32 | 0.795 | 0.85 |
| 31 | 34 | 0.8 | 0.855 |
| 32 | 36 | 0.805 | 0.865 |
| 33 | 38 | 0.81 | 0.87 |
| 34 | 40 | 0.815 | 0.87 |
| 35 | 42 | 0.82 | 0.88 |
| 36 | 44 | 0.82 | 0.885 |
| 37 | 46 | 0.825 | 0.89 |
| 38 | 48 | 0.825 | 0.89 |
| 39 | 50 | 0.83 | 0.89 |
| 40 | 52 | 0.83 | 0.89 |
| 41 | 54 | 0.83 | 0.89 |
| 42 | 56 | 0.835 | 0.89 |
| 43 | 58 | 0.835 | 0.89 |
| 44 | 60 | 0.835 | 0.89 |
| 45 | 65 | 0.84 | 0.89 |
| 46 | 70 | 0.84 | 0.89 |
| 47 | 75 | 0.845 | 0.89 |
| 48 | 80 | 0.845 | 0.89 |
| 49 | 85 | 0.85 | 0.89 |
| 50 | 90 | 0.85 | 0.89 |
| 51 | 95 | 0.85 | 0.89 |
| 52 | 100 | 0.85 | 0.89 |
| 53 | 105 | 0.85 | 0.89 |
| 54 | 110 | 0.85 | 0.89 |
| 55 | 115 | 0.85 | 0.89 |
| 56 | 120 | 0.85 | 0.89 |
| 57 | 130 | 0.85 | 0.89 |
| 58 | 140 | 0.85 | 0.9 |

| | | | |
|---|---|---|---|
| 59 | 150 | 0.85 | 0.9 |
| 60 | 160 | 0.85 | 0.9 |
| 61 | 170 | 0.85 | 0.9 |
| 62 | 180 | 0.85 | 0.9 |
| 63 | 190 | 0.85 | 0.9 |
| 64 | 200 | 0.85 | 0.9 |
| 65 | 210 | 0.85 | 0.9 |
| 66 | 220 | 0.85 | 0.9 |
| 67 | 230 | 0.85 | 0.9 |
| 68 | 240 | 0.85 | 0.9 |
| 69 | 250 | 0.855 | 0.9 |
| 70 | 260 | 0.855 | 0.9 |
| 71 | 270 | 0.855 | 0.9 |
| 72 | 280 | 0.855 | 0.9 |
| 73 | 290 | 0.855 | 0.9 |
| 74 | 300 | 0.855 | 0.9 |
| 75 | 320 | 0.855 | 0.9 |
| 76 | 340 | 0.855 | 0.9 |
| 77 | 360 | 0.855 | 0.9 |
| 78 | 380 | 0.86 | 0.905 |
| 79 | 400 | 0.86 | 0.905 |
| 80 | 420 | 0.86 | 0.905 |
| 81 | 440 | 0.86 | 0.905 |
| 82 | 460 | 0.86 | 0.905 |
| 83 | 480 | 0.86 | 0.905 |
| 84 | 500 | 0.86 | 0.905 |
| 85 | 520 | 0.86 | 0.905 |
| 86 | 540 | 0.86 | 0.905 |
| 87 | 560 | 0.86 | 0.905 |
| 88 | 580 | 0.86 | 0.91 |
| 89 | 600 | 0.865 | 0.91 |
| 90 | 620 | 0.865 | 0.91 |
| 91 | 640 | 0.865 | 0.915 |
| 92 | 660 | 0.875 | 0.915 |
| 93 | 680 | 0.875 | 0.92 |
| 94 | 700 | 0.875 | 0.92 |
| 95 | 720 | 0.88 | 0.92 |
| 96 | 740 | 0.885 | 0.92 |
| 97 | 760 | 0.885 | 0.925 |
| 98 | 780 | 0.885 | 0.93 |
| 99 | 800 | 0.885 | 0.93 |
| 100 | 820 | 0.89 | 0.93 |
| 101 | 840 | 0.89 | 0.93 |
| | | | |

| Site:Belda | | | | |
|---|---|---|---|---|
| Discharge: 743.23m³/day | | | | |
| Distance from pumped well: | | r=15.2 | r=58.35m | r=68.75m |
| | | Observation Well -1 | Observation Well -2 | Observation Well -3 |
| Sn | Time(min) | Draw down(m) | Draw down(m) | Draw down(m) |
| 1 | 1.0 | 0.25 | 0.025 | 0.02 |
| 2 | 1.2 | 0.275 | 0.035 | 0.025 |
| 3 | 1.5 | 0.305 | 0.05 | 0.03 |
| 4 | 2 | 0.34 | 0.07 | 0.05 |
| 5 | 2.5 | 0.37 | 0.095 | 0.055 |
| 6 | 3 | 0.395 | 0.105 | 0.08 |
| 7 | 4 | 0.43 | 0.13 | 0.1 |
| 8 | 5 | 0.455 | 0.16 | 0.12 |
| 9 | 6 | 0.475 | 0.175 | 0.14 |
| 10 | 7 | 0.49 | 0.19 | 0.155 |
| 11 | 8 | 0.505 | 0.205 | 0.16 |
| 12 | 9 | 0.515 | 0.215 | 0.175 |
| 13 | 10 | 0.525 | 0.225 | 0.18 |
| 14 | 12 | 0.535 | 0.24 | 0.195 |
| 15 | 15 | 0.55 | 0.255 | 0.21 |
| 16 | 20 | 0.56 | 0.265 | 0.23 |
| 17 | 25 | 0.565 | 0.275 | 0.235 |
| 18 | 30 | 0.565 | 0.275 | 0.24 |
| 19 | 40 | 0.56 | 0.275 | 0.225 |
| 20 | 50 | 0.545 | 0.255 | 0.215 |
| 21 | 60 | 0.525 | 0.235 | 0.195 |
| 22 | 70 | 0.505 | 0.2 | 0.18 |
| 23 | 80 | 0.485 | 0.185 | 0.16 |
| 24 | 90 | 0.466 | 0.17 | 0.14 |

| Site:Landhaura | | |
|---|---|---|
| Discharge: 3216m³/day | | |
| Distance from pumped well: | | r=14.32 |
| | | Observation Well -1 |
| Sn | Time(min) | Draw down(m) |
| 1 | 7.0 | 0.655 |
| 2 | 11 | 0.704 |
| 3 | 16 | 0.719 |
| 4 | 26 | 0.795 |
| 5 | 31 | 0.826 |
| 6 | 35 | 0.838 |
| 7 | 40 | 0.853 |
| 8 | 45 | 0.868 |
| 9 | 50 | 0.881 |
| 10 | 60 | 0.911 |
| 11 | 70 | 0.929 |
| 12 | 80 | 0.954 |
| 13 | 90 | 0.953 |
| 14 | 110 | 0.981 |
| 15 | 130 | 0.999 |
| 16 | 150 | 1.01 |

| | | |
|---|---|---|
| 17 | 170 | 1.03 |
| 18 | 180 | 1.04 |
| 19 | 210 | 1.03 |
| 20 | 240 | 1.03 |
| 21 | 270 | 1.04 |
| 22 | 300 | 1.06 |
| 23 | 315 | 1.06 |
| 24 | 345 | 1.05 |
| 25 | 365 | 1.05 |
| 26 | 390 | 1.06 |
| 27 | 420 | 1.05 |
| 28 | 450 | 1.06 |
| 29 | 480 | 1.07 |
| 30 | 540 | 1.07 |
| 31 | 600 | 1.09 |
| 32 | 635 | 1.08 |
| 33 | 720 | 1.09 |
| 34 | 780 | 1.07 |
| 35 | 900 | 1.06 |

| Site:Chhutmalpur | | | | |
|---|---|---|---|---|
| Discharge: 715.66m$^3$/day | | | | |
| Distance from pumped well: | | r=20.49 | r=35.30m | r=50.6m |
| | | Observation Well -1 | Observation Well -2 | Observation Well -3 |
| Sn | Time(min) | Draw down(m) | Draw down(m) | Draw down(m) |
| 1 | 1.0 | 0.17 | 0.06 | 0.01 |
| 2 | 1.5 | 0.28 | 0.1 | 0.01 |
| 3 | 2 | 0.38 | 0.14 | 0.01 |
| 4 | 2.5 | 0.45 | 0.18 | 0.01 |
| 5 | 3 | 0.52 | 0.22 | 0.01 |
| 6 | 3.5 | 0.6 | 0.26 | 0.02 |
| 7 | 4 | 0.64 | 0.3 | 0.03 |
| 8 | 4.5 | 0.67 | 0.33 | 0.04 |
| 9 | 5 | 0.7 | 0.36 | 0.05 |
| 10 | 5.5 | 0.72 | 0.4 | 0.06 |
| 11 | 6 | 0.73 | 0.425 | 0.07 |
| 12 | 6.5 | 0.75 | 0.445 | 0.08 |
| 13 | 7 | 0.77 | 0.46 | 0.085 |
| 14 | 7.5 | 0.79 | 0.49 | 0.09 |
| 15 | 8 | 0.805 | 0.52 | 0.1 |
| 16 | 8.5 | 0.83 | 0.55 | 0.11 |
| 17 | 9 | 0.845 | 0.57 | 0.12 |
| 18 | 9.5 | 0.86 | 0.585 | 0.13 |
| 19 | 10 | 0.865 | 0.6 | 0.15 |
| 20 | 11 | 0.88 | 0.605 | 0.17 |
| 21 | 12 | 0.94 | 0.61 | 0.19 |
| 22 | 13 | 1 | 0.62 | 0.195 |
| 23 | 14 | 1.03 | 0.645 | 0.2 |
| 24 | 15 | 1.05 | 0.67 | 0.22 |
| 25 | 16 | 1.06 | 0.695 | 0.24 |

| | | | | |
|---|---|---|---|---|
| 26 | 17 | 1.08 | 0.71 | 0.27 |
| 27 | 18 | 1.11 | 0.72 | 0.29 |
| 28 | 19 | 1.12 | 0.74 | 0.31 |
| 29 | 20 | 1.14 | 0.76 | 0.33 |
| 30 | 22 | 1.17 | 0.785 | 0.36 |
| 31 | 24 | 1.18 | 0.805 | 0.39 |
| 32 | 26 | 1.21 | 0.825 | 0.41 |
| 33 | 28 | 1.24 | 0.855 | 0.43 |
| 34 | 30 | 1.25 | 0.86 | 0.45 |
| 35 | 32 | 1.26 | 0.875 | 0.47 |
| 36 | 34 | 1.28 | 0.89 | 0.49 |
| 37 | 36 | 1.29 | 0.9 | 0.51 |
| 38 | 38 | 1.3 | 0.9 | 0.52 |
| 39 | 40 | 1.31 | 0.91 | 0.53 |
| 40 | 42 | 1.32 | 0.92 | 0.54 |
| 41 | 44 | 1.32 | 0.925 | 0.55 |
| 42 | 46 | 1.33 | 0.935 | 0.56 |
| 43 | 48 | 1.33 | 0.935 | 0.56 |
| 44 | 50 | 1.33 | 0.935 | 0.57 |
| 45 | 55 | 1.34 | 0.945 | 0.58 |
| 46 | 60 | 1.35 | 0.945 | 0.58 |
| 47 | 65 | 1.36 | 0.945 | 0.58 |
| 48 | 70 | 1.36 | 0.945 | 0.59 |
| 49 | 75 | 1.36 | 0.95 | 0.6 |
| 50 | 80 | 1.36 | 0.9525 | 0.605 |
| 51 | 85 | 1.36 | 0.9525 | 0.61 |
| 52 | 90 | 1.36 | 0.9525 | 0.61 |
| 53 | 95 | 1.36 | 0.9525 | 0.61 |
| 54 | 100 | 1.36 | 0.9525 | 0.62 |
| 55 | 110 | 1.365 | 0.955 | 0.62 |
| 56 | 120 | 1.365 | 0.955 | 0.63 |
| 57 | 130 | 1.365 | 0.955 | 0.63 |
| 58 | 140 | 1.365 | 0.955 | 0.63 |
| 59 | 150 | 1.365 | 0.955 | 0.63 |
| 60 | 160 | 1.365 | 0.9525 | 0.64 |
| 61 | 170 | 1.365 | 0.9525 | 0.64 |
| 62 | 180 | 1.365 | 0.9575 | 0.64 |
| 63 | 190 | 1.3675 | 0.96 | 0.64 |
| 64 | 200 | 1.3675 | 0.96 | 0.645 |
| 65 | 220 | 1.37 | 0.9625 | 0.645 |
| 66 | 240 | 1.37 | 0.9625 | 0.64 |
| 67 | 260 | 1.37 | 0.9625 | 0.64 |
| 68 | 280 | 1.3725 | 0.965 | 0.64 |
| 69 | 300 | 1.3725 | 0.965 | 0.645 |
| 70 | 320 | 1.3725 | 0.965 | 0.645 |
| 71 | 340 | 1.3725 | 0.965 | 0.645 |
| 72 | 360 | 1.375 | 0.965 | 0.6475 |
| 73 | 380 | 1.375 | 0.9625 | 0.6475 |
| 74 | 400 | 1.375 | 0.9625 | 0.6475 |
| 75 | 420 | 1.375 | 0.9625 | 0.65 |
| 76 | 440 | 1.375 | 0.9625 | 0.65 |
| 77 | 460 | 1.3775 | 0.965 | 0.6525 |
| 78 | 480 | 1.3775 | 0.965 | 0.6525 |

| | | | | |
|---|---|---|---|---|
| 79 | 500 | 1.3775 | 0.965 | 0.6525 |
| 80 | 550 | 1.38 | 0.9675 | 0.6525 |
| 81 | 600 | 1.38 | 0.97 | 0.6525 |
| 82 | 650 | 1.38 | 0.9725 | 0.655 |
| 83 | 700 | 1.3825 | 0.9725 | 0.655 |
| 84 | 750 | 1.385 | 0.975 | 0.655 |
| 85 | 800 | 1.3875 | 0.9775 | 0.655 |
| 86 | 850 | 1.39 | 0.98 | 0.6575 |
| 87 | 900 | 1.395 | 0.9825 | 0.6575 |
| 88 | 950 | 1.3975 | 0.9825 | 0.66 |
| 89 | 1000 | 1.4 | 0.985 | 0.66 |

| Site:Ismailpur | | |
|---|---|---|
| Discharge: 1554.96m$^3$/day | | |
| | | |
| | | Pumped well |
| Sn | Time(min) | Draw down(m) |
| 1 | 2.0 | 4.65 |
| 2 | 5 | 4.8 |
| 3 | 10 | 4.88 |
| 4 | 14 | 4.95 |
| 5 | 20 | 5.03 |
| 6 | 25 | 4.95 |
| 7 | 30 | 4.95 |
| 8 | 35 | 4.95 |
| 9 | 40 | 5.03 |
| 10 | 45 | 5.1 |
| 11 | 60 | 5.1 |
| 12 | 80 | 5.18 |
| 13 | 100 | 5.18 |
| 14 | 120 | 5.18 |
| 15 | 140 | 5.26 |
| 16 | 160 | 5.26 |
| 17 | 180 | 5.33 |
| 18 | 210 | 5.33 |
| 19 | 240 | 5.33 |
| 20 | 300 | 5.33 |
| 21 | 360 | 5.33 |

| Site:Ganeshpur | | |
|---|---|---|
| Discharge: 2318.64m$^3$/day | | |
| | | |
| | | Pumped well |
| Sn | Time(min) | Draw down(m) |
| 1 | 6.0 | 5.39 |
| 2 | 8 | 5.51 |
| 3 | 9 | 5.59 |
| 4 | 11 | 5.75 |
| 5 | 13 | 5.92 |
| 6 | 16 | 6.07 |
| 7 | 19 | 6.22 |
| 8 | 21 | 6.31 |

| | | |
|---|---|---|
| 9 | 24 | 6.39 |
| 10 | 28 | 5.94 |
| 11 | 29 | 5.96 |
| 12 | 35 | 6.05 |
| 13 | 39 | 6.2 |
| 14 | 42 | 6.33 |
| 15 | 45 | 6.2 |
| 16 | 48 | 6.17 |
| 17 | 52 | 6.19 |
| 18 | 55 | 6.19 |
| 19 | 59 | 6.22 |
| 20 | 64 | 6.24 |
| 21 | 73 | 6.26 |
| 22 | 78 | 6.32 |
| 23 | 84 | 6.36 |
| 24 | 90 | 6.35 |
| 25 | 95 | 6.36 |
| 26 | 175 | 6.53 |
| 27 | 180 | 6.53 |
| 28 | 184 | 6.54 |
| 29 | 189 | 6.54 |
| 30 | 195 | 6.56 |
| 31 | 201 | 6.56 |
| 32 | 206 | 6.6 |
| 33 | 215 | 6.6 |
| 34 | 221 | 6.61 |
| 35 | 231 | 6.64 |
| 36 | 236 | 6.63 |
| 37 | 241 | 6.59 |
| 38 | 246 | 6.64 |
| 39 | 254 | 6.65 |
| 40 | 261 | 6.66 |
| 41 | 262 | 6.56 |
| 42 | 266 | 6.67 |
| 43 | 270 | 6.68 |
| 44 | 271 | 6.48 |
| 45 | 281 | 6.38 |
| 46 | 298 | 6.27 |
| 47 | 303 | 6.29 |
| 48 | 353 | 6.6 |
| 49 | 359 | 6.63 |
| 50 | 363 | 6.83 |
| 51 | 367 | 6.65 |
| 52 | 371 | 6.65 |
| 53 | 374 | 6.66 |

| Site:Jwalapur | | |
|---|---|---|
| Discharge: 2968.8m$^3$/day | | |
| | | |
| | | Pumped well |
| Sn | Time(min) | Draw down(m) |
| 1 | 5.0 | 1.61 |
| 2 | 10 | 1.63 |
| 3 | 15 | 1.63 |
| 4 | 35 | 1.63 |
| 5 | 55 | 1.63 |
| 6 | 75 | 1.64 |
| 7 | 95 | 1.64 |
| 8 | 120 | 1.64 |
| 9 | 152 | 1.64 |
| 10 | 180 | 1.64 |
| 11 | 216 | 1.64 |
| 12 | 255 | 1.65 |
| 13 | 295 | 1.65 |
| 14 | 345 | 1.65 |
| 15 | 385 | 1.66 |
| 16 | 435 | 1.66 |
| 17 | 465 | 1.66 |
| 18 | 495 | 1.66 |
| 19 | 525 | 1.66 |
| 20 | 555 | 1.66 |
| 21 | 615 | 1.66 |
| 22 | 681 | 1.67 |
| 23 | 735 | 1.66 |
| 24 | 795 | 1.66 |
| 25 | 855 | 1.67 |
| 26 | 915 | 1.67 |
| 27 | 975 | 1.67 |
| 28 | 1040 | 1.68 |
| 29 | 1095 | 1.7 |
| 30 | 1155 | 1.7 |
| 31 | 1215 | 1.72 |
| 32 | 1275 | 1.7 |
| 33 | 1335 | 1.71 |
| 34 | 1395 | 1.71 |
| 35 | 1435 | 1.71 |

# APPENDIX-2

## GEOELECTRICAL DATA OF THE STUDY AREA

APPENDIX-2

| Site: | | Gangoh | Nagal | | |
|---|---|---|---|---|---|
| Sounding Number | | VES-1 | VES-2 | | VES-3 |
| AB/2 | MN/2 | Apparent Resistivity | Apparent Resistivity | Chargeability | Apparent Resistivity |
| | | ( Ohm-m) | ( Ohm-m) | ( m-sec) | ( Ohm-m) |
| 2 | 0.5 | 91.06 | 33.733 | 0.49 | 32.73 |
| 3 | 0.5 | 96.45 | 37.066 | 0.43 | 21.78 |
| 4 | 0.5 | 100.23 | 38.44 | 1.08 | 18.59 |
| 5 | 0.5 | 97.32 | 42.775 | 1.35 | 17.79 |
| 5 | 1 | 97.6 | 41.3 | 1.2 | 16.3 |
| 6 | 1 | 94.58 | 46.66 | 1.23 | 19.5 |
| 8 | 1 | 92.35 | 56.417 | 1.25 | 24.62 |
| 10 | 1 | 93.89 | 67.26 | 1.6 | 26.52 |
| 10 | 2 | 92.7 | 66.3 | 1.5 | 26.5 |
| 12 | 2 | 94.67 | 79.327 | 2.01 | 31.1 |
| 15 | 2 | 105.32 | 90.049 | 1.42 | 35.6 |
| 20 | 2 | 125.32 | 101.03 | 1.57 | 53.59 |
| 20 | 4 | 126.8 | 102.5 | 1.6 | 54.9 |
| 25 | 4 | 135.48 | 105.58 | 1.9 | 63.1 |
| 30 | 4 | 146.72 | 88.81 | 2.23 | 71.82 |
| 40 | 4 | 153.86 | 80.6 | 3.14 | 81.81 |
| 50 | 4 | 154.83 | 75.86 | 3.52 | 103.7 |
| 50 | 10 | 156.2 | 76.3 | | 104.9 |
| 60 | 10 | 142.83 | 65.776 | | 114.29 |
| 80 | 10 | 128.78 | 69.309 | | 122.45 |
| 100 | 10 | 102.32 | 66.86 | | 111.13 |
| 100 | 20 | 101.9 | 67.9 | | 110.9 |
| 120 | 20 | 84.79 | 64.011 | | 68.95 |
| 160 | 20 | 65.89 | 60.35 | | 51.96 |
| 200 | 20 | 56.76 | 63.668 | | 48.39 |
| 200 | 40 | 57.68 | 64.3 | | 49.57 |
| 250 | 40 | 50.12 | 70.23 | | 41.25 |
| 300 | 40 | 38.71 | 75.109 | | 38.16 |
| 350 | 40 | 34.82 | 78.23 | | 38.03 |
| 400 | 40 | 30.76 | 83.26 | | 32.01 |

Continued

| Site: | | Nanauta | | | Nakur | |
|---|---|---|---|---|---|---|
| Sounding Number | | VES-5 | | VES-4 | VES-6. | |
| AB/2 | MN/2 | Apparent Resistivity | Chargeability | Apparent Resistivity | Apparent Resistivity | Chargeability |
| | | ( Ohm-m) | (m-Sec) | ( Ohm-m) | ( Ohm-m) | (m-Sec) |
| 2 | 0.5 | 26.85 | 0.21 | 50.86 | 72.18 | 0.21 |
| 3 | 0.5 | 19.64 | 0.12 | 47.6 | 78.01 | 0.12 |
| 4 | 0.5 | 17.06 | 0.39 | 50.09 | 96.08 | 0.39 |
| 5 | 0.5 | 18.27 | 0.35 | 51.28 | 112.6 | 0.35 |
| 5 | 1 | 19.36 | 0.36 | 52.6 | 110.3 | 0.36 |
| 6 | 1 | 17.03 | 0.53 | 52.75 | 119.79 | 0.53 |
| 8 | 1 | 17.6 | 0.54 | 55.78 | 153.6 | 0.54 |
| 10 | 1 | 19.39 | 0.67 | 56.89 | 166.54 | 0.67 |
| 10 | 2 | 19.56 | 0.57 | 57.9 | 165.2 | 0.57 |
| 12 | 2 | 23.24 | 0.92 | 54.73 | 178.25 | 0.92 |
| 15 | 2 | 25.126 | 1.48 | 56.38 | 184.75 | 1.48 |
| 20 | 2 | 25.74 | 1.82 | 56.54 | 172.216 | 1.82 |
| 20 | 4 | 26.89 | 1.23 | 57.6 | 170.6 | 1.23 |
| 25 | 4 | 37.62 | 1.39 | 56.17 | 176.165 | 1.39 |
| 30 | 4 | 37.88 | 1.63 | 54.12 | 182.5 | 1.63 |
| 40 | 4 | 38.24 | 1.87 | 51.97 | 180.92 | 1.87 |
| 50 | 4 | 39.27 | 1.98 | 46.12 | 156.315 | 1.98 |
| 50 | 10 | 39.62 | 1.68 | 47.6 | 158.3 | 1.68 |
| 60 | 10 | 38.13 | 2.49 | 45.27 | 115.39 | 2.49 |
| 80 | 10 | 41.34 | 0.67 | 39.46 | 84.27 | 0.67 |
| 100 | 10 | 43.09 | 0.99 | 36.24 | 66.52 | 0.99 |
| 100 | 20 | 46.2 | 1.23 | 37.9 | 65.32 | 1.23 |
| 120 | 20 | 46.99 | | 39.67 | 86.49 | |
| 160 | 20 | 49.77 | | 36.54 | 71.29 | |
| 200 | 20 | 47.93 | | 33.39 | 70.25 | |
| 200 | 40 | 48.0 | | 34.6 | 69.5 | |
| 250 | 40 | 38.46 | | 40.99 | 49 | |
| 300 | 40 | 36.6 | | 39.36 | 51.28 | |
| 350 | 40 | 31.81 | | 38.16 | 68.38 | |
| 400 | 40 | 29.18 | | | | |

Continued

| Site: | | K.Akbarpur | | Fatehpur | Kashipur |
|---|---|---|---|---|---|
| Sounding Number | | VES-7 | | VES-8 | VES-9 |
| AB/2 | MN/2 | Apparent Resistivity | Chargeability | Apparent Resistivity | Apparent Resistivity |
| | | ( Ohm-m) | (m-Sec) | ( Ohm-m) | ( Ohm-m) |
| 2 | 0.5 | 74.161 | 3.62 | 46.62 | 14 |
| 3 | 0.5 | 66.2 | 2.1 | 38.54 | 16.45 |
| 4 | 0.5 | 68.43 | 1.25 | 36.64 | 19.43 |
| 5 | 0.5 | 73.66 | 1.13 | 40.33 | 20.04 |
| 5 | 1 | 75.6 | 0.8 | 42.3 | 19.6 |
| 6 | 1 | 70.22 | 1.49 | 44.12 | 21.1 |
| 8 | 1 | 81.4 | 2.01 | 54.3 | 22.84 |
| 10 | 1 | 82.35 | 2.86 | 58.17 | 24.06 |
| 10 | 2 | 84.5 | 1.98 | 59.2 | 23.45 |
| 12 | 2 | 88.65 | 2.92 | 60.99 | 26.81 |
| 15 | 2 | 105.99 | 3.31 | 66.44 | 31.17 |
| 20 | 2 | 120.3 | 2.94 | 67.147 | 29.4 |
| 20 | 4 | 125.3 | 1.96 | 68.6 | 30.6 |
| 25 | 4 | 105.17 | 5.38 | 72.42 | 30.61 |
| 30 | 4 | 105.13 | 2.75 | 64.18 | 31.78 |
| 40 | 4 | 98.65 | 1.83 | 59.125 | 30.46 |
| 50 | 4 | 95.26 | 2.04 | 57.133 | 28.76 |
| 50 | 10 | 96.2 | 1.69 | 51.3 | 29.87 |
| 60 | 10 | 91.43 | 2 | 45.11 | 38.57 |
| 80 | 10 | 83.08 | | 49.455 | 38.17 |
| 100 | 10 | 70.09 | | 60.3 | 38.28 |
| 100 | 20 | 69.8 | | 61.2 | 37.24 |
| 120 | 20 | 56.59 | | 44.28 | 35.49 |
| 160 | 20 | 45.69 | | 51.43 | 36.2 |
| 200 | 20 | 35.56 | | 51.54 | 37.3 |
| 200 | 40 | 34.6 | | 56.6 | 36.8 |
| 250 | 40 | 31.57 | | 66.21 | 36.66 |
| 300 | 40 | 33.93 | | 84.31 | 32.68 |
| 350 | 40 | 32.31 | | 105.35 | |
| 400 | 40 | 31.08 | | 124.34 | |

Continued

| Site: | | Barthakaith | Khera Afghan | Salehpur | Kailashpur |
|---|---|---|---|---|---|
| Sounding Number | | VES-12 | VES-12 | VES-14 | VES-17 |
| AB/2 | MN/2 | **Apparent Resistivity** | **Apparent Resistivity** | **Apparent Resistivity** | **Apparent Resistivity** |
| | | **( Ohm-m)** | **( Ohm-m)** | **( Ohm-m)** | **( Ohm-m)** |
| 2 | 0.5 | 48.74 | 101.38 | 67.35 | 25.55 |
| 3 | 0.5 | 50.48 | 73.89 | 70.32 | 25.87 |
| 4 | 0.5 | 48.36 | 75.39 | 82.92 | 28.92 |
| 5 | 0.5 | 50.43 | 89.85 | 93.01 | 32.71 |
| 5 | 1 | 49.6 | 88.76 | 90.2 | 33.8 |
| 6 | 1 | 54.12 | 111.9 | 99.95 | 38.24 |
| 8 | 1 | 57.66 | 155.68 | 101.39 | 48.169 |
| 10 | 1 | 59.91 | 263 | 115.23 | 57.66 |
| 10 | 2 | 58.9 | 269.3 | 114.8 | 56.3 |
| 12 | 2 | 59.23 | 291.23 | 145.36 | 61.21 |
| 15 | 2 | 64.36 | 346.96 | 166.54 | 71.3 |
| 20 | 2 | 68.38 | 423.65 | 170.16 | 82.14 |
| 20 | 4 | 69.6 | 435.6 | 169.3 | 83.98 |
| 25 | 4 | 70.51 | 462.28 | 187.39 | 88.44 |
| 30 | 4 | 72.51 | 464.24 | 196.38 | 91.25 |
| 40 | 4 | 72.43 | 409.71 | 214.49 | 85.98 |
| 50 | 4 | 70.88 | 354.88 | 148.82 | 77.02 |
| 50 | 10 | 71.3 | 362.0 | 149.6 | 76.9 |
| 60 | 10 | 64.01 | 260.58 | 124.73 | 68.08 |
| 80 | 10 | 61.12 | 197.82 | 93.17 | 48.46 |
| 100 | 10 | 61.39 | 165.3 | 76.16 | 44.98 |
| 100 | 20 | 62.3 | 164.3 | 78.6 | 43.6 |
| 120 | 20 | 59.01 | 114 | 65.28 | 40.66 |
| 160 | 20 | 56.77 | 67.25 | 53.8 | 35.1 |
| 200 | 20 | 45.21 | 61.9 | 44.31 | 31.08 |
| 200 | 40 | 45.3 | 60.3 | 45.6 | 32.6 |
| 250 | 40 | 40.27 | 74.57 | 41.44 | 30.89 |
| 300 | 40 | 51.45 | 85.7 | 38.2 | |
| 350 | 40 | 50.11 | 102.49 | 39.76 | |
| 400 | 40 | 47 | 114.2 | 40.1 | |

Continued

| Site: | | Sarsawan | | | Gudam |
|---|---|---|---|---|---|
| Sounding Number | | VES-15 | | VES-16 | VES-18 |
| AB/2 | MN/2 | Apparent Resistivity | Chargeability | Apparent Resistivity | Apparent Resistivity |
| | | ( Ohm-m) | (m-Sec) | ( Ohm-m) | ( Ohm-m) |
| 2 | 0.5 | 69.07 | 0.46 | 69.07 | 174.03 |
| 3 | 0.5 | 71.05 | 0.87 | 71.05 | 240.91 |
| 4 | 0.5 | 79.38 | 1.33 | 79.38 | 288.29 |
| 5 | 0.5 | 88.59 | 1.99 | 88.59 | 304.07 |
| 5 | 1 | 85.57 | 2.01 | 85.57 | 301.3 |
| 6 | 1 | 95.84 | 2.42 | 95.84 | 318.71 |
| 8 | 1 | 113.45 | 3.58 | 113.45 | 328.38 |
| 10 | 1 | 125.81 | 4.84 | 125.81 | 309.3 |
| 10 | 2 | 128.3 | 4.6 | 128.32 | 309.2 |
| 12 | 2 | 128.32 | 6.02 | 127.97 | 258.26 |
| 15 | 2 | 127.97 | 8.02 | 113.65 | 226.73 |
| 20 | 2 | 113.65 | 11.3 | 111.92 | 140.5 |
| 20 | 4 | 111.92 | 12.1 | 101.54 | 134:6 |
| 25 | 4 | 101.54 | 15.6 | 83.46 | 87.96 |
| 30 | 4 | 83.46 | 17.6 | 58.02 | 57.59 |
| 40 | 4 | 58.02 | 13.3 | 46.73 | 38.29 |
| 50 | 4 | 46.73 | 16.61 | 44 | 34.61 |
| 50 | 10 | 44 | 18.3 | 35.12 | 36.3 |
| 60 | 10 | 35.12 | 13.2 | 33.19 | 24.89 |
| 80 | 10 | 33.19 | 13.56 | 36.8 | 21.06 |
| 100 | 10 | 33.14 | 14.88 | 35.14 | 16.44 |
| 100 | 20 | 34.6 | 15.9 | 34.68 | 11.2 |
| 120 | 20 | 34.68 | 15.8 | 40.85 | 28.24 |
| 160 | 20 | 40.85 | 11 | 49.41 | 35.96 |
| 200 | 20 | 49.41 | 10 | 68.09 | 45.38 |
| 200 | 40 | 48.9 | 12.6 | 79.39 | 46.6 |
| 250 | 40 | 58.09 | 8.4 | 89 | 23.15 |
| 300 | 40 | 69.39 | 5.08 | 81.22 | 22.96 |
| 350 | 40 | 107.57 | 5.89 | | 20.17 |
| 400 | 40 | 81.22 | 6.56 | | 17.28 |

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| Site: | | Muzaffarabad | | | Chutmalpur |
|---|---|---|---|---|---|
| Sounding Number | | VES-19 | | VES-20 | VES-29 |
| AB/2 | MN/2 | Apparent Resistivity | Chargeability | Apparent Resistivity | Apparent Resistivity |
| | | ( Ohm-m) | (m-Sec) | ( Ohm-m) | ( Ohm-m) |
| 2 | 0.5 | 48.86 | 1.65 | 103.2 | 84.66 |
| 3 | 0.5 | 40.9 | 1.67 | 78.45 | 92.29 |
| 4 | 0.5 | 39.169 | 1.2 | 59.69 | 97.91 |
| 5 | 0.5 | 38.97 | 1.46 | 47.23 | 105.88 |
| 5 | 1 | 39.6 | 1.5 | 46.9 | 134.4 |
| 6 | 1 | 41.97 | 1.35 | 41.77 | 103.41 |
| 8 | 1 | 43.627 | 1.44 | 40.99 | 94.6 |
| 10 | 1 | 44.95 | 1.44 | 47.5 | 76.23 |
| 10 | 2 | 45.3 | 1.42 | 48.2 | 72.51 |
| 12 | 2 | 41.67 | 1.55 | 60.595 | 68.02 |
| 15 | 2 | 42.57 | 1.47 | 73.299 | 76.66 |
| 20 | 2 | 38.79 | 1.68 | 87.67 | 80.82 |
| 20 | 4 | 39.2 | 1.56 | 86.2 | 88.19 |
| 25 | 4 | 36.49 | | 95.88 | 78.16 |
| 30 | 4 | 36.5 | | 94.78 | 75.98 |
| 40 | 4 | 31.66 | | 68.48 | 70.62 |
| 50 | 4 | 30.67 | | 46.78 | 65.21 |
| 50 | 10 | 31.6 | | | 72.53 |
| 60 | 10 | 27.92 | | 38.82 | 61.81 |
| 80 | 10 | 28.06 | | 25.2 | 51.13 |
| 100 | 10 | 28.74 | | 17.186 | 46.93 |
| 100 | 20 | 29.6 | | 16.3 | 42.3 |
| 120 | 20 | 29.76 | | 20.69 | 30.11 |
| 160 | 20 | 33.79 | | 17.23 | 26.82 |
| 200 | 20 | 32.3 | | 17.9 | 24.16 |
| 200 | 40 | 30.2 | | 18.34 | 22.3 |
| 250 | 40 | 29.29 | | 24.04 | 23.15 |
| 300 | 40 | 30.11 | | 19.77 | 22.96 |
| 350 | 40 | 30.95 | | 14.31 | 20.17 |
| 400 | 40 | 31.05 | | 22.92 | 17.28 |

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| Site: | | Bhanera | | | |
|---|---|---|---|---|---|
| Sounding Number | | VES-23 | | VES-21 | VES-22 |
| AB/2 | MN/2 | Apparent Resistivity | Chargeability | Apparent Resistivity | Apparent Resistivity |
| | | ( Ohm-m) | (m-Sec) | ( Ohm-m) | ( Ohm-m) |
| 2 | 0.5 | 324.84 | 0.72 | 148.9 | 165.28 |
| 3 | 0.5 | 278.98 | 0.84 | 196.32 | 169.03 |
| 4 | 0.5 | 275.66 | 0.86 | 215.9 | 159.23 |
| 5 | 0.5 | 314.87 | 0.92 | 235.9 | 148.03 |
| 5 | 1 | 315.8 | 0.98 | 256.35 | 136.26 |
| 6 | 1 | 327.27 | 1.16 | 265.89 | 145.69 |
| 8 | 1 | 396.07 | 1.28 | 265.47 | 165.38 |
| 10 | 1 | 455.97 | 1.52 | 275.69 | 139.23 |
| 10 | 2 | 451.6 | 1.26 | 289.87 | 155.43 |
| 12 | 2 | 500.09 | 1.61 | 317.23 | 224.51 |
| 15 | 2 | 513.92 | 1.71 | 355.19 | 351.68 |
| 20 | 2 | 534.22 | 1.69 | 406.55 | 626.35 |
| 20 | 4 | 530.2 | 1.2 | 373.69 | 310.86 |
| 25 | 4 | 511.04 | 1.71 | 375.85 | 487.48 |
| 30 | 4 | 462.97 | 1.85 | 378.9 | 703.36 |
| 40 | 4 | 379.98 | 2.01 | 348.29 | 1252.86 |
| 50 | 4 | 296.14 | 2.04 | 313.69 | 1959.36 |
| 50 | 10 | 291.6 | 1.98 | 247.23 | 974.97 |
| 60 | 10 | 193.72 | 2.1 | 189.26 | 1406.3 |
| 80 | 10 | 144.58 | 2.96 | 248.65 | 693.56 |
| 100 | 10 | 125.31 | 3.59 | 198.56 | 1243.44 |
| 100 | 20 | 124.6 | 2.59 | 71.03 | 1554.3 |
| 120 | 20 | 96.533 | 4.68 | 56.04 | 1099.36 |
| 160 | 20 | 69.637 | 3.98 | 32.69 | 1507.2 |
| 200 | 20 | 58.362 | 3.74 | | 2390.32 |
| 200 | 40 | 61.706 | | | 3469.7 |
| 250 | 40 | 60.489 | | | |
| 300 | 40 | | | | |
| 350 | 40 | | | | |
| 400 | 40 | | | | |

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| Site: | | Landhaura | | | |
|---|---|---|---|---|---|
| Sounding Number | | VES-27 | | VES-26 | VES-28 |
| AB/2 | MN/2 | Apparent Resistivity | Chargeability | Apparent Resistivity | Apparent Resistivity |
| | | ( Ohm-m) | (m-Sec) | ( Ohm-m) | ( Ohm-m) |
| 2 | 0.5 | 74.26 | 1.02 | 75.44 | 59.28 |
| 3 | 0.5 | 70.23 | 1.07 | 81.87 | 52.95 |
| 4 | 0.5 | 50.35 | 1.14 | 82.63 | 50.35 |
| 5 | 0.5 | 64.43 | 1.06 | 86.49 | 51.025 |
| 5 | 1 | 63.5 | 1.05 | 87.23 | 52.03 |
| 6 | 1 | 65.44 | 1.09 | 90.01 | 55.615 |
| 8 | 1 | 76.16 | 0.75 | 100.23 | 60.68 |
| 10 | 1 | 86.41 | 0.64 | 124.81 | 72.063 |
| 10 | 2 | 87.6 | 0.62 | 123.81 | 73.65 |
| 12 | 2 | 96.49 | 0.24 | 133.63 | 76.188 |
| 15 | 2 | 112.76 | 0.73 | 162.55 | 91.49 |
| 20 | 2 | 135.84 | 0.39 | 201.43 | 113.04 |
| 20 | 4 | 136.9 | 0.49 | 202.6 | 116.3 |
| 25 | 4 | 149.39 | 0.84 | 230.19 | 133.93 |
| 30 | 4 | 164.11 | 0.39 | 244.26 | 150.48 |
| 40 | 4 | 184.02 | 0.25 | 257.39 | 174.96 |
| 50 | 4 | 191.48 | 4.96 | 276.89 | 185.26 |
| 50 | 10 | 190.6 | 3.65 | 277.6 | 183.65 |
| 60 | 10 | 211.55 | 2.99 | 218.7 | 187.53 |
| 80 | 10 | 195.84 | 2.55 | 262.11 | 180.86 |
| 100 | 10 | 175.79 | | 233.16 | 163.28 |
| 100 | 20 | 179.6 | | 234.56 | 160.2 |
| 120 | 20 | 170.56 | | 209.9 | 154.37 |
| 160 | 20 | 135.30 | | 153.54 | 124.59 |
| 200 | 20 | 122.70 | | 121.32 | 72.59 |
| 200 | 40 | | | 122.5 | 71.36 |
| 250 | 40 | | | 105.17 | 90 |
| 300 | 40 | | | 76.33 | 92.05 |
| 350 | 40 | | | | 100.12 |
| 400 | 40 | | | | 110.15 |
| | | | | | 126.69 |

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| Site: | | Belda | | Ismailpur | Deoband |
|---|---|---|---|---|---|
| Sounding Number | | VES-24 | | VES-31 | VES-41 |
| AB/2 | MN/2 | Apparent Resistivity | Chargeability | Apparent Resistivity | Apparent Resistivity |
| | | ( Ohm-m) | (m-Sec) | ( Ohm-m) | ( Ohm-m) |
| 2 | 0.5 | 174.66 | 1.6 | 314.75 | 50.2 |
| 3 | 0.5 | 178.82 | 2.23 | 352.11 | 38.59 |
| 4 | 0.5 | 183.95 | 2.47 | 359.71 | 40.29 |
| 5 | 0.5 | 192.72 | 2.84 | 348.54 | 37.59 |
| 5 | 1 | 190.3 | 2.6 | 352.3 | 36.58 |
| 6 | 1 | 204.41 | 2.6 | 350.42 | 35.26 |
| 8 | 1 | 224.52 | 2.1 | 298.62 | 36.25 |
| 10 | 1 | 229.09 | 2.28 | 212.1 | 36.19 |
| 10 | 2 | 230.6 | 2.02 | 220.3 | 35.62 |
| 12 | 2 | 207.27 | 1.02 | 138.58 | 35.81 |
| 15 | 2 | 166.36 | 0.25 | 108.09 | 33.56 |
| 20 | 2 | 117.56 | 0.33 | 81.64 | 36.18 |
| 20 | 4 | 110.3 | 0.29 | 79.6 | 37.89 |
| 25 | 4 | 82.7 | 0.16 | 57.4 | 36.92 |
| 30 | 4 | 61.65 | | 45.07 | 37.21 |
| 40 | 4 | 59.04 | | 46.59 | 41.51 |
| 50 | 4 | 47 | | 51.02 | 45.29 |
| 50 | 10 | 46.9 | | 52.6 | 46.28 |
| 60 | 10 | 44.78 | | 52.56 | 46.21 |
| 80 | 10 | 33.62 | | 53.45 | 49.89 |
| 100 | 10 | 30.1 | | 54.95 | 54.23 |
| 100 | 20 | 31.6 | | 53.6 | 55.29 |
| 120 | 20 | 32.4 | | 47.68 | 58.32 |
| 160 | 20 | 32.15 | | 41.75 | 60.59 |
| 200 | 20 | 35.87 | | 44.14 | 62.83 |
| 200 | 40 | 34.9 | | 46.6 | 61.59 |
| 250 | 40 | 35.85 | | 43.125 | 65.82 |
| 300 | 40 | 33.82 | | 33.62 | 66.72 |
| 350 | 40 | 29.32 | | 26.44 | |
| 400 | 40 | | | 20.19 | |

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| Site:Ganeshpur | | Sounding Number | | | |
|---|---|---|---|---|---|
| | | VES-34 | | VES-32 | VES-33 |
| AB/2 | MN/2 | Apparent Resistivity | Chargeability | Apparent Resistivity | Apparent Resistivity |
| | | ( Ohm-m) | m.sec. | ( Ohm-m) | ( Ohm-m) |
| 2 | 0.5 | 606.06 | 0.46 | 554.36 | 693.312 |
| 3 | 0.5 | 763.72 | 0.59 | 700.4 | 944.44 |
| 4 | 0.5 | 897.1 | 0.67 | 822.84 | 1090.2 |
| 5 | 0.5 | 1039.3 | 0.74 | 928 | 1135.11 |
| 5 | 1 | 1010.2 | 0.77 | 1005.6 | 1165.3 |
| 6 | 1 | 1113.1 | 0.79 | 1035.25 | 1141.7 |
| 8 | 1 | 1170.2 | 0.82 | 1179.99 | 1238.73 |
| 10 | 1 | 1225.8 | 0.26 | 1212.54 | 1284.26 |
| 10 | 2 | 1208 | 0.86 | 1122.3 | 1269.2 |
| 12 | 2 | 1233.7 | 1.13 | 1261.65 | 1211.78 |
| 15 | 2 | 1341.9 | 1.069 | 1387.54 | 1218.71 |
| 20 | 2 | 1346.4 | 0.61 | 1168.08 | 1061.94 |
| 20 | 4 | 1274 | 1.26 | 1156.3 | 1056.3 |
| 25 | 4 | 1220.8 | 1.27 | 1054.12 | 882.13 |
| 30 | 4 | 969.9 | 2.06 | 933.34 | 774.32 |
| 40 | 4 | 667.51 | 5.11 | 668.97 | 585.29 |
| 50 | 4 | 409.88 | 2.87 | 488.45 | 519.67 |
| 50 | 10 | 508.03 | 17.6 | 492.6 | 513.6 |
| 60 | 10 | 188.2 | 154 | 319.2 | 425.03 |
| 80 | 10 | 129.91 | 159 | 188.62 | 269.68 |
| 100 | 10 | 164.6 | 17.2 | 168.05 | 221.05 |
| 100 | 20 | 162.63 | 14.7 | 172.69 | 219.6 |
| 120 | 20 | 162.42 | 0.092 | 149.46 | 110.29 |
| 160 | 20 | 134.25 | 7.05 | 108.51 | 98.51 |
| 200 | 20 | 115.2 | 36.6 | 112.3 | 95.6 |
| 200 | 40 | 135.42 | 12.4 | 116.56 | 112.13 |
| 250 | 40 | 236.41 | 8.4 | 141.02 | 133.35 |

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| Site: | | Jwalapur | | Roorkee | |
|---|---|---|---|---|---|
| Sounding Number | | VES-35 | VES-36 | VES-39 | VES-39 |
| AB/2 | MN/2 | Apparent Resistivity ( Ohm-m) | Apparent Resistivity ( Ohm-m) | Apparent Resistivity ( Ohm-m) | Apparent Resistivity ( Ohm-m) |
| 2 | 0.5 | 40.85 | 56.62 | 163.79 | 184.63 |
| 3 | 0.5 | 38.56 | 58.54 | 133.5 | 144.69 |
| 4 | 0.5 | 39.39 | 33.64 | 126.1 | 118.57 |
| 5 | 0.5 | 39.7 | 40.33 | 121.1 | 92 |
| 5 | 1 | 34.4 | 41.3 | 120.3 | 93.56 |
| 6 | 1 | 41.15 | 44.12 | 109.9 | 76.18 |
| 8 | 1 | 43.61 | 54.3 | 90.99 | 59.89 |
| 10 | 1 | 46.62 | 57.17 | 79.94 | 52.02 |
| 10 | 2 | 52.51 | 59.2 | 78.69 | 51.29 |
| 12 | 2 | 58.46 | 60.99 | 66.6 | 53.53 |
| 15 | 2 | 52.73 | 66.44 | 55.68 | 58.37 |
| 20 | 2 | 60.15 | 67.147 | 41.126 | 67.39 |
| 20 | 4 | 58.19 | 64.6 | 40.25 | 66.98 |
| 25 | 4 | 63.58 | 78.42 | 37.86 | 77.8 |
| 30 | 4 | 65.68 | 69.18 | 36.88 | 81.24 |
| 40 | 4 | 74.48 | 54.125 | 38.42 | 93.79 |
| 50 | 4 | 85.99 | 52.133 | 37.34 | 99.4 |
| 50 | 10 | 72.53 | 56.3 | 36.89 | 97.58 |
| 60 | 10 | 98.19 | 55.11 | 33.08 | 108.39 |
| 80 | 10 | 120.67 | 59.455 | 33.83 | 116.46 |
| 100 | 10 | 138.33 | 70.3 | 33.88 | 121.61 |
| 100 | 20 | 142.3 | 61.2 | | 119.58 |
| 120 | 20 | 150.12 | 44.28 | | 125.14 |
| 160 | 20 | 155.68 | 51.43 | | 132.49 |
| 200 | 20 | 159.47 | 51.54 | | 138.35 |
| 200 | 40 | 162.3 | 86.6 | | 144.47 |
| 250 | 40 | 168.51 | 66.21 | | |
| 300 | 40 | 159.6 | 84.31 | | |
| 350 | 40 | 149.95 | 155.35 | | |
| 400 | 40 | 138.02 | 124.34 | | |

Continued

| Site: | | Pilkhani | Bahadarabad | Ambehta |
|---|---|---|---|---|
| Sounding Number | | VES-42 | VES-40 | VES-43 |
| **AB/2** | **MN/2** | **Apparent Resistivity** | **Apparent Resistivity** | **Apparent Resistivity** |
| | | **( Ohm-m)** | **( Ohm-m)** | **( Ohm-m)** |
| 2 | 0.5 | 26.49 | 50.85 | 133.76 |
| 3 | 0.5 | 29.75 | 35.56 | 153 |
| 4 | 0.5 | 32.09 | 32.39 | 154.77 |
| 5 | 0.5 | 32.87 | 33.7 | 144.54 |
| 5 | 1 | 33.6 | 34.4 | 143.6 |
| 6 | 1 | 33.07 | 41.15 | 156.05 |
| 8 | 1 | 34.32 | 43.61 | 184.76 |
| 10 | 1 | 35.12 | 46.62 | 225.32 |
| 10 | 2 | 36.3 | 52.51 | 221.9 |
| 12 | 2 | 37.69 | 58.46 | 241.78 |
| 15 | 2 | 41.8 | 52.73 | 290.75 |
| 20 | 2 | 41.99 | 60.15 | 348.16 |
| 20 | 4 | 42.3 | 58.19 | 350.8 |
| 25 | 4 | 42.05 | 63.58 | 370.97 |
| 30 | 4 | 43.57 | 65.68 | 363.97 |
| 40 | 4 | 45.69 | 74.48 | 333.86 |
| 50 | 4 | 46.79 | 80.99 | 265.55 |
| 50 | 10 | 47.6 | 72.53 | 267.9 |
| 60 | 10 | 43.02 | 98.19 | 199.32 |
| 80 | 10 | 39.95 | 110.67 | 121.46 |
| 100 | 10 | 36.52 | 138.33 | 95.17 |
| 100 | 20 | 37.8 | 132.3 | 94.3 |
| 120 | 20 | 44.83 | 140.12 | 72.006 |
| 160 | 20 | 47.27 | 145.68 | 63.52 |
| 200 | 20 | 48.02 | 159.47 | 63.41 |
| 200 | 40 | 49.6 | 162.3 | 62.9 |
| 250 | 40 | 36.47 | 168.51 | 58.8 |
| 300 | 40 | 35.77 | 159.6 | 52.73 |
| 350 | 40 | 31.69 | 149.95 | 68.66 |
| 400 | 40 | 30.25 | 148.02 | 72.3 |

Continued

| Site: | | Badheri | | | Yamuna Bridge |
|---|---|---|---|---|---|
| Sounding Number | | VES-45 | | VES-46 | VES-44 |
| AB/2 | MN/2 | Apparent Resistivity ( Ohm-m) | Chargeability (m-Sec) | Apparent Resistivity ( Ohm-m) | Apparent Resistivity ( Ohm-m) |
| 2 | 0.5 | 466.29 | 1.6 | 189.1 | 63.23 |
| 3 | 0.5 | 329.146 | 2.23 | 166.46 | 59.33 |
| 4 | 0.5 | 258.12 | 2.47 | 157.25 | 57.55 |
| 5 | 0.5 | 218.36 | 2.84 | 155.26 | 57.61 |
| 5 | 1 | 182.43 | 2.6 | 154.4 | 58.3 |
| 6 | 1 | 116.02 | 2.6 | 143.41 | 58.35 |
| 8 | 1 | 92.31 | 2.1 | 114.56 | 61.22 |
| 10 | 1 | 69.56 | 2.28 | 94.73 | 64.05 |
| 10 | 2 | 58.46 | 2.02 | 72.51 | 69.6 |
| 12 | 2 | 55.73 | 1.02 | 56.97 | 64.62 |
| 15 | 2 | 51.39 | 0.25 | 51.39 | 68.87 |
| 20 | 2 | 53.8 | 0.33 | 52.63 | 69.18 |
| 20 | 4 | 58.62 | 0.29 | 58.19 | 67.8 |
| 25 | 4 | 65.61 | 0.16 | 65.42 | 69.79 |
| 30 | 4 | 57.53 | 1.6 | 57.14 | 69.39 |
| 40 | 4 | 57.71 | | 68.05 | 70.06 |
| 50 | 4 | 58.93 | | 70.56 | 70.88 |
| 50 | 10 | 57.47 | | 72.53 | 69.3 |
| 60 | 10 | 53.21 | | 80.11 | 69.67 |
| 80 | 10 | 75.36 | | 88.28 | 71.9 |
| 100 | 10 | 92.5 | | 58.08 | 73.05 |
| 100 | 20 | 109.29 | | 53.53 | 70.2 |
| 120 | 20 | 129.54 | | 48.62 | 73.85 |
| 160 | 20 | 140.3 | | 43.33 | 76.95 |
| 200 | 20 | 466.29 | | 189.1 | 78.34 |
| 200 | 40 | 329.146 | | 166.46 | 77.6 |
| 250 | 40 | 258.12 | | 157.25 | 69.37 |
| 300 | 40 | | | | 60.54 |
| 350 | 40 | | | | 57.41 |
| 400 | 40 | | | | 57.88 |

Continued

## Horizontal Profiling Data

| Distance From Bahadarabad | Apparent Resistivity |
|---|---|
| **Starting point( 29°55'13" ; 78°03'09")** | ( ohm-m) |
| 0 | 34087.84 |
| 40 | 20623.52 |
| 80 | 30370.08 |
| 160 | 7435.52 |
| 200 | 10022.88 |
| 240 | 8339.84 |
| 280 | 14117.44 |
| 320 | 10751.36 |
| 360 | 5878.08 |
| 400 | 16202.4 |
| 440 | 13622.576 |
| 480 | 14147.584 |
| 520 | 14479.168 |
| 560 | 14898.672 |
| 600 | 10701.12 |
| 640 | 12605.216 |
| 680 | 12341.456 |
| 720 | 11612.976 |
| 760 | 11369.312 |
| 800 | 10854.352 |
| 840 | 11025.168 |
| 880 | 10595.616 |
| 920 | 10251.472 |
| 960 | 10517.744 |
| 1000 | 9960.08 |
| 1040 | 9409.952 |
| 1080 | 8608.624 |
| 1120 | 9234.112 |
| 1160 | 9354.688 |
| 1200 | 8907.552 |
| 1240 | 8603.6 |
| 1280 | 9937.472 |
| 1320 | 8450.368 |
| 1360 | 8696.544 |
| 1400 | 7852.512 |
| 1440 | 7598.8 |
| 1480 | 6619.12 |
| 1520 | 6578.928 |
| 1560 | 9095.952 |
| 1600 | 6237.296 |
| 1640 | 5443.504 |
| 1680 | 4888.352 |
| 1720 | 4639.664 |
| 1760 | 4355.808 |
| 1800 | 4765.264 |
| 1840 | 4378.416 |
| 1880 | 4162.384 |
| 1920 | 3574.576 |

| Distance From Bahadarabad | Apparent Resistivity |
|---|---|
| 1960 | 3928.768 |
| 2000 | 3577.088 |
| 2040 | 2954.112 |
| 2080 | 3177.68 |
| 2120 | 2823.488 |
| 2160 | 2599.92 |
| 2200 | 2414.032 |
| 2240 | 2514.512 |
| 2280 | 2042.256 |
| 2320 | 2049.792 |
| 2360 | 1904.096 |
| 2400 | 1652.896 |
| 2440 | 1163.056 |
| 2480 | 350.424 |
| 2520 | 89.4272 |
| 2560 | 1150.496 |
| 2600 | 1145.472 |
| 2640 | 329.8256 |
| 2680 | 269.0352 |
| 2720 | 53.0032 |
| 2760 | 934.464 |
| 2800 | 434.0736 |
| 2840 | 205.7328 |
| 2880 | 25.6224 |
| 2920 | 2.0096 |
| 2960 | 6.0288 |
| 3000 | 13.71552 |
| 3040 | 76.616 |
| 3080 | 75.8624 |
| 3120 | 6.28 |
| 3160 | 11.304 |
| 3200 | 22.63312 |
| 3240 | 47.25072 |
| 3280 | 18.11152 |
| 3320 | 34.9168 |
| 3360 | 118.3152 |
| 3400 | 16.328 |
| 3440 | 22.68336 |
| 3480 | 16.00144 |
| 3520 | 54.5104 |
| 3560 | 5.7776 |
| 3600 | 8.4152 |
| 3640 | 19.468 |
| 3680 | 17.40816 |
| 3720 | 15.1976 |
| 3760 | 5.75248 |
| 3800 | 8.94272 |
| 3840 | 102.2384 |
| 3880 | 24.6176 |
| 3920 | 24.76832 |
| 3960 | 54.008 |
| 4000 | 33.1584 |