Hydrogeological Studies of The Karak Village N.W.F.P

Determination of aquifer properties by using resistivity-seismic conversion

By
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DEDICATION

TO

My Mother, Father, Brothers and Sisters

And

My Best Friend

Asam Farid

CERTIFICATE

This dissertation submitted by **KASHIF ALI S/O MUHAMMAD ALI** is accepted in its present form by the Department of Earth Sciences, Quaid-I-Azam University Islamabad as satisfying the requirement for the award of **M.Phil** degree in **Geophysics**.

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Abstract

Karak is a district of N. W. F. P province. It consists of an east-west elongated alluvial plain surrounded by mountains. To the north and east lies Kohat Salt Range (Samana Range), south by the Shingar mountains while towards west it is open. Width ranges from 2Km to 5Km and length about 32Km. The valley is arid with temperate climate. There are no canals in the area that meet the irrigation requirements. There is no big river flowing through the area. Whole of the area depends upon rain or ground water for domestic uses or for irrigation to a very small extent. The alluvium is eroded from the surrounding mountains and deposited by the small streams flowing in the area. The alluvium is not very much sorted and consists mainly of gravel loams and clays. The hydraulic conductivities obtained by pumping tests are very low. Which suggest that the extent of ground water is very limited. The maximum thickness of the water conductive strata is not more than 50m. There is a need of finding the hydraulic conductive zones. Drilling too much boreholes is very expensive, therefore there is a need of some other technique for the estimation of hydraulic conductivities. One technique is by using the formation factors obtained by Vertical Electrical Soundings (VES). But this method does not account for clay contents. The approach used here accounts for the conversion of resistivity curves into seismic slowness curves. Then to establish a relationship between seismic slowness and hydraulic conductivity, so that hydraulic conductivity should be mapped throughout the area, to locate places for high hydraulic conductivities. The hydraulic conductivities obtained by pumping test, from resistivity logs, from surface resistivity curves and from the seismic slowness relationship are in good match.

ACKNOWLEDGEMENT

In the name of Allah, the most beneficent, the most merciful. All praises for almighty Allah, the creature of universe. I bear witness that Holly Prophet Muhammad (PBUH) is the last messenger, whose life is a perfect model for the whole mankind till the Day of Judgment. Allah blessed me with knowledge related to the earth. I am enabled by Allah to complete my work. Without the blessings of Allah, I could not be able to complete my work as well as to be at such a place.

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KASHIF ALI

Chapter # 1

INTRODUCTION

Resistivity Data
Bore hole Data
Well logs

Objectives

Objectives of the present study are as follows.

- Conversion of resistivity logs to sonic logs
- Conversion of surface resistivity curves to seismic curves.
- Determination of petrophysical parameters of the aquifer system.
- Determination of hydrological parameters of the aquifer system.
- Determination of Iso-Resistivity Section.
- Finding fresh water zones and marking well locations.
- Determination of void ratio.
- Determination of seismic drift.
- Determination of hydraulic conductivity with different methods and comparison of these methods.
- Finding best method for the study area.

CHAPTER#1: INTRODUCTION

1.1 Our Earth

Our earth came into being 4.6 billion years ago. Since then there are a number of processes being operated on and below the surface of the earth. The processes have considerably changed the faces of the earth. All those process that have originated and being operated inside the surface of the earth are called " Processes Of Internal Origin of endo-genetic processes " and all those processes that have originated outside the surface of the earth are called " Processes Of external Origin or exogenetic processes ". Water have played the key role in these processes. Evaporation from the sea surface to atmosphere, traveling to the land surface, condensation to cloud formation and precipitation to stream flows and ground water recharge, baseflow to springs and stram recharge to rivers and to sea again. A lot of other processes are associated with the ground water flow such as carving making Karst Topography (Kazmi & Jan,1997)

1.2 Location of the area

Karak Valley is located on the north-eastern side of Domail Plain and is situated between the latitudes of 33°0 41 and 33°12' North and the longitudes of 71 00 and 72° 22 East (Figure 1).Administratively the area belongs to Karak District. Karak, the main village in the area, is the seat of the District Head Quarters. It is connected to Damkili (Sabir Abad) in the east ,and Bannu in the west by an all-weather metalled road. Total drainage area is 274 Km^2 out of which 149 Km^2 is covered by alluvium.

Boundaries of the Karak district

North: Kohat District
South: Lakki Marwat District
South East: Mianwali District
West: Bannu and Waziristan Agency

1.3 Physical features

The topography of the Karak consists of a succession of ranges of broken hills whose general trend is from east to west. The general elevation of the district is from 600 meters to 1400 meters above sea level. The Khattak range starts from the boundary of Karak with south Waziristan and runs in an east-west direction upto the river Indus. Its average height is 1000 meters above sea level. The general drainage of the district, north

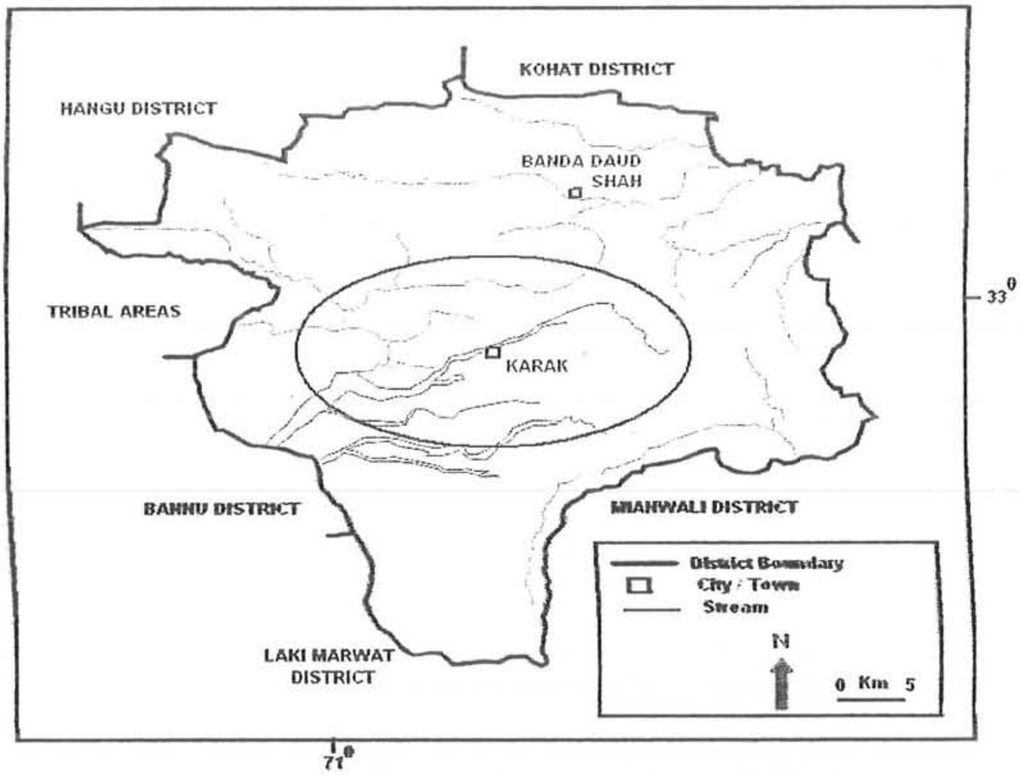

Figure: 1.1 shows the location of the Karak District.

of the Khattak hills is from west to east while that of the south of the Khattak hills is from north east to south west. In general the height of these hills decrease from west to east. Two important hill ranges are located in the south-east. One, lying in the south eastern part of the district, along the boundary of Karak and Mianwali, is known as Surgarh while the other, close to it, further north west is known as the Shingarh. The average height of these hills are about 1000 meters above sea level. The height point in the range is 1482 meters above sea level.

The largest valley in the district is Karak. It lies between the Karak range and the Shingarh range. It is drained by the Tarkha Alghad stream in the upper part and the Kashu Alghad in the lower part. The drainage is from north east to south east. The Kashu Alghad flows through the adjacent Bannu district and joins the Kurram river. There are other small valleys: such as those of Banda Daud Shah whose drainage is from west to east towards the Indus river. The most important stream draining this area is the Teri Toi. Its main tributary is a non perennial stram namely Lilan Alghad.

1.4 Soil

The major constituent soil of Karak district is medium textured (silty loam), developed in subrecent piedmont material derived from the Siwaliks from the surrounding mountains. The soils occur in a semi arid, sub tropical and continental climate.

The soils are used for dry formed and torrent watered cultivation. Main crops are wheat, gram and millets.

Another constituent soil of Karak district is well drained, very deep, calcareous, fine textured soils developed in Pleistocene period in piedmont of tertiary shales of Kohat range. The soils occupy level to nearly level and undulating piedmont plains.

1.5 Topography of the area

Karak Valley consists of an east-west elongated alluvial plain surrounded by mountains. The valley plain is bounded by mountains of the Kohat Salt Range (Samana Range) in the north and east and by the Shingar Mountains (Surgarh Range) in the south. The valley opens towards the west where its plain is connected to the Domail Plain. The plain has a length of about 32 km and its width ranges from 2 to 5 km.

The drainage basin sizes 274 km2, out of which 149 km2 is. covered with alluvium. With respect to its drainage pattern the area can be divided,into two parts with a water divide running north-south from Khwaja Khel to Mangar Khel. The larger western part is drained by the Targha Algad towards the west, the smaller eastern part by the Zebi and Damo Algads in.northern direction.

The alti tude of the alluvial plain dips gradually from abou.t 850 metres above mean sea level (MSL) in the east to about 450 metres above MSL in the west. The plain is intersected by numerous gullies and nullahs which originate in the mountainous parts and generally contain water during rainy periods and shortly thereafter. The surface of the plain is undulating, locally with steeper slopes near the mountains. These surrounding mountains attain heights of upto 1250 metres above MSL.

1.6 Climate

The climate of Karak Valley is semi-arid with hot summers and mild winters. The annual temperature ranges are wide. The daily temperature rises to over 40^0C in summer-time and may drop to 0^0C during winter time. Figure 1.2 shows the minimum and maximum average annual temperatures for the study area. Figure 1.3 shows the average precipitation curve for the study area. The annual precipitation based on the records from 1966 to 1979 at Bannu averages about 330 mm, out of which about 35% is received during the rainy months of January to April and about 28% during the wet period of July to August. The winter rains are generally of long duration and low intensity, whereas the summer rains come in short showers with a high intensity due to their monsoon character. Figure 1.4 shows the average relative humidity.

1.7 Rivers and Streams

The Samana and Sheenghar mountain ranges descend into Thall plain in south and west, which then imperceptibly blends into the Wazir Thall plain of district Bannu. This rather monotonous landscape is intercepted by a large number of nullahs. These torrential streams meander their way into river Kurram in the West. Many of these have quasi-romantic names such as Lawaghar, Changhoos, Tarkha and Kashoo etc.One is named after a women. It is called Silkhona Algada (nullah)

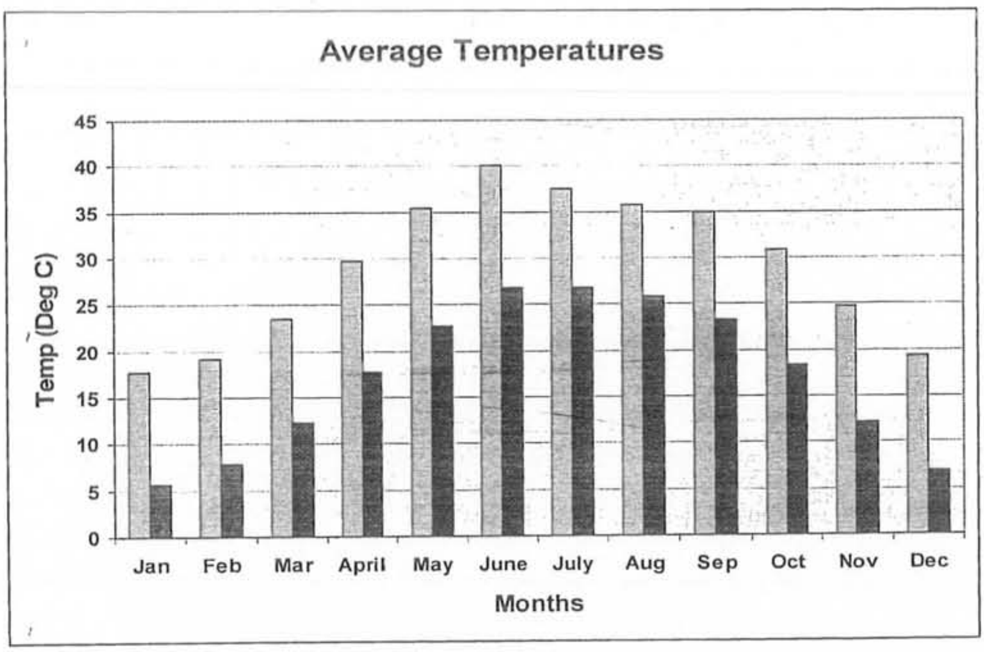

Figure: 1.2: Average temperatures for the study area

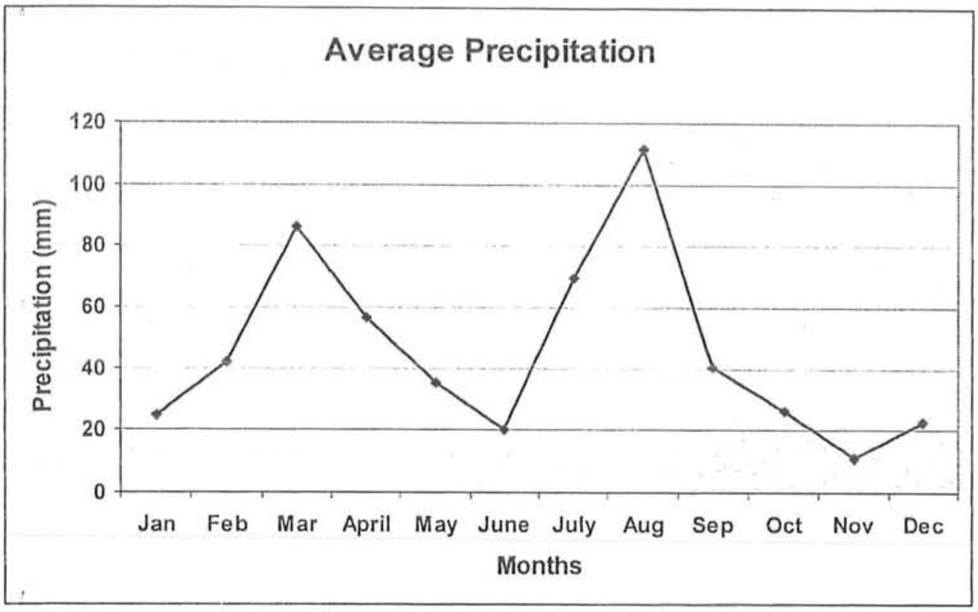

Figure: 1.3 Average precipitation curves for the study area

1.8 Population and sources of income

Exact figures of the population in the Valley of Karak are not available. However, _le population is estimated to be between 60,000 and 70,000 people (Census Report, 1998). The majority of the people lives in small villages scattered allover the 3.rea. Most of the lat"ger villages are situated in those parts of the valley where water is easily ava_.lable for" domestic as well as for irrigation purposes.

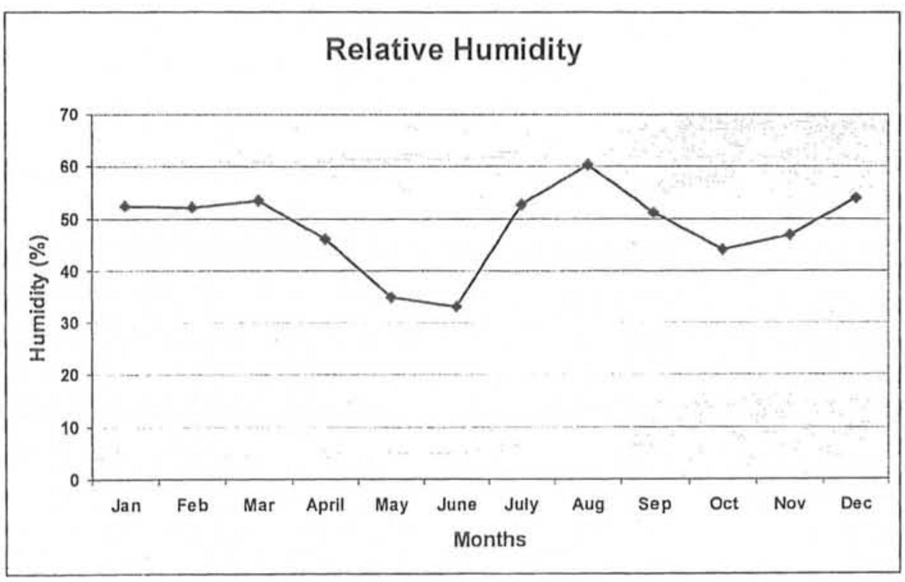

Figure: 1.4 Relative Humidity for the area.

Agriculture is the main source of income. The main crops are wheat, barley and maize and to a lesser extent potatoes and horticultural crops. In most parts of the area agriculture depends exclusively upon the rainfall. Due to relatively little rainfall, concentrated in two rainy seasons, in these "barard" areas at the most two crops per year can be grown. The yield of the crops is generally low, even from very fertile lands. In the centre-.l and eastern part of the valley irrigation with water from open wells and springs gives better crops.

Other scurces of income are small industrj es and various types of commerce and services.

1.9 Water Supply

Water supply in the narrow western part of the valley depends largely on open wells, installed in the fresh water zone. The water is used for domestic purposes as well as for irrigation of fields. For the latter purpose a large number of these wells have been provided with centrifugal pumps. For better drir_ing water supply in these areas Public Health Engineering Department (PHED) installed a tubewell at Karak.

In the south-eastern part of the valley, where the water table is deep, villages like Talab Khel, Mangar Khel and Badin Khel are connected to a pipeline system which collects its water from nullahs breaking through the southern mountain ridge. Other tubewells of PHED have been installed near Dam Kili (Sabir Abad) and Kimanai.

In addition a number of natural springs located in the mountains discharge small quantities of water, sufficient for domestic use or fer irrigation of small areas.

1.10 Irrigation

Karak is a semi arid region and the total cultivated area is Barani. There is no river or cannal passing through the district to serve irrigation purposes.

1.12 Previous Investigations:

In April 1981 a comprehensive program of groundwater survey was started in the Valley of Karak, Karak District, North \!lest Frontier Province (N.W.F.P.), Pakistan. The survey carried out for the Provincial Government of the N.W.F.P. was part of a bilateral agreement between Pakistan and The Netherlands. The study was conducted by the

Hydrogedlogy Directorate, WAPDA, Peshawar in consultation with a team of Groundwater Survey TNO, Delft, The Netherlands.

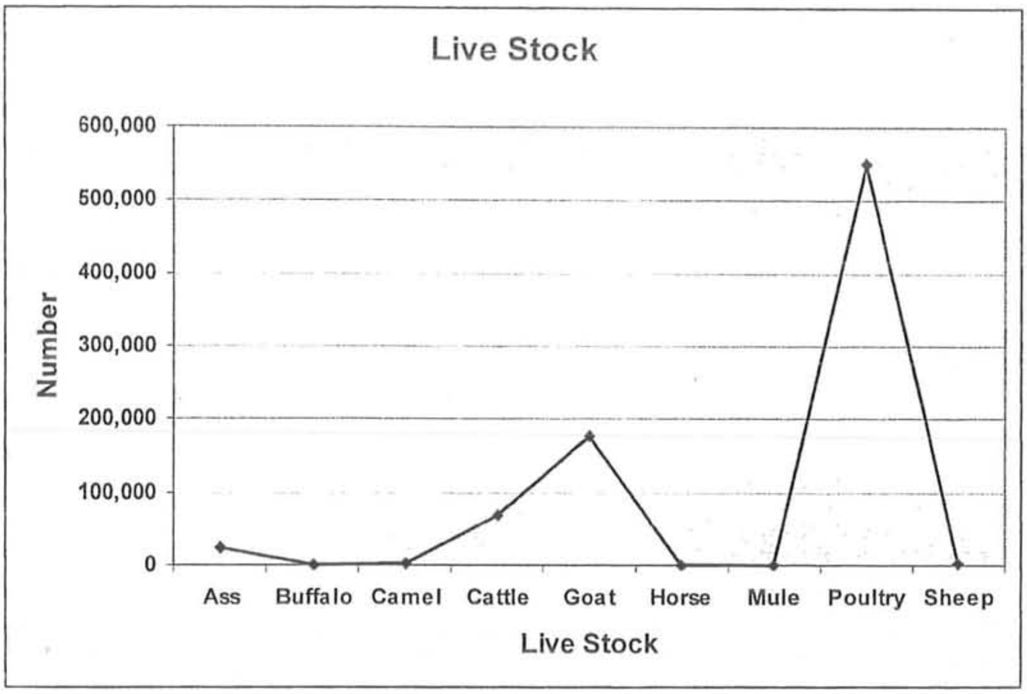

Figure: 1.5 Shows the number of live stock.

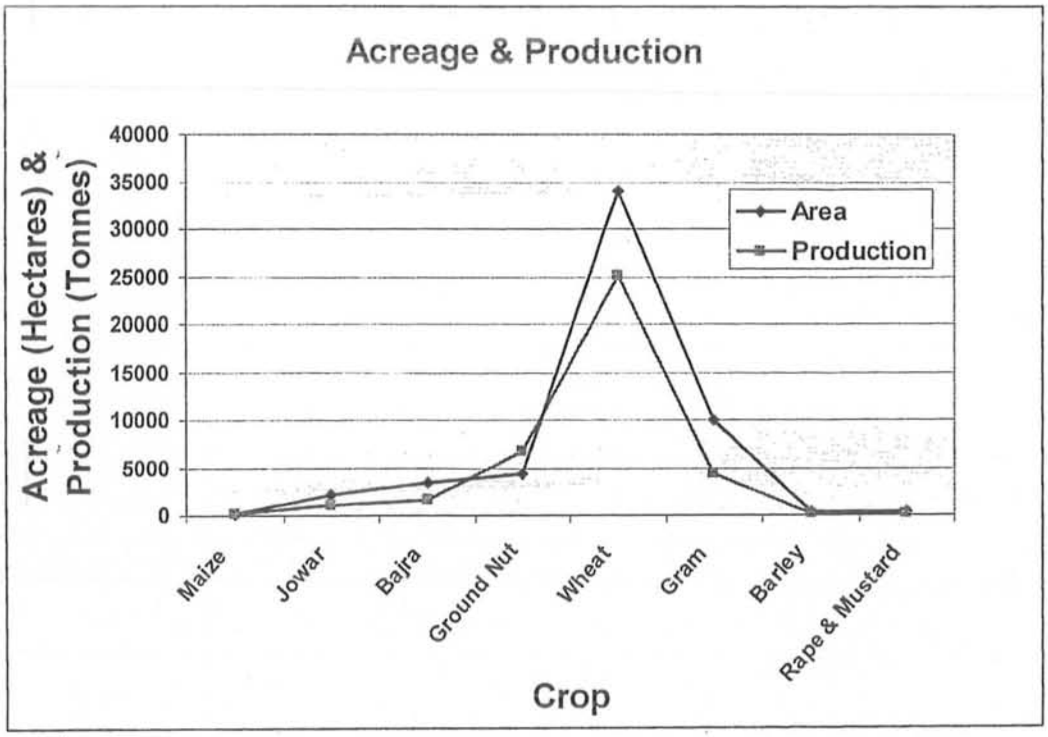

Figure: 1.6 Shows the amount of total area cultivated and production for crops.

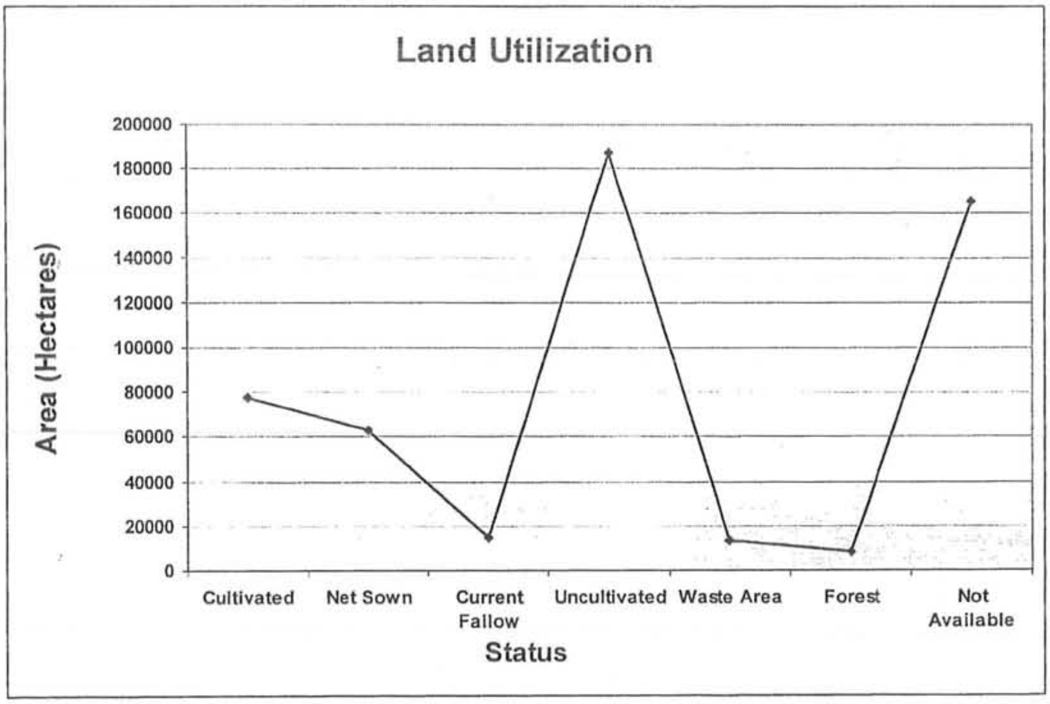

Figure: 1.7 Shows the amount of Land Utilization

The investigations were primarily directed at establishing the' groundwater potential and the best zones for groundwater exploitation. The present Technical Report contains all the important data, the 8valuation of these data and the results and conclusions arrived at. These results should be considered a first approximation and further development of the groundwater resources should be accompanied by a further collection and evaluation of data, so that the first estimates may be checked and if necessary corrected.

1.13 Review of Investigations:

In 1973 hydrogeological investigations were started in the Karak Valley by the Hydrogeology Section of the Groundwater Directorate, WAPDA, and Peshawar. During the period 1973-1974 two test holes with depths of 94.5 and 125.9 meters respectively were drilled. The information obtained proved to be inadequ6.te for an estimate of the groundwater potential.

Detailed investigations were, therefore, started under the present Pak-Dutch program. The field Work included <3 general well inventory, carrying out of 78 geoelectrical soundings, drilling of another three test holes, conversion of all of them into testwells and pumping tests in these wells, water level measuring and water sampling in selected open wells and measuring of surface run-off. The groundwater recharge has been calculated by means of a groundwater balance for the eastern alluvial basin. In the western part .of the alluvial fill the groundwater surplus was analyzed from the outflow to the Domai l area.

1.14 Present Study:

Present study focuses on estimating the petrophysical and hydrogeological parameters by converting electrical resistivity to sonic. The parameters that were calculated are porosity, effective porosity, hydraulic conductivity, volume of clay, transmissivity, lithology interpretation using seismic slowness curves and void ratio.

CHAPTER#2: TECTONIC FRAMEWORK OF PAKISTAN AND GENERAL GEOLOGY OF AREA

Pakistan is unique in as much it belongs to the two domains of landmasses, i.e Tethyan Domain and Gondawanian Domain and is sustained by the Indo-Pakistan crustal plate. The northern most and western regions of Pakistan fall in Tethyan Domain and present a complicated geology and complex crustal structure (Kadri,I.B,1995)

On the basis of plate tectonic features, geologic structure, orogenic history (age and nature of deformation, magmatism and metamorphism) and lithofacies, Pakistan may be divided into following broad tectonic zones (Kazmi & Jan, 1997).

- *Indus platform and foredeep.*
- *East Baluchistan fold-and-thrust belt.*
- *Northwest Himalayan fold-and-thrust belt.*
- *Kohistan-Ladakh magmatic arc.*
- *Karakoram Block.*
- *Kakar Khorasan flysch basin and Makran accretionary zone.*
- *Chagai magmatic arc.*
- *Pakistan offshore.*

2.1 North West Himalayan Fold and Thrust Belt:

The Northwest Himalayan fold-and-thrust belt occupies a 250 km wide and about 560 km long, irregularly shaped mountainous region stretching from Afghan border near Parachinar upto Kashmir Basin. The Hazara-Kashmir and Nanga Parbat syntaxes form its eastern margin. It covers all the terrain between the Main Mantle Thrust (MMT) in the north and the Salt Range Thrust in the south. This region is comprised of the mountain ranges of Nanga Parbat, Hazara, and southern Kohistan, Swat, Margalla, Kalachitta, Kohat, Sufaid Koh, Salt Range and its western extension.

Intermontane basins like *Peshawar Basin, Haripur Basin, Campbellpur Basin* and *Mansehra Basin* etc lies in this tectonic division (Longwell, C.R., 1955).

2.2 The Kohat Plateau:

West of Potwar, the Kohat plateau is comprised of Eocene and younger sediementary rocks that were deposited in a tectonically restricted basin. The Eocene sequence evaporates (Bahadar Khel Salt and Jatta Gypsum) which are restricted to the southern part of the plateau. On the surface these rocks form east-west trending, gentle to steeply dipping, doubly plunging, overturned folds over tens of kilometers long.

The structures in the north are significantly different from those in the southern part. The northern region is characterized by tight, commonly overturned folds, out-of syncline faults and several thrusts faults. The Eocene evaporite sequence is greatly reduced or missing in the north. Instead Panoba shales is exposed in the anticlinal cores.

In the southern part of the Kohat Plateau east-west trending folds and north-and south dipping reverse faults are common. Most of the faults tip out laterally into anticlines (fault propagation folds). The Bahadar Khel salt is exposed in anticlinal cores whereas Jatta Gypsum is commonly imbricated and folded with silvers of Panoba Shale. North of Shakardarra the structures have an east-west orientation. However, near Shakardarra, the structures abruptly change direction from east-west to north south.

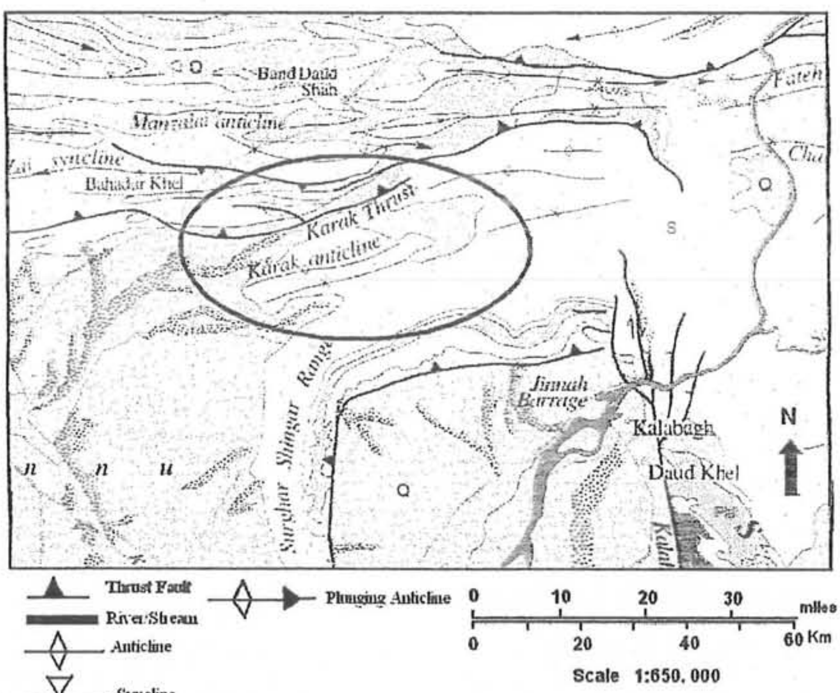

Figure: 2.1 Structural setup of the area

2.3 Stratigraphy of the area:

The stratigraphy of the area is as follows.

Panoba Shales:

In the Kohat area, the Eocene sequence conformably rests on the Paleocene Patal formation and includes the Panoba shales (With Bahadar Khel Salt). Type Locality of the Panoba shale is Panoba Village. Lithology is grey to olive, silty and calcareous shale with burrow markings. At places it is furrogenious, gypsiferrous and contains subordinate alum shale or thin flaggy limestone. Southwards it grades into Bahadur Khel Salt.

Jatta Gypsum & Shekhan Limestone:

It rests conformably on the Panoba Shale and consists of yellow to grey, thin bedded to massive, nodular limestone in the lower part and gypsiferrous shale in the upper part. In the vicinity of Mami Khel the upper part becomes gypsiferrous and farther south in the Jatta area the Formation grades into the Jatta Gypsum Formation.

Mami Khel Clays:

Consists of brownish red clay with conglomerate and sandstone beds. It is impermeable.

Kohat Formation:

This formation rests on the Kuldana Formation conformably. It consists mainly of cream coloured, massive, nodular limestone and olive shale. It includes a lower Kaladhand Limestone Member; middle Sadkal Shale Member and an upper Habib Rahi Limestone Member. The Kohat Formation is overlain unconformably by the Neogene sequence which has a thin conglomerate at the base.

Kamlial Formation:

Kamlial Formation overlies the Murree Formation conformably and transitionally; though at some localities it lies unconformably on the Eocene Sakesar Limestone. The Formation consists mainly of grey-brick red medium to coarse grained sandstone interbedded with purple shale and intrformational conglomerate.

Chinji Formation:

This Formation mainly consists of red clays with subordinate grey to brown, fine to medium grained, gritty, and soft, cross bedded Sandstone.

Nagri Formation:

The Formation lies conformably over the Chinji Formation. It mainly consists of thick bedded to massive, greenish grey, medium to coarse grained, salt and pepper textured, calcareous sandstone, interbedded with sub ordinate brown to reddish sandy clay and conglomerate.

2.4 Basement:

The alluvial fill in the valley is underlain by shales and sandstones of different ages. Since only a few deep test holes have been drilled in the area so far, investigations concerning the thickness of the alluvial fill largely depend on the results of the resistivity survey. Unfortunately contrasts between resistivity values of alluvial fill containing saline water and underlying shales are so little, that the depth-to-bedrock cannot be distinguished in the saline areas.

2.5 Surface Geology:

The Figure 2.2 shows the surface geology of the studied area. The yellow portion represents the sandstones of Siwaliks Group. This constitutes the southern portion and the north eastern portion. The northern portion and the north western portion constitutes the gypsum, salt and limestone outcrops. Due to the presence of salt in this area makes the water highly saline. The presence of saline water in the sub surface is also identified by the low values of resistivity. The pink portion represents the Holocene alluvium. The alluvium consists of clay, sand and gravel beds. These alluvial deposits are the potential aquifers in the area except the clay deposits. The alluvial fill of the valley consists of eroded material from surrounding mountains which was transported over short distances.

2.6 Hydrostratigraphy

2.6.1 Bedrock:

There is no significant difference between the electrical resistivities of bedrock of the Siwalik group and very clayey deposits of the alluvial cover, so that they cannot be distinguished from each other in interpreted electrical soundings. Since both types of formations may be considered rather impermeable, they can both be termed "Basement ". Bedrock of the Siwalik Group was encountered at a depth of about 41 meters in borehole WA-01 near Karak and at 49 meters in borehole WA-02 near Mittha Khel. The Samples collected at borehole WA-03 near Buland Kili show a change from coarse material to silty clay and sandstone (probably of the Siwalik Group) at a depth of about 54 meters. Surrounding resistivity soundings generally confirm these depths. From tail values of resistivity soundings it is inferred that all the bedrock underlying the alluvial fill in the fresh groundwater zones show low electrical resistivities, so that the presence of Limestones can be excluded.

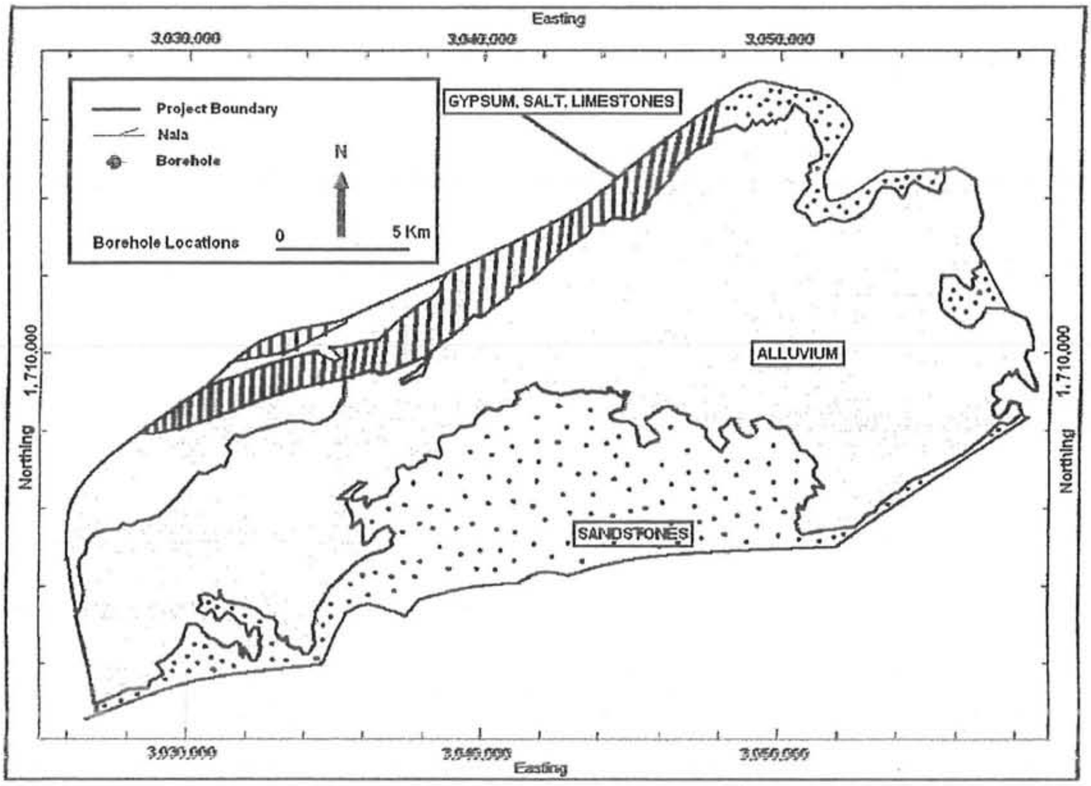

Figure: 2.2 Surface geology of the area

2.6.2 The Alluvial Cover

Saline water in the alluvial fill along it's northern boundary causes very low electrical resistivities throughout the deposits making accurate interpretation impossible. In the fresh groundwater zone in the western part of the valley, borehole WA-01 shows that coarse alluvial deposits overly the basement which is found at the depth of about 41 meters. The upper part of the saturated zone is composed of deposits of sand and gravel probably alternated with clay layers at other locations. From the soundings in the western part it is therefore concluded that the alluvial fill is no more thick than 50 m.

The alluvial cover is found to be cemented at the location of borehole WA-02. The formation resistivities are high in this zone and water quality is bad (1000<EC<2000 µS/cm).

In the area east of Mittha Khel the thickness of formations with high resistivities (between 70 and 150 ohm.m) increases reaching depths of upto 110 meters approximately in the centre of the eastern plain. From borehole WA-03 it is inferred these high resistivities correspond with gravel and boulder layers alternated with some clay lenses. It is not known upto what extent these high resistivities may be caused by conglomerates in other parts of the area.

2.6.3 Thickness of the Aquifers:

The thickness of the boreholes is correlated to find the thickness of the lithologies. From Figure 2.3 we can see that the thickness of the gravel pack is maximum towards the eastern side where PH-02 well lies and minimum towards the NW where WA-02 and PH-01 lies. The top of the gravel column is covered with clays with the western side and takes the form of confined aquifer whereas towards the eastern side the aquifer is unconfined and the gravel layer is exposed to surface.

The Figure 4 shows the thickness of the gravel in the area. This gravel is the main source of fresh water in the area. The thickness of the gravel is maximum towards the eastern side and minimum near the well WA-02 and WA-03.

Figure 5 shows the top of the gravel. We can see that the aquifer lies near the surface towards the eastern side. This area may be the recharge area for the fresh water for the aquifer.

2.7 Hydrogeology:

Fresh groundwater is encountered in the alluvial fill along the southern boundary. The groundwater body extends from the entrance of the valley to the eastern boundary.

2.7.1The area west of Mittha Khel:

The alluvial fill contains only fresh groundwater in the higher situated strip, along the southern mountains. Electrical resistivities in the fresh area vary over short distances from 30 ohm.m to 140 ohm.m indicating the heterogeneous aquifer.

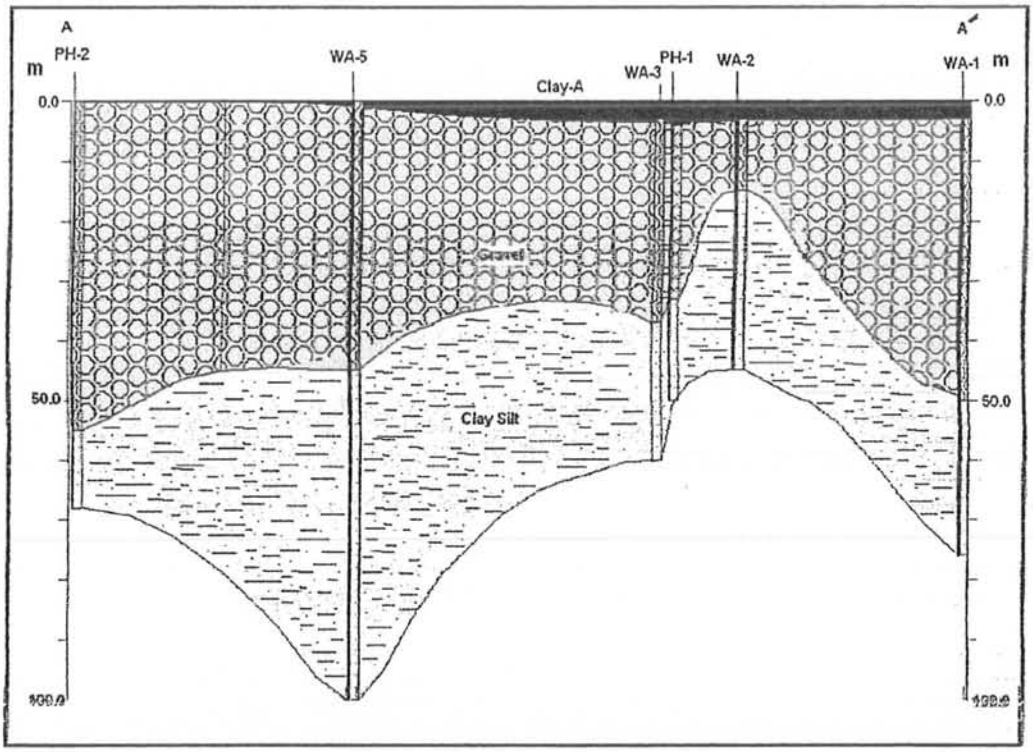

Figure: 2.3 Thickness of the water conductive and non conductive layers

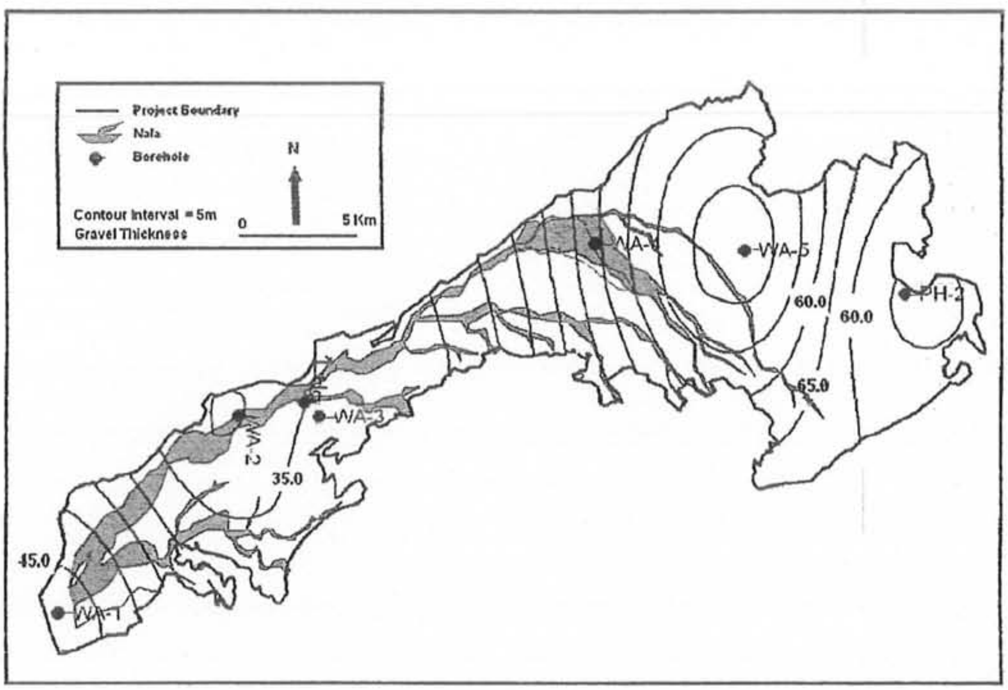

Figure: 2.4 Thickness of the water conductive gravel

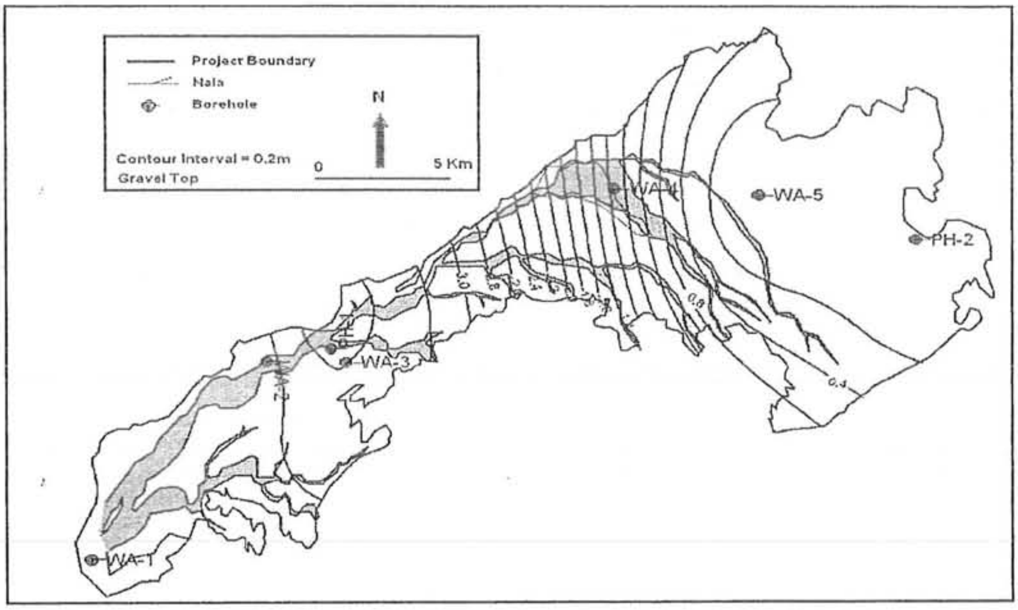

Figure: 2.5 Represents the top of the water conductive gravel

Low resistivity values near Mittha Khel and south west of Karak correspond with an abundance of clayey deposits, so that the aquifer virtually ends. Near the central part the formation resistivity indicated cementation of the deposits. The transmissivity of the aquifer of in the area is termed as moderate.

2.7.2 The area east of Mittha Khel:

The resistivity soundings in this area have relatively high formation resistivities. These high resistivities are attributed to represent gravel-boulder beds. It is not known up to what extent the high resistivities at other places are due to same gravel deposits or correspond to impermeable conglomerates as found at greater depths. The underlying basement in this area consists of Siwalik shales and sandstones which contain fresh water.

2.7.3 Run off:

The alluvial plain of the valley is part of two watersheds. A water divide runs from Khwaja Khel near the northern mountains southwards to Mangar Khel.

2.7.4 The western watershed:

West of this divide the larger eastern part of the area is drained into a south-western direction. The main drainage line is the Tarkha Algad, which leaves the valley about 7 km west of Karak to join the Kurram River. The Tarkha Algad is fed by saline nullahs from the northern and by fresh nullahs from the southern mountains. The mixture of water is highly saline with an electric conductivity exceeding 10,000 us/cm (micro Siemens per centimetre) in dry periods. Baseflow, measured at the outlet of the valley was less than 100 *m3/hr*. (1 cusec) in the month of January. It has been observed that the algad collects water in the central part of the valley east of Karak, part of which it loses again in its lower reaches.

2.7.5 The eastern watershed:

The eastern part of the area is drained by a number of streams towards the north, the most important of which are the Zebiand Damo Algads .These algads do not carry water in -the dry season but become perennial in the gorges where they leave the plain and where the alluvium virtually ends. Baseflow measured in January 1984 at these outlets amounted to about 50 m^3 /hr. (0.5 cusec) for the Damo Algad and 150 m^3 /hr. (1.5 cusec) for the Zebi Algad. These figures are rather rough since the streams are not very regular and the thickness of the sediments at the places of measurement might still be some metres. However, it is expected that they give a fair impression of the limited discharge in dry periods. Since the alluvial fill of the eastern pro't is enclosed by mountains on all sides, except for the water divide, the baseflow of these algads represents the actual surplus of groundwater, flowing from the area.

2.7.6 Groundwater quality:

The main aspect of the groundwater quality in the area is its salinity which was largely determined by the occurrence of salt rocks in the northern catchment area and by the drainage pattern. As already mentioned a north-south running water divide splits the area into two separate watersheds. The larger western part is drained by the Tarkha Algad in western direction, the smaller eastern part by the Damo Algad and the Zebi Algad in northern direction.

2.7.7 The western part of the alluvial plain:

Rock salt occurs along the northern boundary of the western part of the valley (see Geological Map, Figure 2), causing a high salt content in the water discharged from this area. From the southern side of the valley surface water and groundwater are both fresh. Water from both sides comes together in the alluvial area with the result that the main drainage line discharges a highly saline water while the interface between fresh and saline groundwater can be found winding through the middle of the elongated valley. Because of its higher specific gravity saline water tends to displace the fresh water in the alluvial fill. . It is not known to what extent saline water occurs in the basement of shales. However, some very low resistivities indicate the presence of saline water at great depths.

2.7.8 The eastern part of the alluvial plain:

In the eastern part of the area, east of the water divide groundwater is mainly fresh. A few soundings close to the water divide between Khwaja Khel and Ahmad Khel indicate that saline water may be present at greater depths, probably due to displacement of the fresh water from this zone. Further to the south resistivity values rule out the presence of saline water. This absence can be explained from the drainage pattern, assuming that saline water has been discharged towards the west in recent geological era. Open wells along the northern boundary show an electrical conductivity of more than 1000 us/cm which can be explained from a considerable evapotranspiration of groundwater in that zone.

CHAPTER#3: ELECTRICAL RESISTITIVTY SURVEY

3.1 Resistivities of rocks and minerals

Of all the physical properties of rocks and minerals, electrical resistivity shows the greatest variation. Whereas the range in density, elastic wave velocity and radioactive content is quite small, in magnetic susceptibility it may be as large as 10^5. However, the resistivity of metallic minerals may be as small as 10^{-5} Ωm, that of dry, close-grained rocks, like gabbro as large as 107 Ωm. The maximum possible range is even greater, from native silver (1.6×10^{-8} Ωm) to pure Sulphur (10^{16} Ωm).

A conductor is usually defined as a material of resistivity less than 10-5 Ωm, whereas an insulator is one having a resistivity greater than 107 Ωm. Between these limits lies the semiconductors. The metals and graphite are all conductors; they contain a large number of free electrons whose mobility is very great. The semiconductors also carry current by mobile electrons but have fewer of them. The insulators are characterized by ionic bonding so that the valence electrons are not free to move; the charge carriers are ions that must overcome larger barrier potentials than exist either in the semiconductors or conductors.

A further difference between conductors and semiconductors is found in their respective variation with temperature. The former vary inversely with temperature and have their highest conductivities in the region of 0K. The semiconductors, on the other hand, are practically insulators at low temperature.

In a looser classification, rocks and minerals are considered to be good, intermediate and poor conductors within the following ranges:

a) Minerals of resistivity 10^{-8} to about 1 Ωm.
b) Minerals and rocks of resistivity 1 to 10^7 Ωm.
c) Minerals and rocks of resistivity above 10^7 Ωm.

Group (a) includes the metals, graphite, the sulphides except for sphalerite, cinnabar and stibnite, all the arsenides and sulpho-arsenides except SbAs2, the antimonides except for some lead compounds, the tellurides, and some oxides such as magnetite, manganite, pyrolusite and ilmenite. Most oxides, ores and porous rocks containing water are intermediate conductors. The common rock forming minerals, silicates, phosphates and the carbonates, nitrates, sulfates, borates and so forth, are poor conductors.

3.2 Electrical Resistivity Method

All resistivity methods employ an artificial source of current, which is introduced into the ground through point electrodes or long line contacts; the later arrangement is rarely used nowadays. The procedure is to measure potentials at other electrodes in the vicinity of the current flow. Because current is measured as well, it is possible to determine an effective or apparent resistivity of the subsurface (Robinson,1988).

In this regard the resistivity technique is superior, at least theoretically, to all the other electrical methods, because quantitative results are obtained by using a controlled source of specific dimensions. Practically as in other geophysical methods, the maximum potentialities of resistivity are never realized. The chief drawback is its high sensitivity to minor variations in conductivity near surface; in electronic parlance the noise level is high. An analogous situation would exist in ground magnetic surveys is one where to employ a magnetometer with sensitivity in picotesla range.

The limitation, added to the practical difficulty involved in dragging several electrodes and long wires through rough wooded terrain, has made the electromagnetic method more popular than electrical resistivity in mineral exploration. Nor is resistivity particularly suitable for oil prospecting. However it is by no means obsolete, because the rapid development of induced polarization technique, which includes resistivity data, guarantees its continued use. Furthermore the search for geothermal reservoirs normally involves resistivity surveying and it is also employed routinely in groundwater exploration, which is of increasing worldwide importance, and in civil engineering (Robinson,1988).

3.3 Effects of inhomogeneous ground

What we want to detect is the presence of anomalous conductivity in various forms, such as lumped bodies (Three Dimensional), dikes, faults, and vertical or horizontal contacts between beds. The resistivity method is most suitable for outlining horizontal beds and vertical contacts, less useful on bodies of irregular shape.

3.4 Distortion of current flow at a plane interface

Consider two homogeneous media of Resistivities ρ1 and ρ2 separated by a plane boundary as shown in figure. Suppose a current of density J1 is flowing in medium (1) in such a direction as to meet the boundary at an angle θ1 to the normal. To determine the direction of of this current in medium (2) we recall the conditions, using Ohm's law to express the results in terms of the current density, we obtain

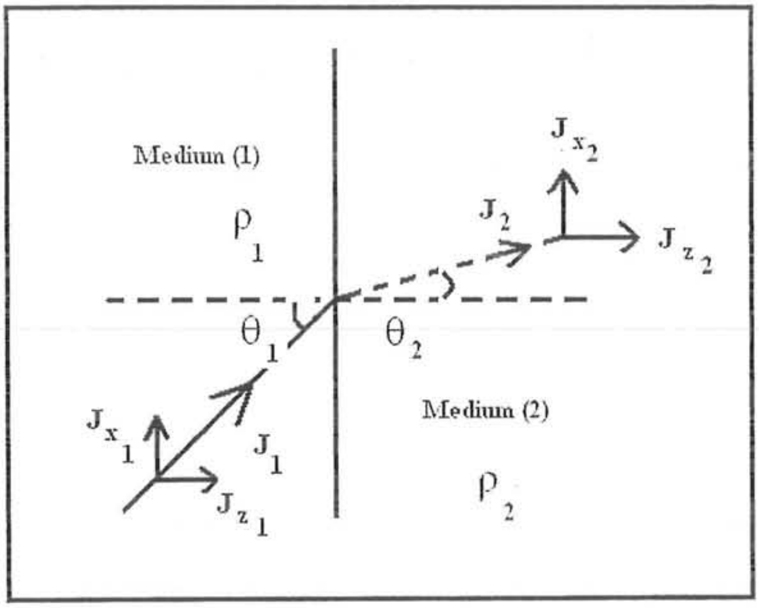

Figure: 3.1 Distortion of current at an interface.

$Jx1\rho1 = Jx2\ \rho2$ and $Jx1 = Jx2$

Dividing these expressions, we have

$\rho1\ (Jx1/\ Jz1) = \rho2\ (Jx2\ /\ Jz2)$ or $\rho1\ \tan\theta1 = \rho2\ \tan\theta2$

so that

$\tan\theta2\ /\ \tan\theta1 = \rho1\ /\ \rho2$

Thus the current lines are bent in crossing the boundary. If $\rho1 < \rho2$, they will be bent toward the normal and vice versa.

3.5 FIELDWORK AND DATA COLLECTION

3.5.1 Resistivity Soundings

Electrical resistivity measurements in Karak Valley started in May 1981 and were completed in June 1982. Soundings were run at 78 suitable locations on the alluvial plain. The measurements were carried out in Schlumberger configuration with a half current electrode distance. They are numbered consecutively per 1:50,000 topographic map sheet and their locations have been marked in Figure 3.2.

3.5.2 Method of Interpretation

The interpretation of resistivity soundings makes use of a method of curve matching in which the field curve is compared with a set of standard curves or with the curve plotted with a computer programme The standard curve as well as the computer curves correspond with a system of horizontal layers an their specific electrical resist- . ivities, which can be correlated with the hydrogeological set-up of the subsoil or with a fresh-saline interface of the groundwater. The final interpretation makes use of the local hydrogeological information such as geological maps, lithological and geophysical data of boreholes, the depth to the groundwater table and the. electrical conductivity of the groundwater. In order to calibrate the interpretation model resistivity logs of test holes are necessary for which reason sometimes extra test holes are drilled.

The parameters utilized are the formation resistivity Rf' the formation factor F and the resistivity of the formation water *Rw.* The relation between them is expressed in the following formula:

$$Rf = F \times Rw$$

The formation factor F depends on characteristics of the formation, such as porosity, *clay* content and degree of cementation. An increasing grain size is usually accompanied by an increasing formation factor and a higher permeability. Clean sand and gravel formations, for instance, show formation factors ranging from about 3 to 8. Increasing clay or fine salt contents cause lower formatior factors and lower permeabilities. The relation between formation factor and permeability is adversely affected by cementation or poor sorting of sediments causing a higher formation factor but a strongly decreasing permeability.

The resistivity of the formation water Pw' being the reciprocal value of the electrical conductivity (EC), is determined from water samples taken from boreholes or wells applying the following formula.

$$Rw = 10000/EC$$

In this formula Rw is expressed in ohm.m and the electrical conductivity in uSjcm (micro Siemens per centimetre).

3.5.3 Formation Resistivities Encountered in the Area

Due to a considerable variation in water quality (and its electrical conductivity) in the area the signification of formation resistivities is not unique. In fact a certain formation resistivity may be the result of different combinations of water resistivities and formation factors, so that the w8.ter resistivity must be known to find the formation factor and conversely. Table *A-1* shows certain combination for types of water encountered in the area.

Table A-1 –Formation resistivities for different combinations of formation factors and electrical conductivities

Formation factor	EC<1000	1000<EC<2000	EC>2000
2	20	10 - 20	10
5	50	20 - 50	25
10	100	50 -100	50

Where EC is electrical conductivity

The range of water resistivities and formation factors in the area is as under:

The resistivity of the formation water measured on water samples ranges from 1.8 to 25 ohm.m corresponding with electrical conductivities (EC) of between 400 and 9000 ;uS/cm. Formation water with a resistivity less than 5 ohm.m (EC more than 2000;uS/cm) has been considered saline, whereas water with a resistivity of 5 ohm.m or more (EC value less than *2000flS/cm)* has been considered fresh...

The formation factors in the area were determined from geophysical w811 logs of two boreholes and from the resistivity OI the formation water measured in the well installed. Because of the rapid alternation of layers. in the saturated zone *an* average formation fact0r representing the whole zone or a large part of it had to be taken. It ranges between 2 and 14. The lithology corresponding with the average formation factors is given in Table A-2.

Table A-2 –Relation between average formation factor and lithology in the Karak Valley

Formation Factor	Lithology
2-3	Silty clay, alternated by fine sand
3-5	Alternating (silty) clay, sand and gravel
5-10	Coarse sand, gravel and boulders
10-14	Coarse sand, gravel and boulders possibly cemented

3.5.4 Layer Models Applied

Resistivity logs of boreholes are used for calibration of interpretation models. The resistivity and depth relation as shown by the resistivity logs can be schematized to a sequence of horizontal homogeneous layers with their respective electrical resistivities.

A resistivity curve calculated on the basis of this layer model will be equivalent to the field curve measured at the surface, provided that the assumptions of horizontal layers is not violated.

The layer model found in this way is generally too complicated to be used for the interpretation of the field curves because of its large number of successive layers. In order to achieve a more practical interpretation model, several successive layers of the schematic layer model are to be substituted by one single layer with an average resistivity in such a way, that the corresponding curve remains the same. The simplified model is taken as the base model for the final interpretation of the surrounding field curves.

With respect to the hydrogeological situation encountered and the layer models applied, three types of areas can be distinguished.

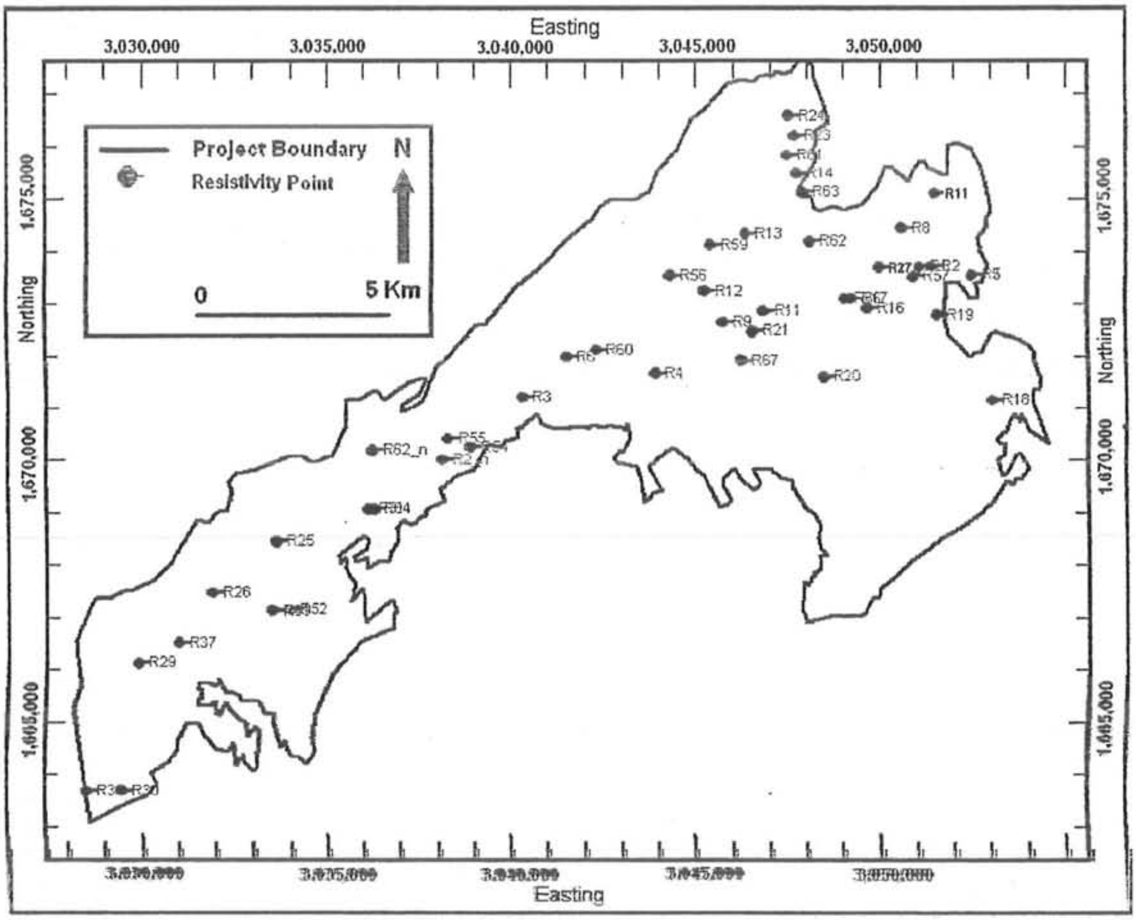

Figure: 3.2 Electrical Resistivity Points.

Figure 3.2 shows the ERS (Electrical Resistivity Survey) points. On the basis of these resistivity model has been generated as shown in Figure 3.4. From the model it is suggested that the area contains remarkable clay deposits. Figure 3.3 shows the occurrence of saline and fresh ground water and has been established by water sampling at different sites.

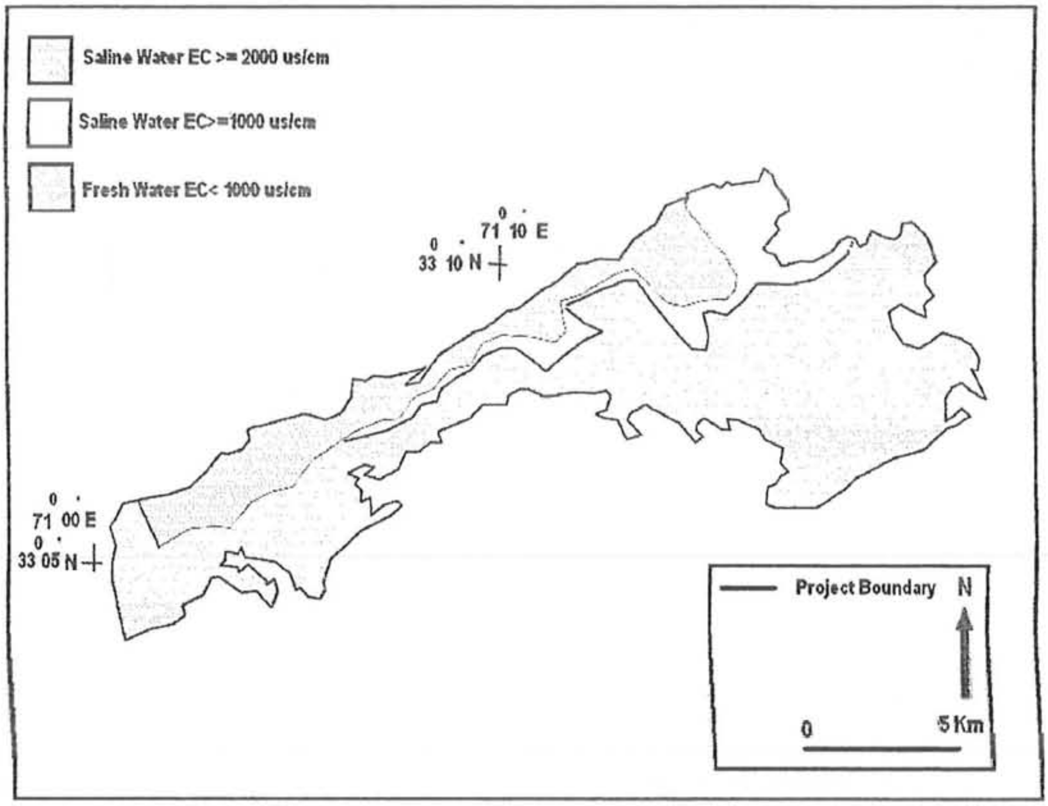

Figure: 3.3 Occurrence of Saline & Fresh Water.

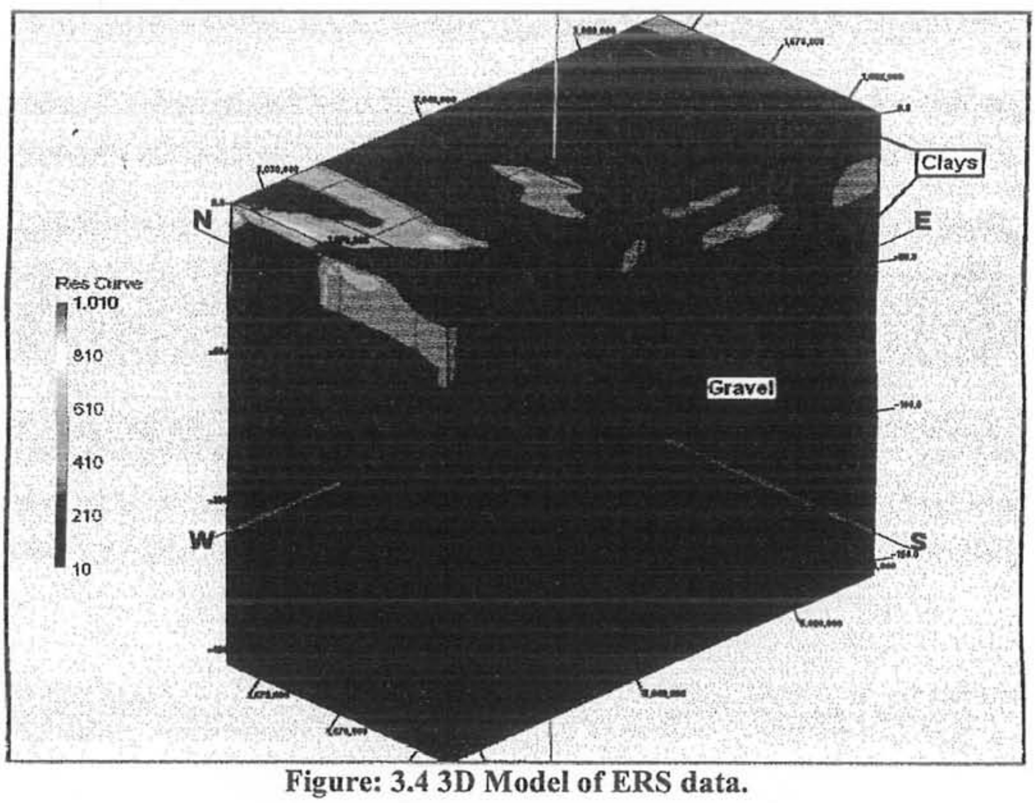

Figure: 3.4 3D Model of ERS data.

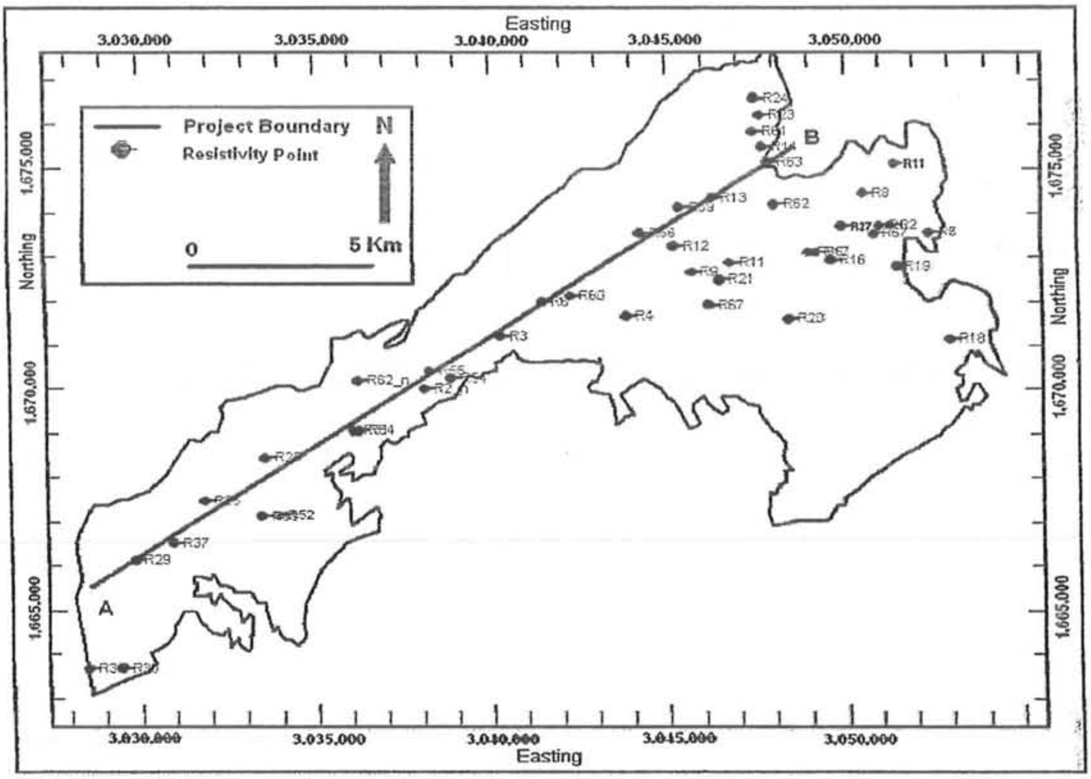

Figure 3.5 Shows the resistivity cross section AB

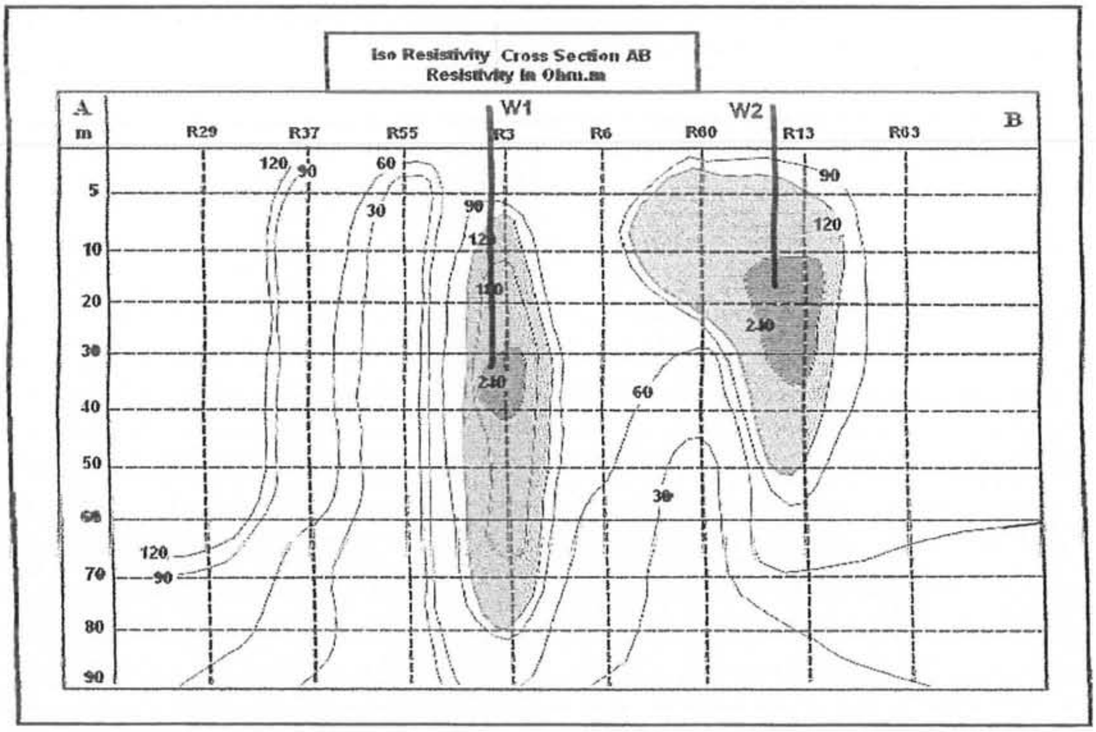

Figure 3.6 Iso Resistivity Section for the cross section AB.

Figure 3.5 shows the resistivity cross section of the selected points. Figure 3.6 shows the Iso resistivity cross section for the cross section AB. The portion enclosed by the contours of 120 to 240 ohm.m represents the zones of fresh water and they are favorable for the drilling new wells.

4.1 Introduction

It has been mentioned earlier that deposition in the area has occurred in an extremely mixed configuration and it is impossible to determine layer properties on the basis of resistivity data. An attempt has been made to convert the resistivity data to sonic and then find the layer properties. The layer properties which were used to be found are Porosity, Effective Porosity, Hydraulic Conductivity, Transmissivity and Clay Volume. This is to be found on well logs and surface resistivity sounding curves. A relationship is to be established between the well logs and the surface resistivity soundings for porosity and volume of Clay. We can directly calculate the porosity and shale volume form surface resistivity by using these relationships.

4.2 Seismic Velocity

Lithology is the most obvious factor we would expect to control velocity. However velocity ranges are so broad and there is so much overlap that velocity alone does not provide a good basis for distinguishing Lithology. Sand Velocities for example can be smaller or larger than shale velocities, and the same is true for densities: both density and velocity play important roles in seismic reflectivity.

Porosity appears to be the most important single factor in determining the rock's velocity, and the dependence of porosity on depth of burial and pressure relationships makes velocity sensitive to these factors also. Velocity is generally lowered when gas or oil replaces water as the interstitial fluids, sometimes by so much that amplitudes result from hydrocarbon accumulation.

The near surface layer of the earth usually differs markedly from the remainder of the earth in velocity and some other properties. This makes the near surface low velocity layer (LVL) especially important; our determinations of depths, attitudes, and continuity of deeper events are affected as reflections pass through this layer. In arctic areas, a zone of permanently frozen earth, permafrost, distorts deeper events because of exceptionally high velocity. Fluid pressure that exceeds that of a column of fluid extending to the surface ("normal" pressure) lowers seismic velocity; this is used to predict abnormal pressures. Gas hydrates that form in the sediments just below the sea floor in deep water also produces velocity changes (Yilmaz, 2001)

Seismic velocity is measured in boreholes by sonic logs and by VSP (Vertical Seismic Profiles). Velocity is also measured by surface seismic data because of the dependence of normal move out on velocity. The reflection coefficient equation can be used to obtain velocity information from amplitudes, a form of inversion (Sheriff & Geldart, 1999).

A critical part of many groundwater and environmental studies is obtaining quantitative information about the hydrogeologic properties of the groundwater aquifers. Numerous techniques have been developed to provide such information; these techniques vary in terms of the scale and accuracy of measurement. Most of the commonly used methods of subsurface hydrogeologic testing require a wellbore. Wellbores are expensive to drill, so there are often too few wells to provide good spatial coverage. In addition, there can be problems associated with the invasive nature of contaminants in contaminated regions. Hydrogeologists have recognized the benefits that can be gained by having seismic data from a subsurface region of interests. The basic concept is that the subsurface can be divided into regions, each with a distinct range of seismic velocity. These regions, defined by their seismic properties, can be assigned hydraulic properties (Jarvis & Knight, 2002).

4.3 Effects of lithology

Velocity is not a good criterion for determining Lithology except in a general sense. High velocity for sedimentary rocks generally indicates carbonates and low velocity sands or shales, whereas intermediate velocities can indicate either. The broad ranges for each of the Lithologies illustrate that many other variables are involved, especially porosity and age.

Sandstones often contain appreciable clay filling the pore spaces, and clay content is the next most important factor (after porosity) in determining the velocities. The reduction of P-Wave velocity when pores are clay filled is about 30% of that when fluid filled, and the factor for S-Wave velocity is 50% (Sheriff & Geldart, 1999).

4.4 Effect of density

The density of a rock is simply a volume weighted average of the densities of the rock constituents. The densities of the minerals that constitute most sedimentary rocks encompass a relatively narrow range of about + - 7% (Halite expected). The major reason that the rocks vary in density ρ is because they vary in porosity. The densities of igneous and metamorphic rocks are generally higher than those of sedimentary rocks because they have low porosity.

Seismic velocity appears to be proportional to mean atomic weight, determining by dividing the molecular weight by the number of atoms. Most of the relatively abundant minerals have mean atomic weights around 20 as shown in table 1. Metallic ores generally have higher mean atomic weights, for example, 30.4 for Ilmenite, 31.9 for hematite, and 33.1 for magnetite (Sheriff & Geldart, 1999).

Mineral	Density (gm/cc)	Mean Atomic Weight
Calcite	2.71	20
Dolomite	2.87	18.4
Anhydrite	2.96	22.7
Halite	2.16	29.2
Quartz	2.68	20
Albite	2.62	20.2
Orthoclase	2.55	21.4
Kaolinite	2.6	15.2
Muscovite	2.83	19

Table 4.1 Density and atomic weights of rock forming minerals.

4.5 Effects of depth of burial and pressure

Porosity generally decreases with increasing depth of burial (or overburden pressure) and hence velocity increases with depth. The elastic constants also depend on the pressure because of the structure of sedimentary rocks, which are not homogeneous as elasticity theory assumes.

The pore spaces in rocks are filled with a fluid under a pressure, which is usually different from that resulting from the weight of the overlying rocks; the effective pressure on the granular matrix is the difference between the overburden and fluid pressures. Normal fluid pressure is that of a column of fluid extending to the surface. Where formation fluids are overpressured, the differential pressure becomes that appropriate to a shallower depth and the velocity tends to be that of shallower depth. Laboratory measurements show that show that velocity is essentially constant when the overburden and the fluid pressures are changed, provided the differential pressure remains constant. Abnormal fluid pressure constitutes a severe hazard in drilling wells and one use of seismic velocity measurements is in predicting such zones (Sheriff & Geldart, 1999).

4.6 Effect of age, frequency and temperature

Faust included the age of the rock as a factor in determining velocity. Older rocks generally have high velocities than younger rocks, but most geophysicists agree that age is merely a measure of the net effect of many geologic processes, that is older rocks have had longer time to be subjected to cementation, tectonic stresses and so on which decrease porosity. The history of rock varies so much in time and space that the time factor must be only approximate. Time-dependent strain may play some part, but how large a part is not known.(Tolman, C.F.1937)

4.7 Effect of porosity

Porosity is the measure of pore spaces in rocks.It is defined as the percentage of pore spaces existing in a given volume of rock.The loose sand and gravel may have porosity up to 50%,sandstones may have porosity up to 15%while porosity of igneous rocks are 2 to 3%(Todd, D.K,1960)

Porosity is the most important factor in determining a rock's velocity. It should be noted that the interstitial water in shales is mostly bound water rather than free water in pore spaces; nevertheless the volume fraction occupied by this water is usually treated as porosity. Adding terms for clay content reduced the scatter from 6.6% to 2.8% for P-wave velocity and from 10.3 to 5.1% for S-wave velocity (Sheriff & Geldart, 1999).

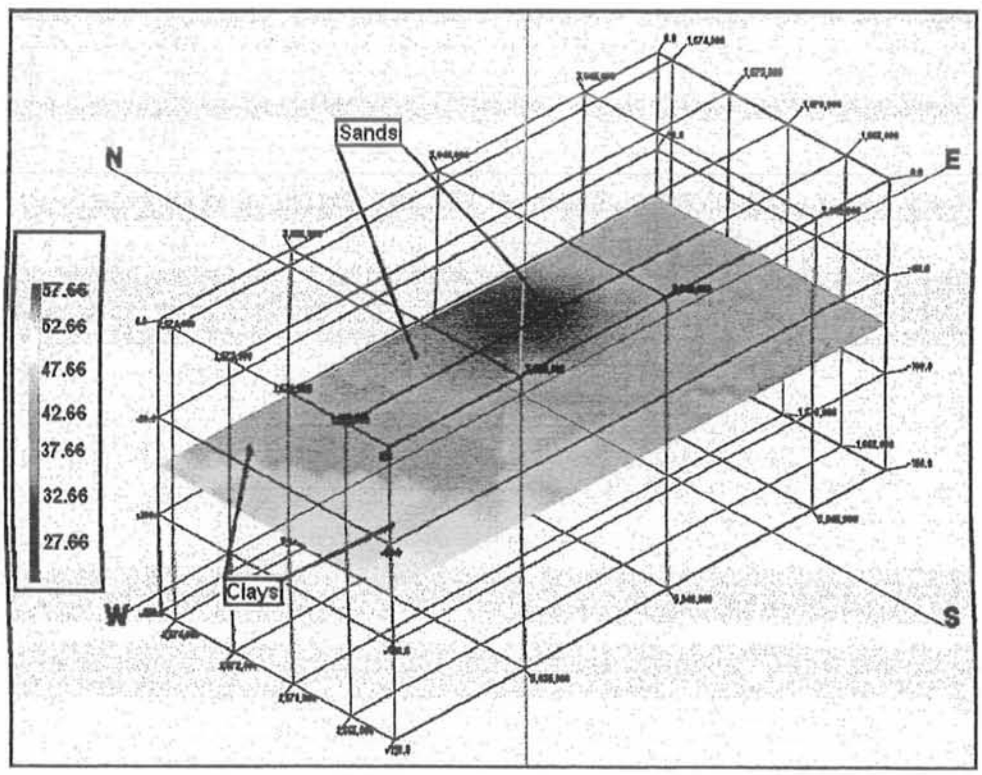

Figure: 4.1 The porosity slice from the porosity model.

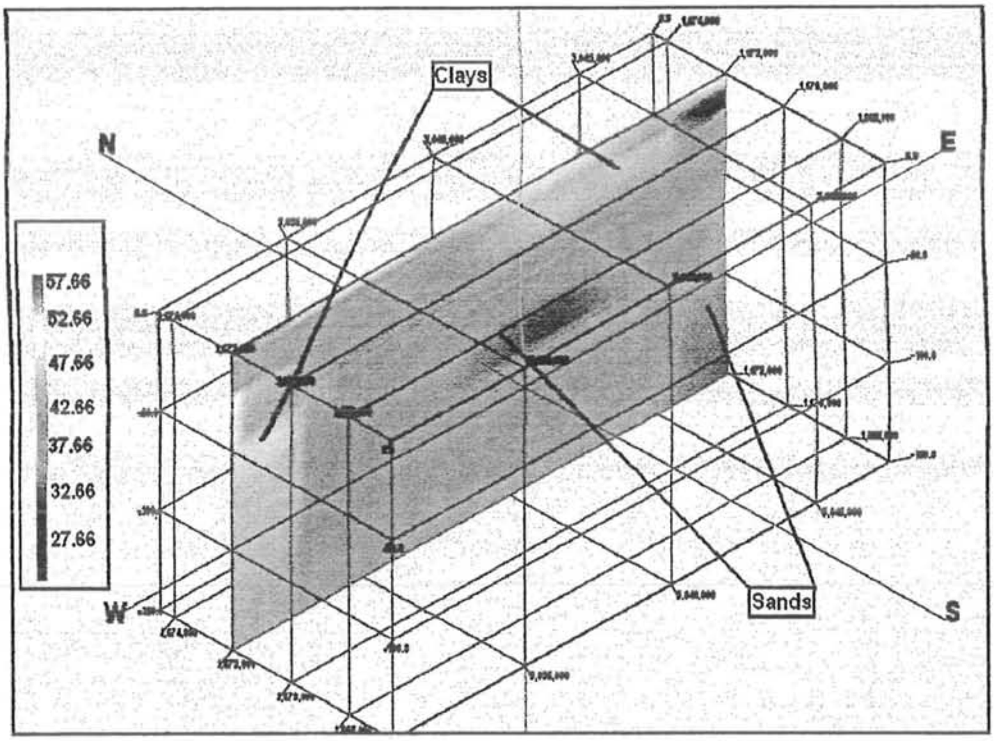

Figure: 4.2 The vertical cross section through the porosity model.

Velocity is expected to change with frequency because of absorption, the manner of change depending upon the absorption mechanism. There is some dispersion in fluid filled rocks and it is concluded that this happens due to the movement of fluids along the pore surfaces. Dispersion decreases with pressure and increasing porosity and decreases with increasing clay content.

Velocity appears to vary slightly with temperature, decreasing by 5% to 6% with 100 degree Celsius rise in temperature. However, velocity in heavy crude oil and tar varies considerably with temperature and the same applies to rocks saturated with them. The velocity in water-saturated rocks increases markedly as temperature is lowered through the freezing point. As the temperature drops, the liquid in the larger pores freezes first, the salinity of the liquid controlling the freezing curve. At a slightly lower temperature, the liquid in the smaller pores freezes (Sheriff & Geldart, 1999).

4.8 Effects of interstitial fluids

Porous rocks are always saturated with fluids, generally salt water, the pores in oil and gas reservoirs being filled with varying amount of water, oil, and gas. The replacement of water by oil or gas changes the bulk density and the elastic constants, and hence also the P-wave velocity and the reflection coefficient. These changes are sometimes sufficient to indicate the presence of gas or oil. Horizontal variations in reflection amplitude, velocity, frequency and other factors are sometimes important indicators of oil and gas accumulations. The low velocities when gas fills the pore space at least partially explain the low velocities observed in the weathered (LVL) layer and why its lower boundary is so often the **water table.** The ratio of P- to S-wave velocity (Vp/Vs) has been used a method of distinguishing the fluid filling the pore space (Sheriff & Geldart, 1999).

4.9 The weathered or low velocity layer

Seismic velocities that are lower than the velocity in water usually imply that gas fills at least some of the pore space. Such low velocities are usually seen on land near the surface in a zone called the weathered or low velocity layer, often abbreviated as LVL. This layer which is of varying thickness are characterized by seismic velocities that are not too low, but at times highly variable. Frequently the base of the LVL concides roughly with the water table, indicating that the low velocity layer corresponds to the aerated zone above the water saturated zone, but this is not always the case. In areas of seasonal fluctuation of the water table, leaching and redeposition of minerals may produce the effect of double-weathering layers. Double weathering effects sometimes result from a perched water table or changes at the base of glacial drift that is at a different depth than the water table. In sandy desert areas where there may be no definite water table, the LVL may grade continuously into sediments with normal velocity. In subarctic areas, muskeg swamp is mushy with low velocity in summer and frozen with high velocity in winter.

The importance of the low-velocity layer is five fold.

1) The absorption of energy is high in this zone.
2) The low velocity and the rapid changes in velocity have a disproportionately large effect on travel times.
3) Because of the low velocity, wavelengths are short and hence much smaller features produce significant scattering and other noise.
4) The marked velocity change at the base of the LVL sharply bends seismic rays so that their travel through the LVL is nearly vertical regardless of their direction of travel beneath the LVL.

5) The very high-impedance contrast at the base of the LVL makes it an excellent reflector, important in multiple reflections and in mode conversion. Because of the first factor, records where the sources are within this layer often are of poor quality; shots in the borehole are often placed 5 to 10 meters below the LVL.

4.10 Electrical resistivity model

The interpreted resistivity data as shown in Appendix-I is used to map the subsurface in the studied area. The model shown in Figure 4.3 is the modeled true resistivity. From the figure it is clear that the studied area do not exhibit many hydraulically conductive stratums. Only a small proportion of subsurface which is confined only to the upper part is composed of gravels and sands, which contains fresh water. Area is remarkably characterized by the presence of clays, which are not suitable for the accumulation of groundwater. The alluvium is deposited by the erosion of material from the surrounding mountains and the level of sorting of alluvium is very low. This is indicated by the low values of hydraulic conductivities and transmissivities for the wells present in the area.

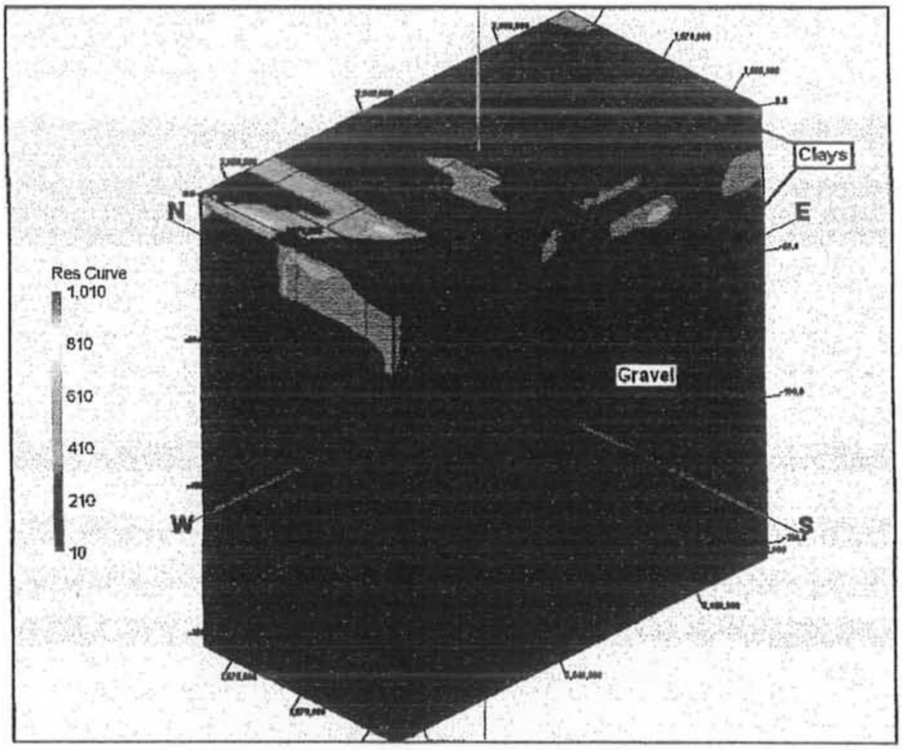

Figure: 4.3 Modeled interpreted resistivity data.

4.11 Hydraulic Conductivity by using resistivity data

The hydraulic conductivity has been calculated by using the resistivity logs as well as the surface resistivity soundings by using the following relationship by Shevnin et al, 2006. The hydraulic conductivity derived from surface resistivity, from resistivity logs and from pumping test shows a good correlation. Figure 4.4 shows the relationship to calculate the hydraulic conductivity from resistivity data.

$$K = 0.66528 \,.\, F^{2.09}$$

Where K = Hydraulic Conductivity
F = Formation Factor

$$F = \frac{R_f}{R_w}$$

R_f = Formation Resistivity
R_w = Resistivity Of Water

Formula 4.1: Calculation of hydraulic conductivity by using resistivity measurements.

From Well Logs (m/day)	From Surface Resistivity (m/day)	From Pumping Test (m/day)
3.07	3.62	3.6

Table: 4.2 Correlation between the hydraulic conductivities by three methods.

Table 4.2 shows the correlation between the hydraulic conductivities determined by three methods.

4.12 The Faust's Equation

The resistivity LN logs are converted to Sonic logs by using the Faust (1953) equation which is as follows.

Velocity = Constant * (Depth * Resistivity) ^ Exponent

Where Constant is called Faust Constant = 1947, Exponent is called Faust Exponent = 0.1667 and Sonic = 1000000 / Velocity. The figure shows the well WA-01. The lithologies have been marked by using the litholog as provided by the driller. The wells in the area have only Spontaneous Potential (SP), Resistivity (LN & SN) and Gamma Ray

(GR) Logs. The sonic logs are not available. The resistivity log was converted to sonic by using the above equation.

4.13 Hydraulic conductivity by using seismic data

Inferring heterogeneous aquifer properties become a critical research topic in hydrogeology. Groundwater flows preferentially along high hydraulic conductivity paths within the three dimensional structure of an aquifer. Accurate estimation of heterogeneous flow properties is critical to predict solute transport along such paths. Estimating values of subsurface hydraulic properties is difficult because the environment is largely inaccessible and common measurements used to deduce these properties are sparse. Geophysical methods could provide the needed high resolution estimates of aquifer properties, but the relations between the estimated geophysical properties and the desired hydraulic properties are unknown at the field scale. An improved understanding of these relations would allow more quantitative use of geophysical measurements to estimate hydraulic properties (Hyndman et al, 2000).

Hyndman et al, established a relation between seismic slowness and hydraulic conductivity at the field scale. The electrical resistivity curves have been converted to seismic slowness by using the Faust's equation. The Hyndman equation have been balanced for the studied area to calculate the hydraulic conductivity.

$$\ln(K) = 0.041 * \text{Seismic Slowness} - 31.83$$

$$K = \ln^{-1}(0.041 * \text{Seismic Slowness} - 31.83)$$

Where K = Hydraulic Conductivity

Formula 4.2 Hyndman Equation for relationship of hydraulic conductivity and seismic slowness.

The Figure: 4.5 show the Hyndman equation to relate hydraulic conductivity and seismic slowness. This equation does not perform well for our studied area. So there is some need to balance this equation. The above equation is balanced in such a way that the hydraulic conductivity resulting from the equation matches the hydraulic conductivity of the well. For this resistivity log for the well WA-05 and the surface resistivity sounding have been used. The balanced equation is as follows.

$$K = \ln^{-1} (0.041 * \text{Seismic Slowness} - 21)$$

Where K = Hydraulic Conductivity

4.14 Seismic Drift

Difference between the surface slowness and log slowness is termed as seismic drift. This happens due to two reasons. 1) The logs are effected by the formations lithology, fluid contents etc. Sonic logs recode the true formation velocities whereas from surface seismic average velocities are obtained. Also the wave slows down as it moves down in the subsurface. The Surface seismic is corrected by applying this drift correction.

Seismic Drift = Surface seismic slowness – Log seismic slowness

SD = Ss - Sl

The seismic drift is added or subtracted from the surface seismic slowness, it depend upon the results. If it is negative then it will be added and vice versa. Figure 4.6 shows the calculated seismic drift.

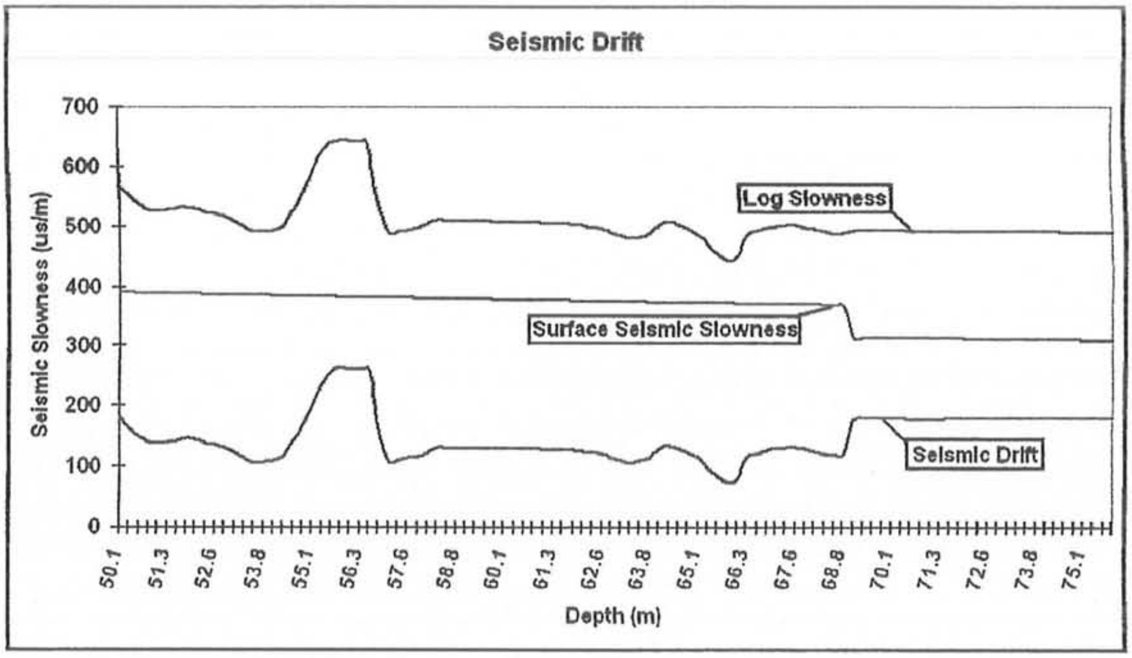

Figure: 4.6 Show the calculated seismic drift.

4.15 Results compared

The results of the three methods are shown in Table 4.3. The value of hydraulic conductivity obtained by pumping test is 3.6 m/day. Comparing this to the results of the Table 4.3, it is observed that the values of surface resistivity matches with the pumping test.

From Well Logs (m/day)	From Surface Resistivity (m/day)	From Hyndman Balanced Equation
3.07	3.62	3.85

Table 4.3: Comparison of the results for the calculation of Hydraulic Conductivity.

4.16 Void ratio

The variations in shear wave velocity can be transformed into variations in void ratio, a parameter that has more relevance for hydrogeological investigations. The relationship between shear wave velocity and void ratio as studied by Hardin and Richart through an extensive set of laboratory experiments on dry materials ranging from coarse sands to fine silts with void ratios from 0.7 to 1.3. Their laboratory study showed that velocity primarily depends on void ratio and confining pressure, with very little dependence upon grain size, resulting in the following relationship (Jarvis & Knight, 2002).

$$Vs = (104 - 35e)\sigma^{1/4}$$

Where Vs = Shear Wave Velocity, e = Void Ratio and σ = Confining Pressure.

To adapt this equation for the saturated state of the aquifer unit, and can be written as

$$e = 2.6 - Vs / (37\sigma^{1/4})$$

The equation have been applied for the studied area for well WA-05 and results are shown in the Figure 4.7.

Shear Wave velocity is calculated by using the formula $Vs = 0.80416\ Vp - 0.85588$ as mentioned by Bacon et al, 2003. The confining pressure is calculated by using the relationship $\sigma = \rho * g * Z$, described by Bachrach et al, 2000. Where ρ = density, g is acceleration due to gravity and Z is the depth. Density is calculated by using the Gardner's equation.

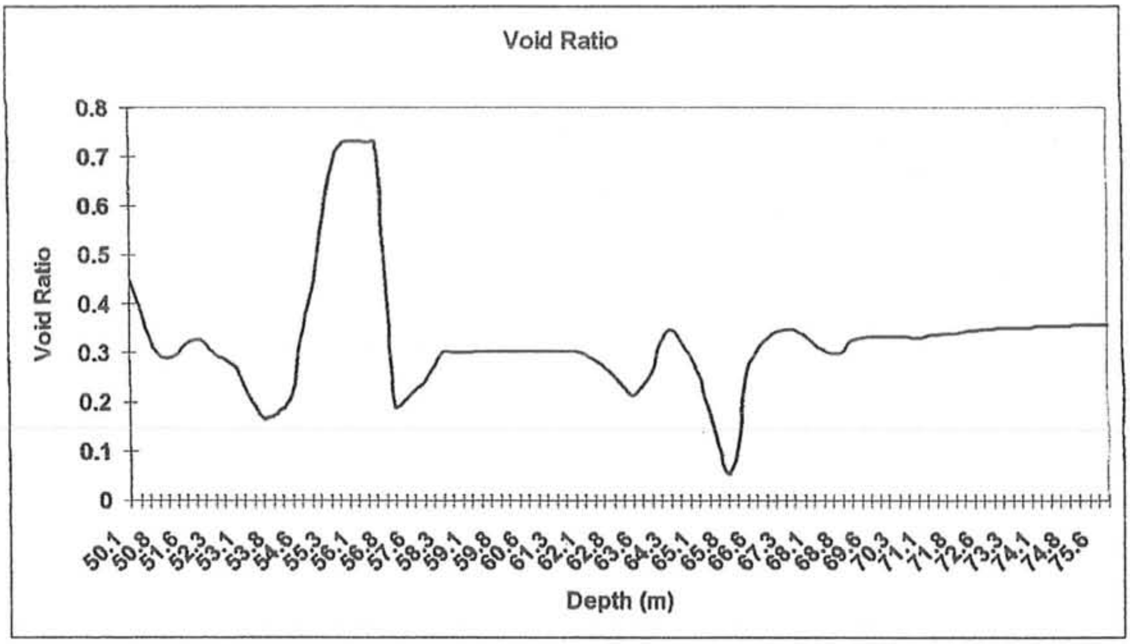

Figure: 4.7 Void ratio calculated for Well-05.

Conclusions:

- Porosity has been effectively mapped in the area. Gravels exhibit relatively low porosities than clays.
- Void ratio has been found by using the idea of effective pressure and shear wave velocity.
- Gravels exhibit sufficient value of void ratio to store water.
- Seismic drift is incorporated into calculations to match the hydraulic conductivities for surface seismic curves and well logs.
- The alluvial deposits are not very well sorted as indicated by the low hydraulic conductivities.
- The hydraulic conductivities of the aquifers in the studied area are too low. They may not be favorable for commercial supply of water.
- The resistivity conversion method is used for the estimation of hydraulic conductivities effectively.
- The hydraulic conductivities obtained by pumping test, resistivity logs and surveys and seismic curves are in good match.
- This method measures hydraulic conductivity for ground water exploration and can be achieved economically by the utilization of above three methods.

Recommendations:

- Seismic drift calculations must be incorporated into study to obtain hydraulic conductivity values from surface measurements.
- To achieve economic benefits, wells must be drilled at places with high hydraulic conductivities obtained by surface measurements.
- According to the well data and interpretated results through different methods applied, high resistivity aquifers are at shallow depth varying from 20m to 50m.
- Two high resistivity aquifers are recommended at resistivity points R3 and R13 at depth 35m and 28m respectively.

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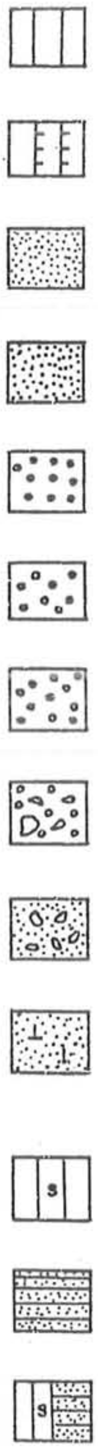
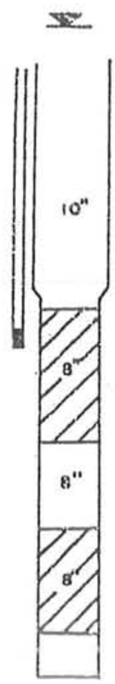
L E G E N D

LITHOLOGICAL LOG



- CLAY
- SILTY CLAY
- FINE SAND
- MEDIUM SAND
- COARSE SAND
- GRAVEL
- (COARSE) SAND WITH GRAVEL
- GRAVEL WITH BOULDERS
- SAND WITH BOULDERS
- SAND CEMENTED
- SHALES
- SANDSTONE
- ALTERNATING SANDSTONE / SHALE LAYERS

WELL DESIGN



STATIC WATERLEVEL

TEST WELL

WITH PIEZOMETER

10" CASING

REDUCTION CONE 10" TO 8"

8" SCREEN.

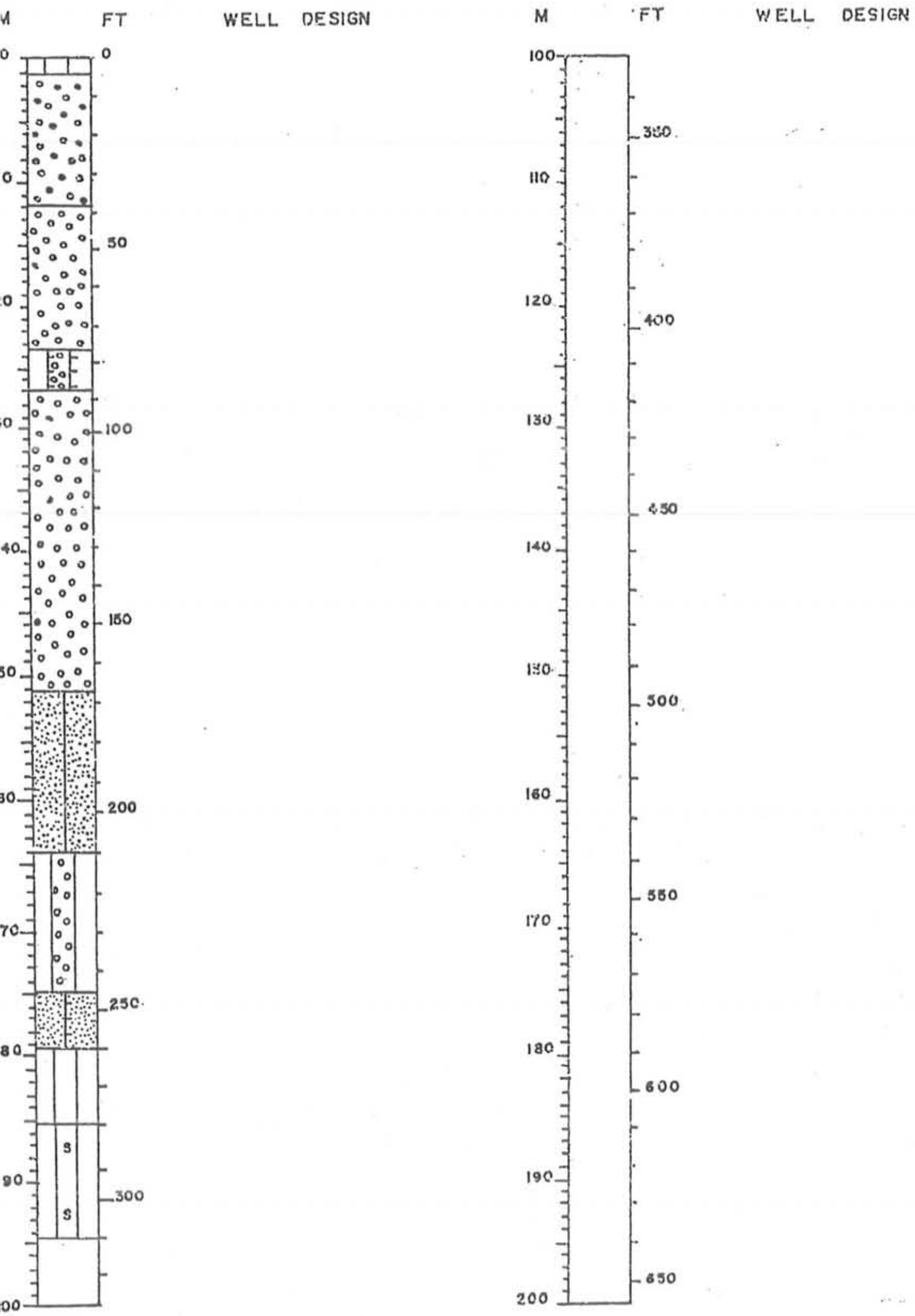
8" INTERMEDIATE BLIND

8" SCREEN

WAPDA HYDROGEOLOGY DIRECTORATE, PESHAWAR

LITHOLOGICAL LOG

AREA	KARAK	BORE HOLE NO.	WA 1
LOCATION	N·E SURTI KILI	MAP SHEET	38 O/4
CO-ORDINATES	33°-4'-0"N 71°-0'-50"E	WELL TYPE	TEST HOLE
GROUND LEVEL	468.8 m above M.S.L	GEOPHYSICAL LOG	N.A
DRILLING STARTED	22·12·73	SAMPLE LOG BY	KHURSHID AKHTAR KHAN
DRILLING COMPLETED	30·12·73	DRILLING MACHINE	ROTARY STRAIGHT FLUSH.
WELL COMPLETED	N.A.	DRILLER	BABU DIN & SHAKUT.

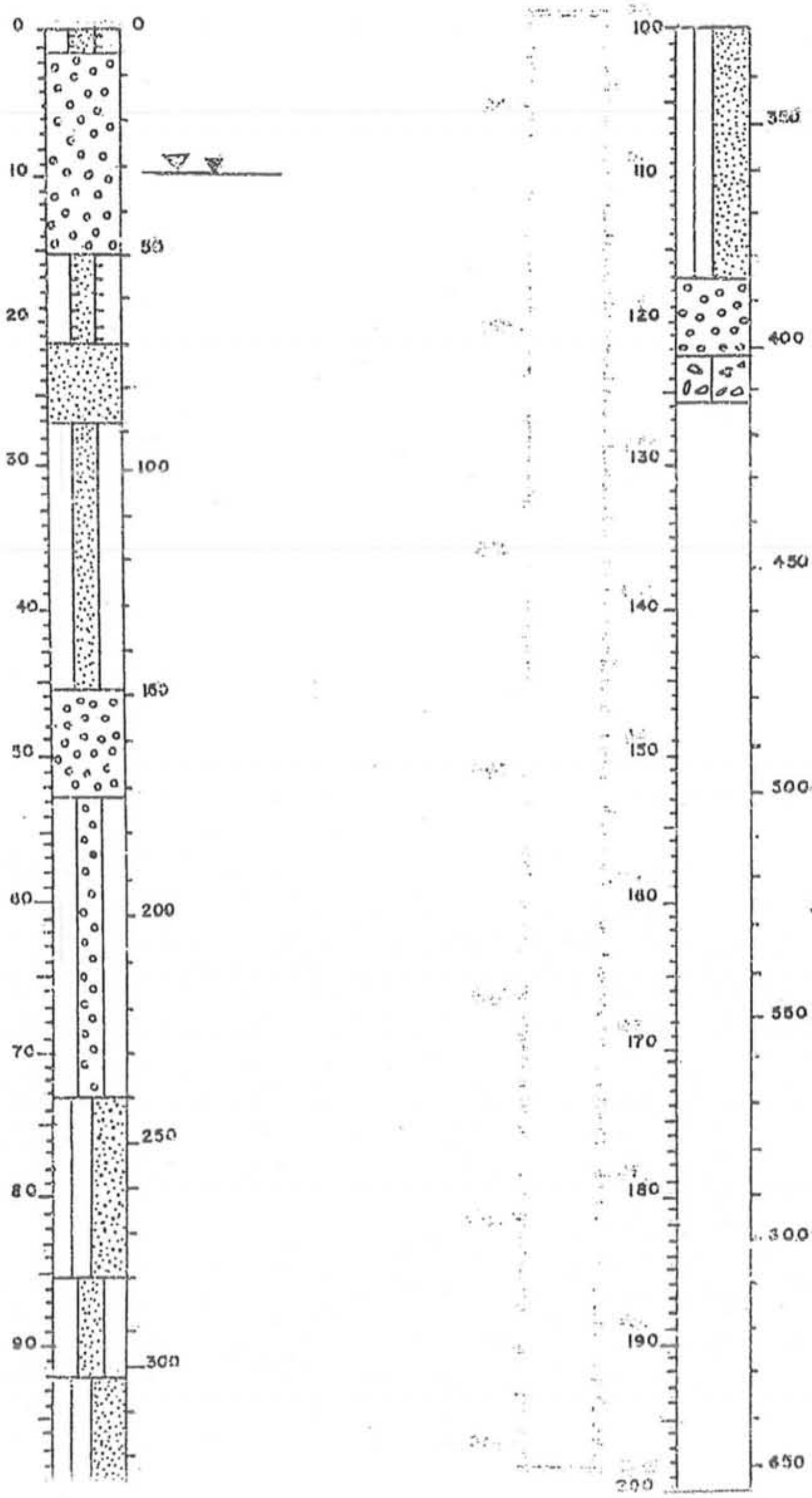


WAPDA HYDROGEOLOGY DIRECTORATE PESHAWAR

LITHOLOGICAL LOG

AREA: KARAK	BORE HOLE NO.: WA-2
LOCATION: S.W. OF KARAK TOWN	MAP SHEET: 38 O/4
CO-ORDINATES: 33°-4'-42"N - 71°-[illegible]-55"E	WELL TYPE: TESTHOLE
GROUND LEVEL: 534.9 m above M.S.L.	GEOPHYSICAL LOG: N.A
DRILLING STARTED: 17-1-74	SAMPLE LOG BY: KURSHID AKHTAR KHAN
DRILLING COMPLETED: 5-2-74	DRILLING MACHINE: ROTARY STRAIGHT FLUSH
WELL COMPLETED: N.A.	DRILLER: BABU DIN AND SHAKHUAT

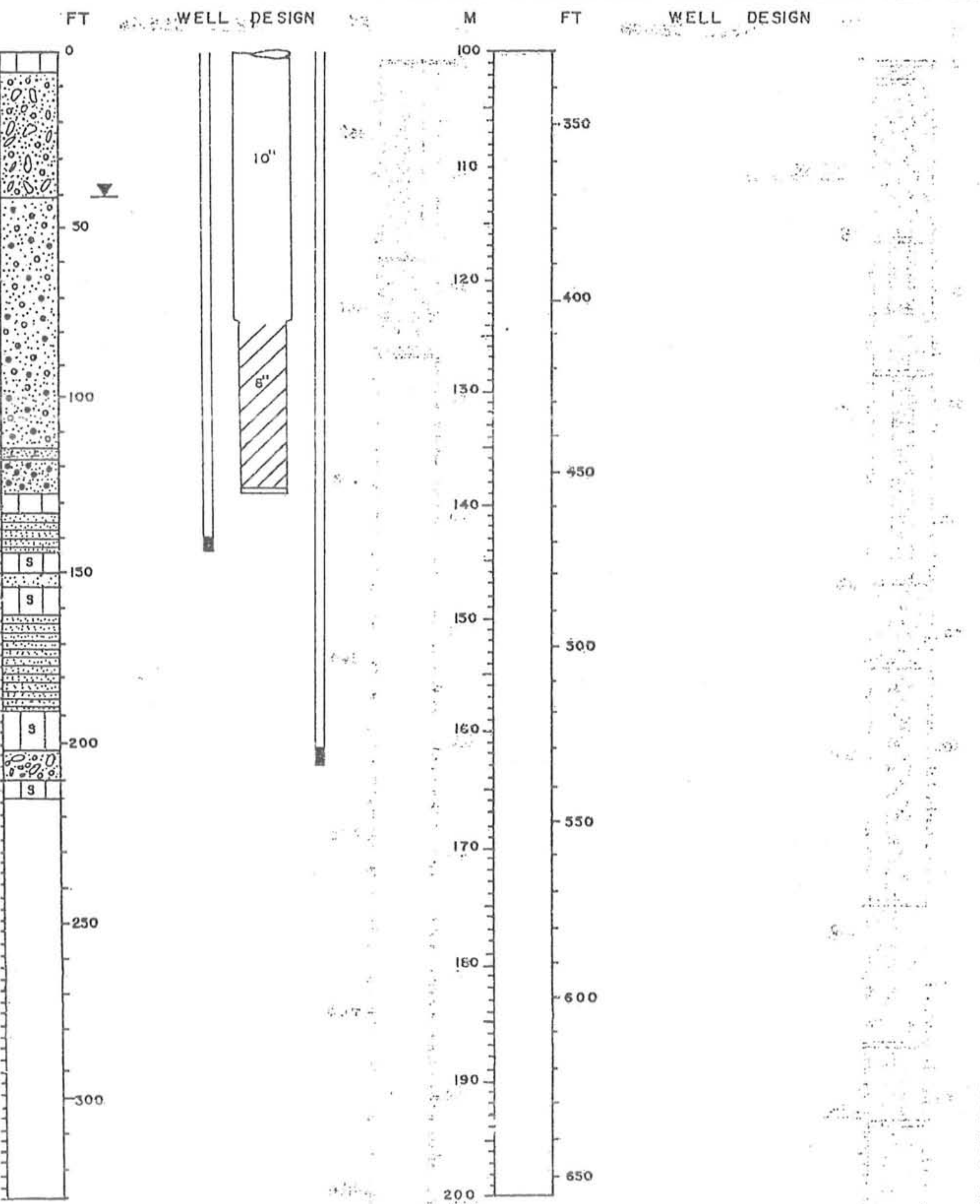
M FT WELL DESIGN M FT WELL DESIGN



WAPDA HYDROGEOLOGY DIRECTORATE PESHAWAR

LITHOLOGICAL LOG

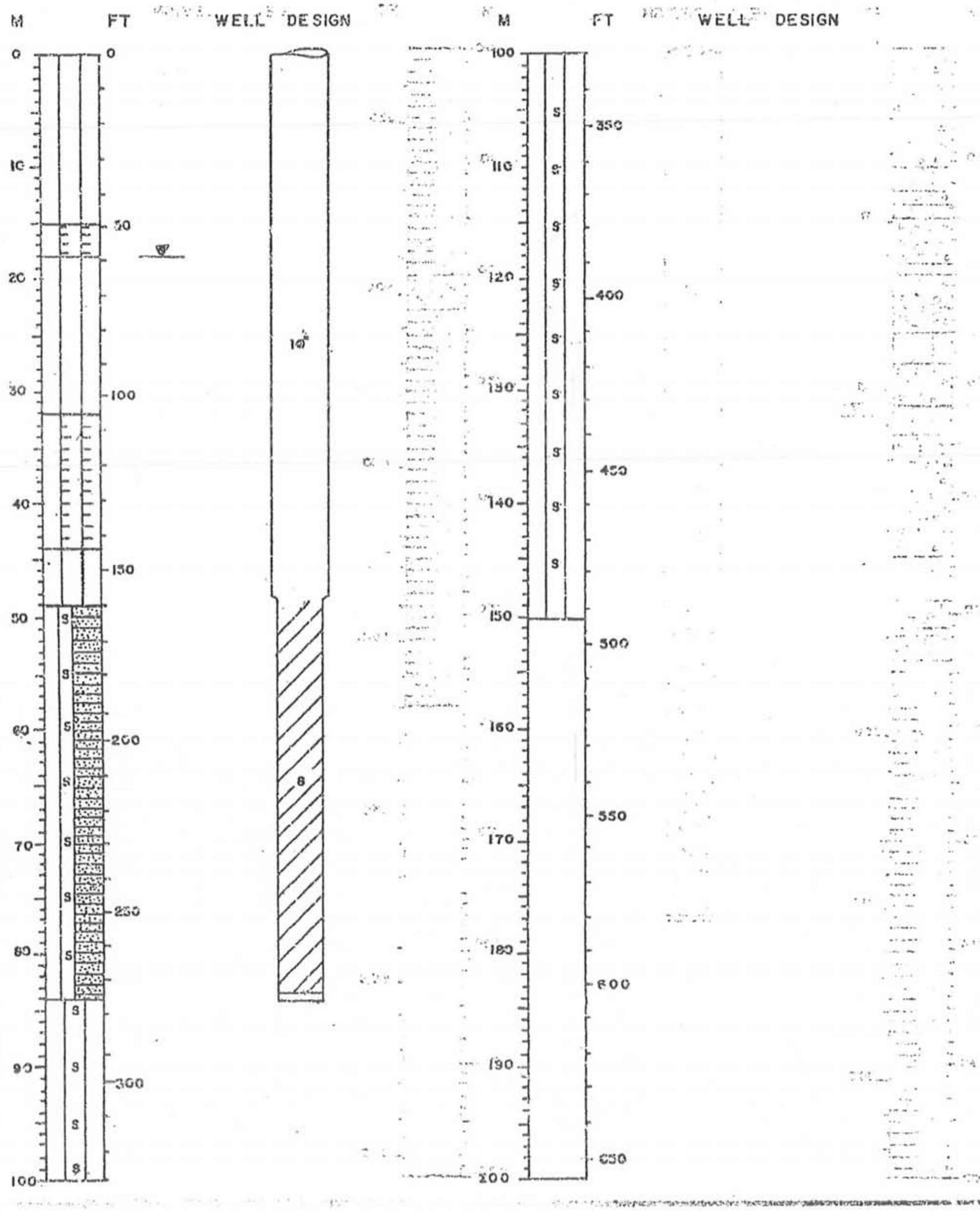
EA KARAK	BORE HOLE NO. WA - 3
CATION KARAK TOWN.	MAP SHEET 38 O/4
-ORDINATES 33-7 ON, 71-6-40E	WELL TYPE TEST WELL.
OUND LEVEL 606m above M.S.L.	GEOPHYSICAL LOG N.A.
ILLING STARTED 17.3.82	SAMPLE LOG BY ZABIHULLAH
ILLING COMPLETED 8.4.82	DRILLING MACHINE PERCUSSION.
LL COMPLETED 14.4.82	DRILLER AZAM KHAN.



WAPDA HYDROGEOLOGY DIRECTORATE PESHAWAR

LITHOLOGICAL LOG

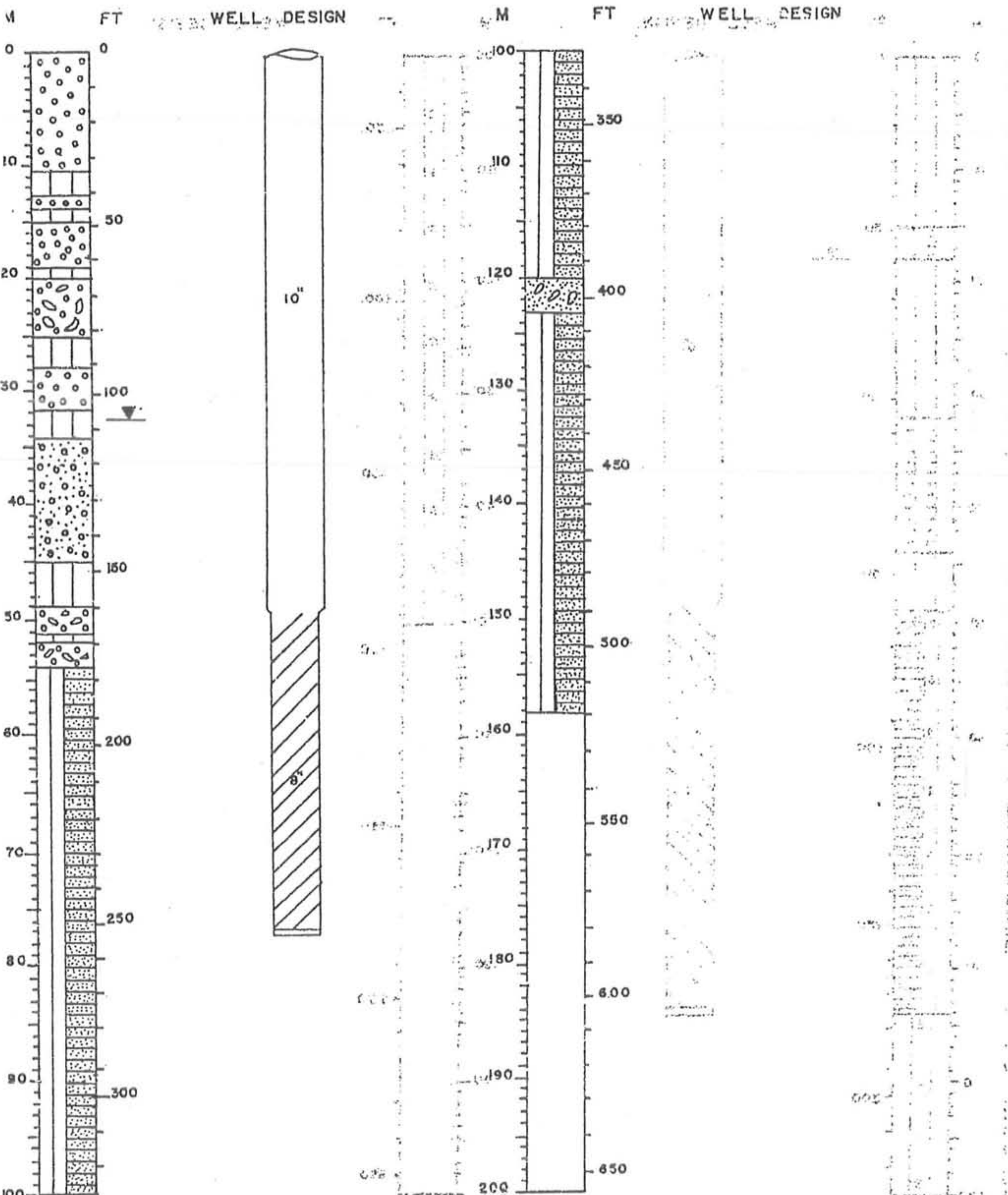
AREA: KARAK	BORE HOLE NO: WA - 4
LOCATION: 2400 m NE OF MITHA KHEL	MAP SHEET: 38 O/4
CO-ORDINATES: 33°-9'-10"N, 71°-12'-55"E	WELL TYPE: TEST WELL
GROUND LEVEL: 733 m above M.S.L	GEOPHYSICAL LOG: 5 . 5 . 82
DRILLING STARTED: 24 . 4 . 82	SAMPLE LOG BY: SAJJAD ALI
DRILLING COMPLETED: 4 . 4 . 82	DRILLING MACHINE: ROTARY STRIGHT FLUSH
WELL COMPLETED: 25 . 5 . 82	DRILLER: UMAR KHAN



WAPDA HYDROGEOLOGY DIRECTORATE, PESHAWAR

LITHOLOGICAL LOG

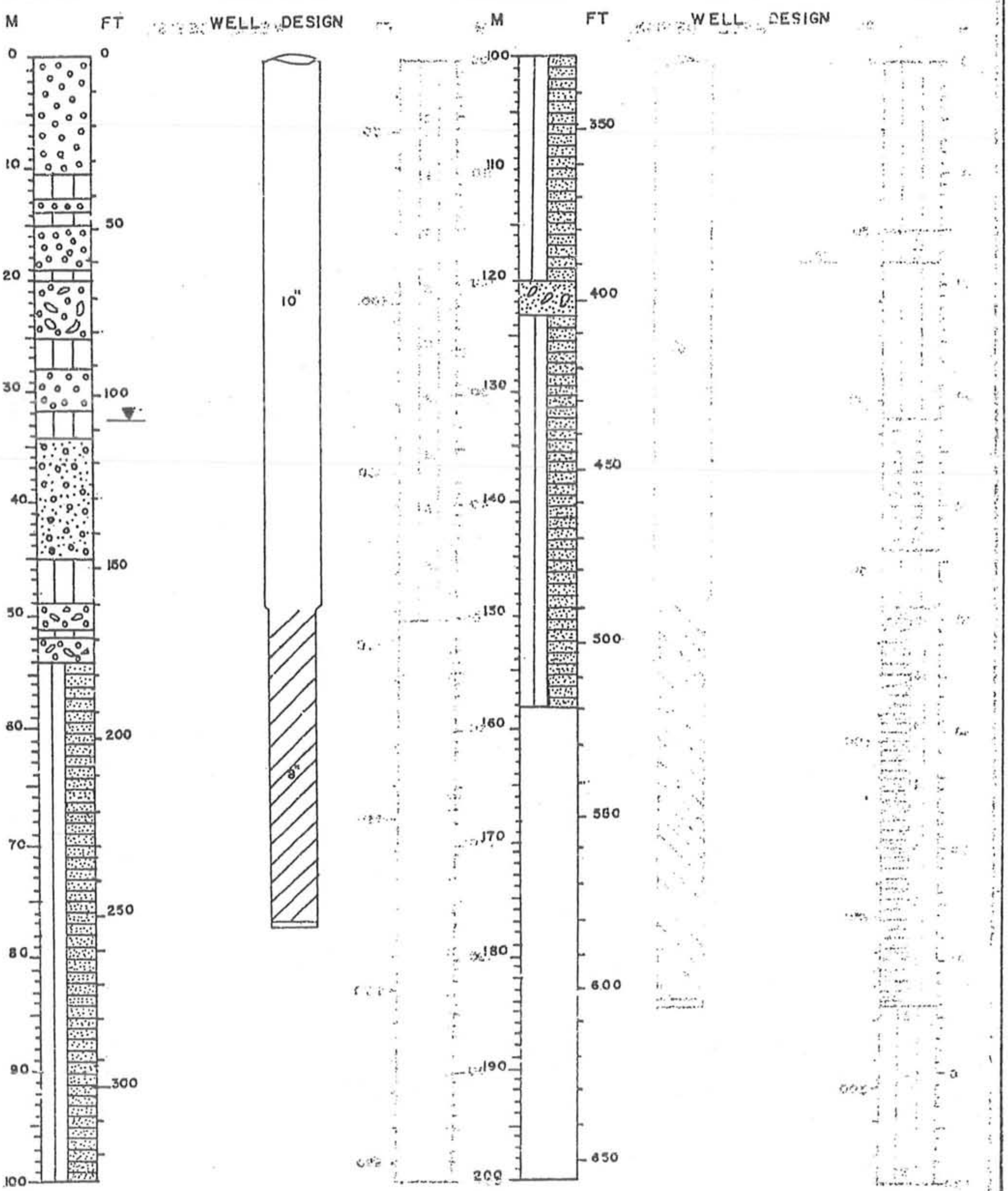
AREA: KARAK	BORE HOLE NO. WA 5
LOCATION: 550 m N OF TALAB KHEL	MAP SHEET: 38 O /8
CO-ORDINATES: 33-9-0 N, 71-16-35E	WELL TYPE: TEST WELL
GROUND LEVEL: 823 m above M.S.L.	GEOPHYSICAL LOG: 16-5-82
DRILLING STARTED: 7·5·82	SAMPLE LOG BY: SAJJAD ALI
DRILLING COMPLETED: 15·5·82	DRILLING MACHINE: ROTARY, STRAIGHT FLUSH
WELL COMPLETED: 3·6·82	DRILLER: MALIK AZIM



WAPDA HYDROGEOLOGY DIRECTORATE, PESHAWAR

LITHOLOGICAL LOG

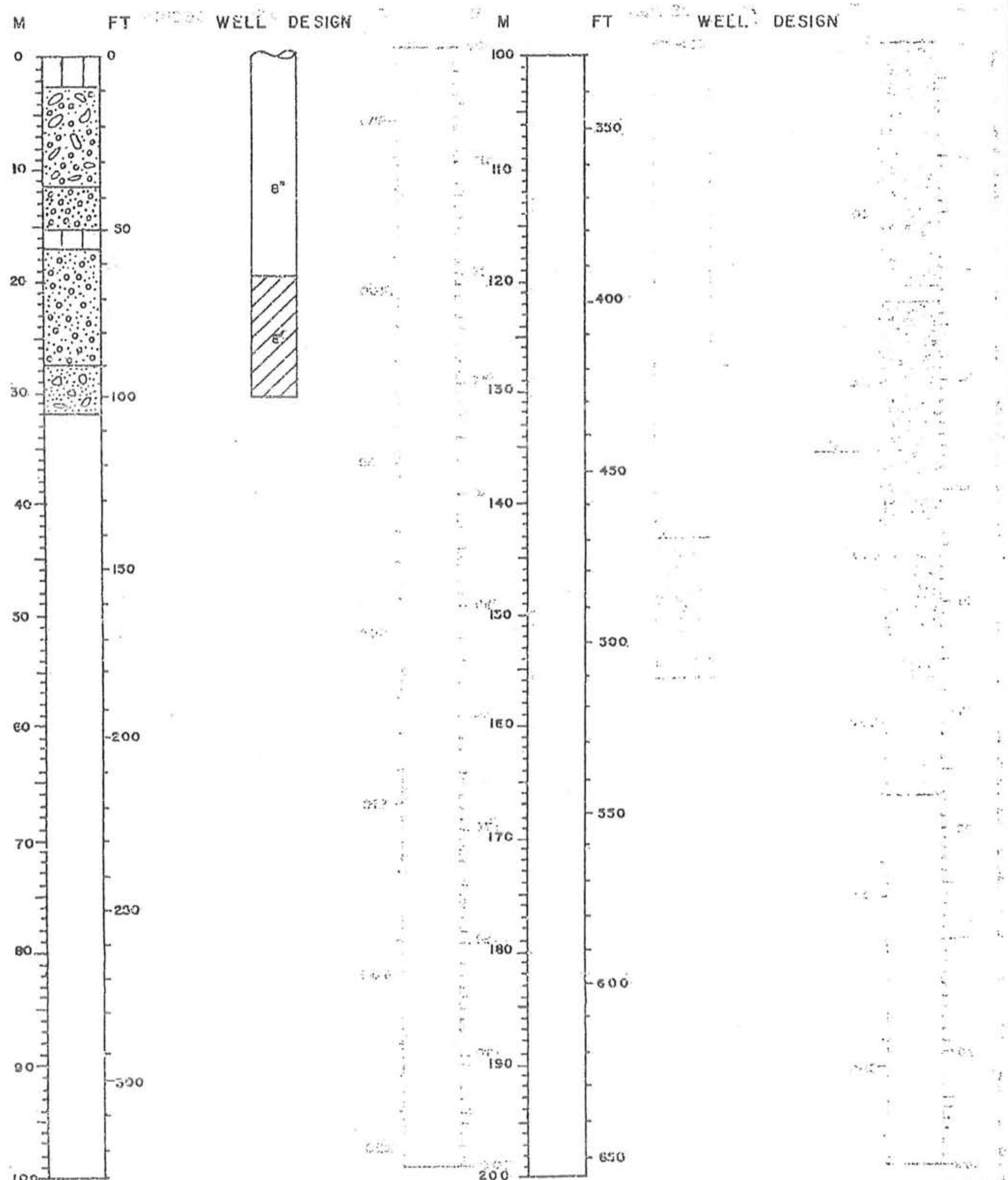
AREA	KARAK	BORE HOLE NO.	WA 5
LOCATION	550 m N OF TALAB KHEL	MAP SHEET	38 O/8
CO-ORDINATES	33-9-0 N, 71-16-35 E	WELL TYPE	TEST WELL
GROUND LEVEL	823 m above M.S.L.	GEOPHYSICAL LOG	18-5-82
DRILLING STARTED	7·5·82	SAMPLE LOG BY	SAJJAD ALI
DRILLING COMPLETED	15·5·82	DRILLING MACHINE	ROTARY, STRAIGHT FLUSH
WELL COMPLETED	3·6·82	DRILLER	MALIK AZIM



WAPDA HYDROGEOLOGY DIRECTORATE PESHAWAR

LITHOLOGICAL LOG

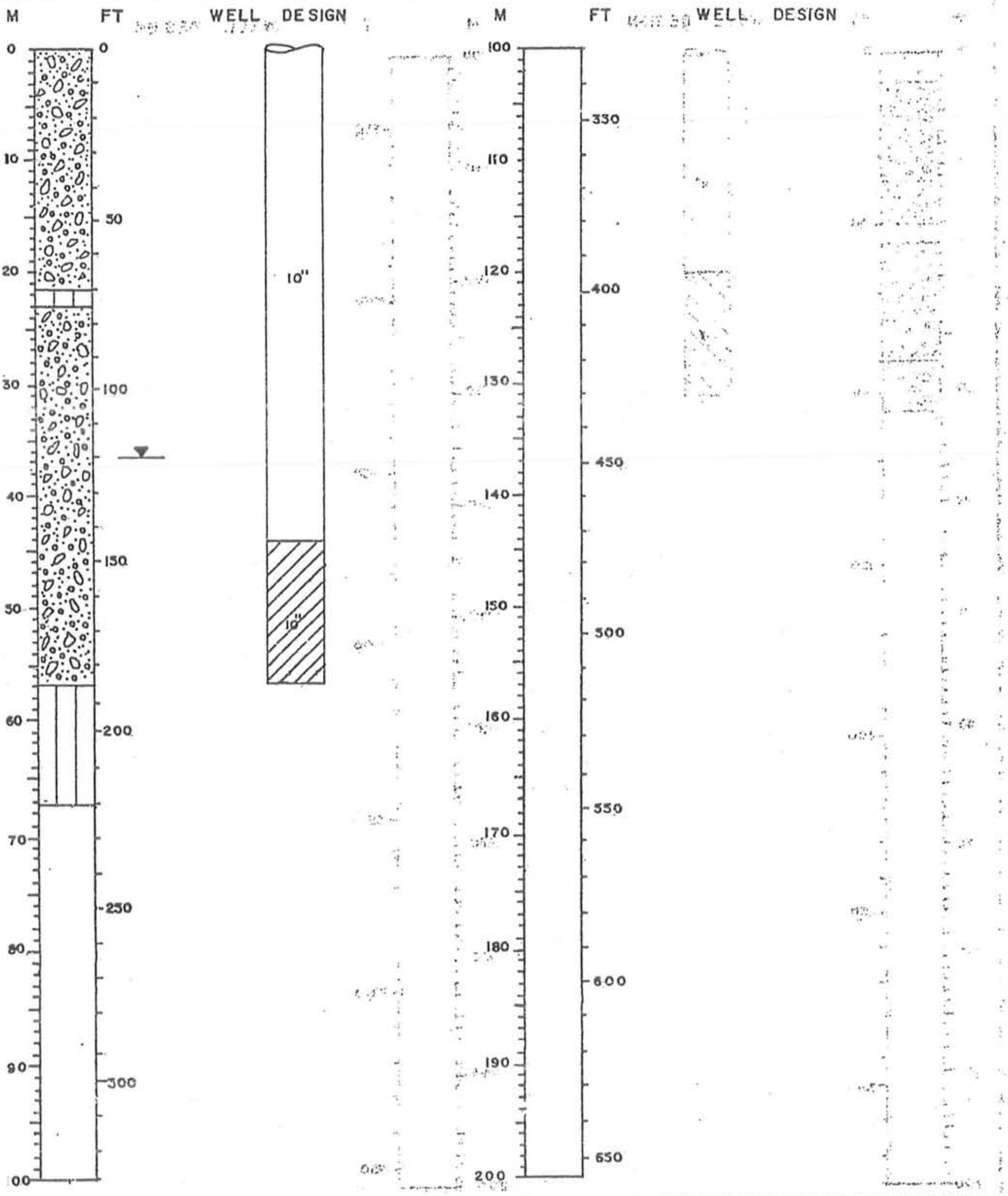
AREA	KARAK	BORE HOLE NO.	PUBLIC HEALTH
LOCATION	KARAK TOWN	MAP SHEET	38074
CO-ORDINATES	33°-2'-5"N 71°-5'-20"E	WELL TYPE	PRODUCTION
GROUND LEVEL	602 m above M.S.L.	GEOPHYSICAL LOG	No
DRILLING STARTED		SAMPLE LOG BY	
DRILLING COMPLETED		DRILLING MACHINE	
WELL COMPLETED		DRILLER	

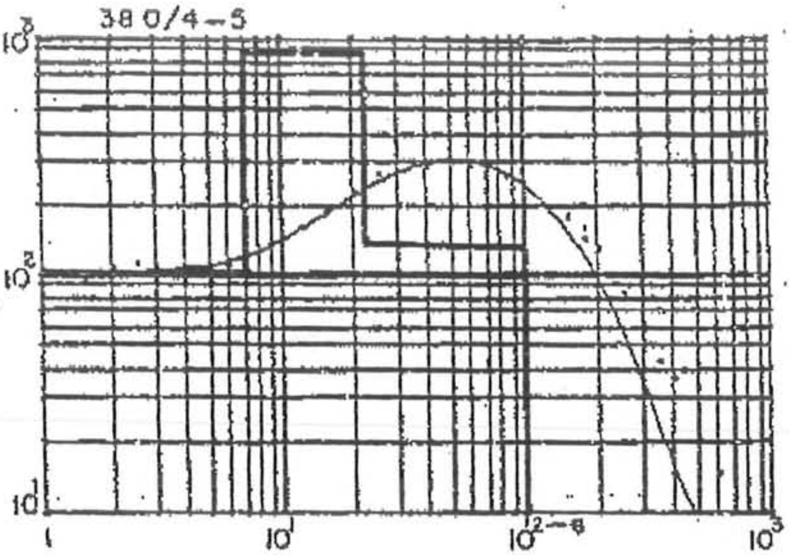


WAPDA HYDROGEOLOGY DIRECTORATE, PESHAWAR

LITHOLOGICAL LOG

AREA	KARAK	BORE HOLE NO	PUBLIC HEALTH
LOCATION	PLOSA SAR	MAP SHEET	380/6
CO-ORDINATES	30°-8'-20" N 71°-19'-46" E	WELL TYPE	PRODUCTION
GROUND LEVEL	914 m above M.S.L.	GEOPHYSICAL LOG	NO
DRILLING STARTED	–	SAMPLE LOG BY	–
DRILLING COMPLETED	1979	DRILLING MACHINE	–
WELL COMPLETED	–	DRILLER	–





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10¹
10²-8
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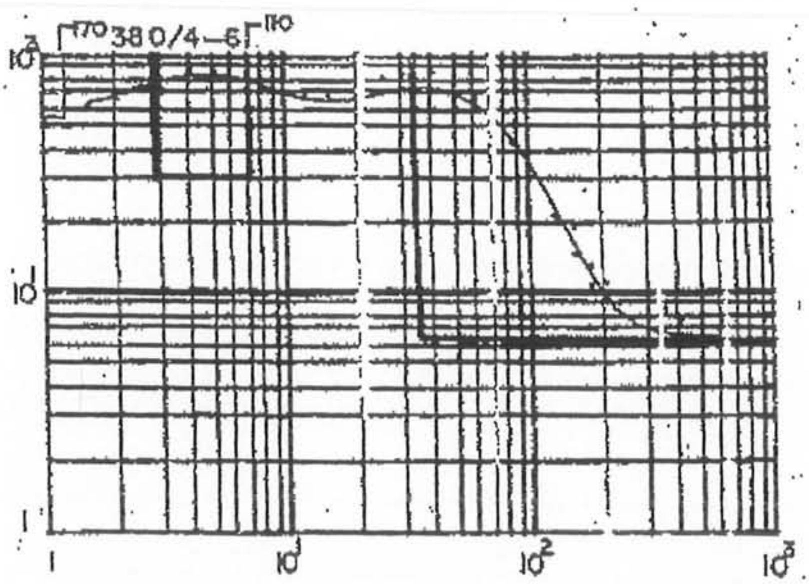

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1
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10²
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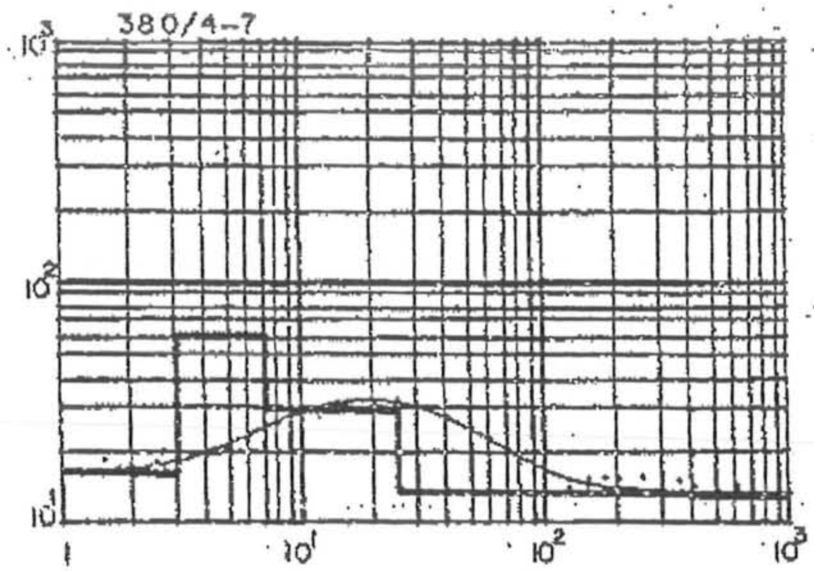
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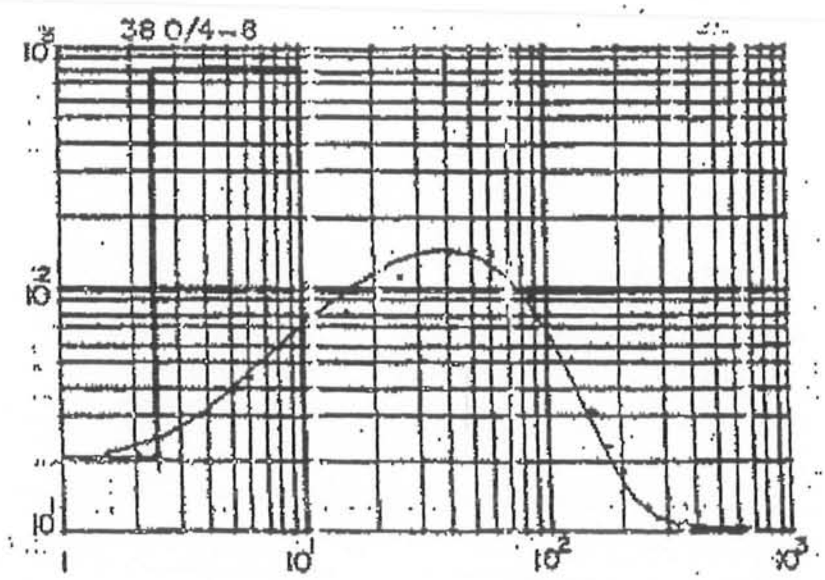
10^3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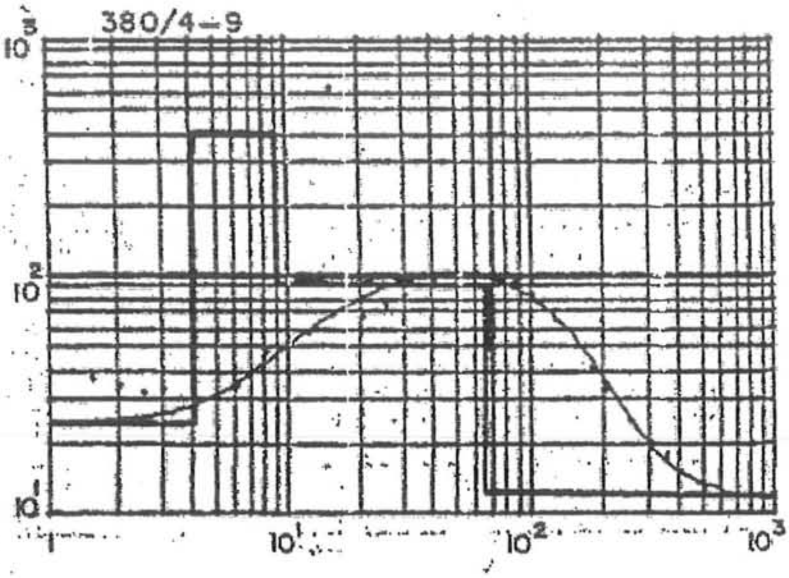
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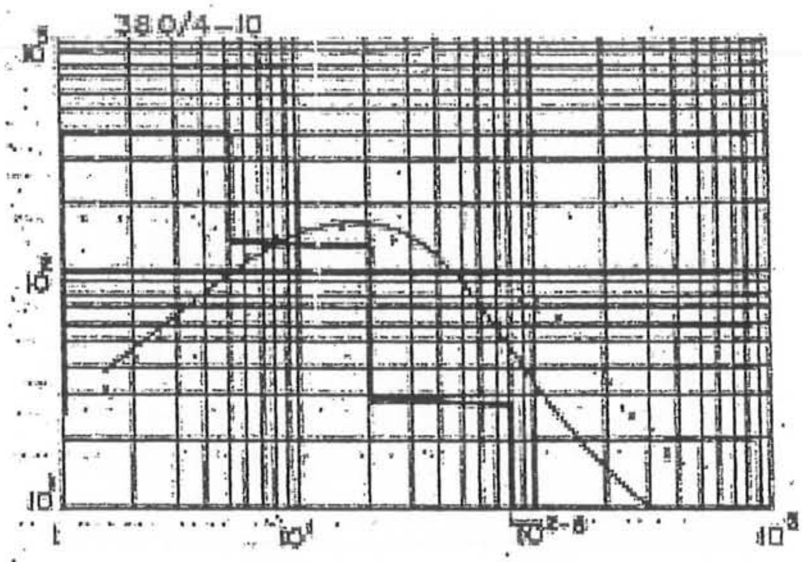
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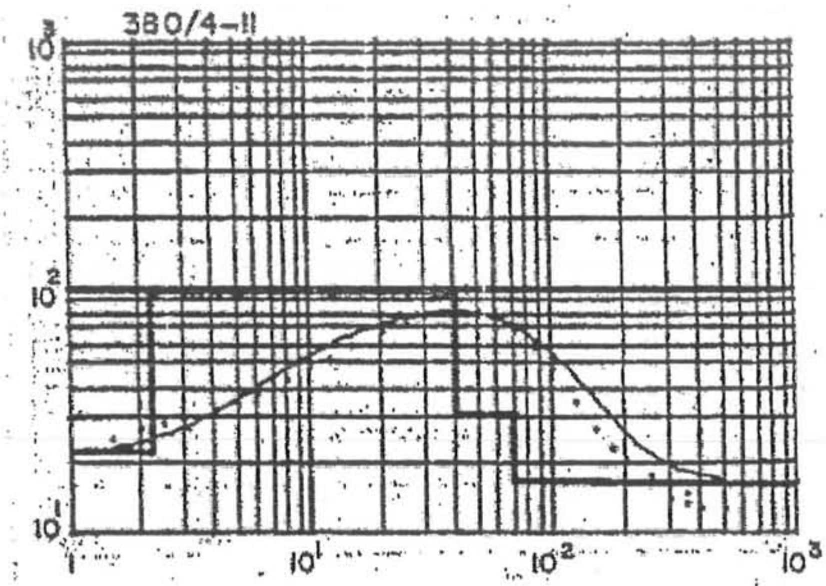

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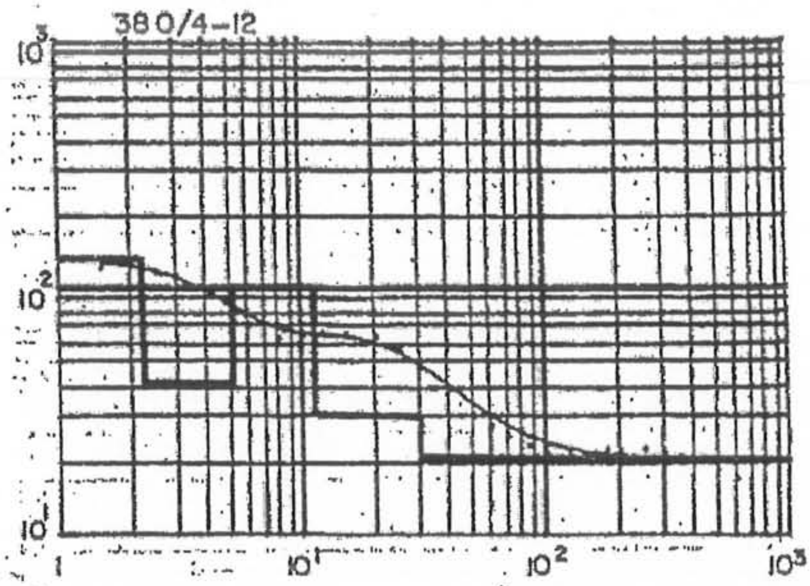

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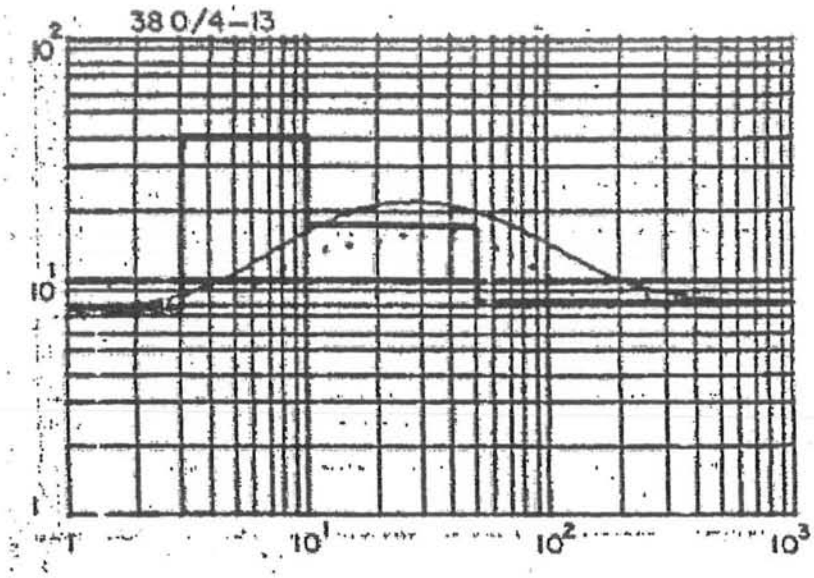

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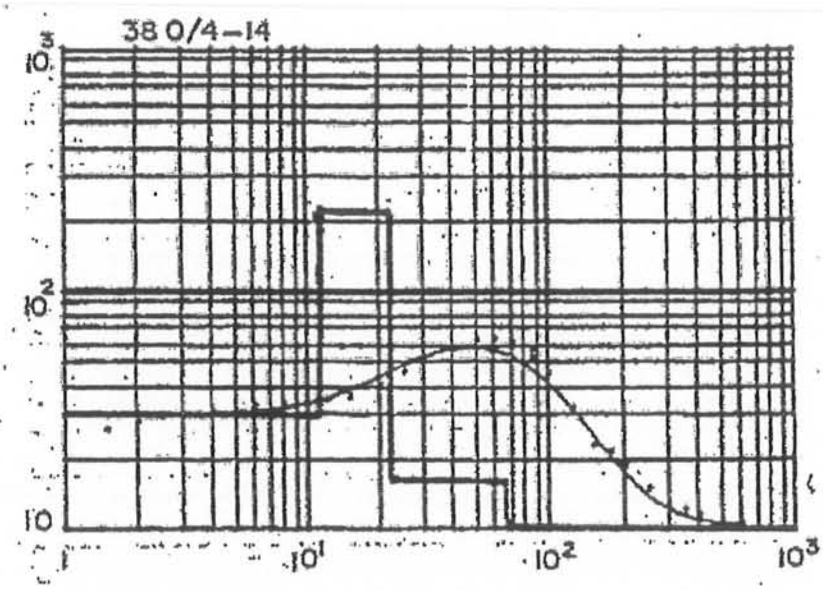

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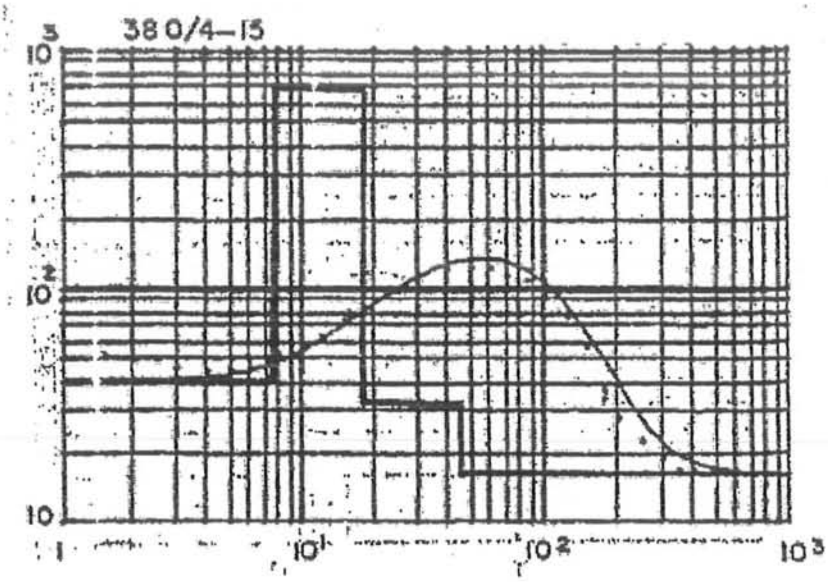
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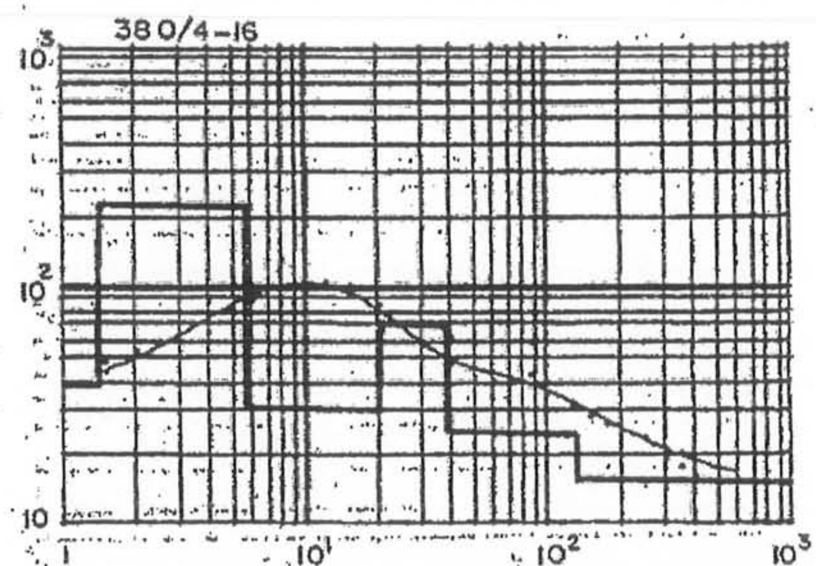
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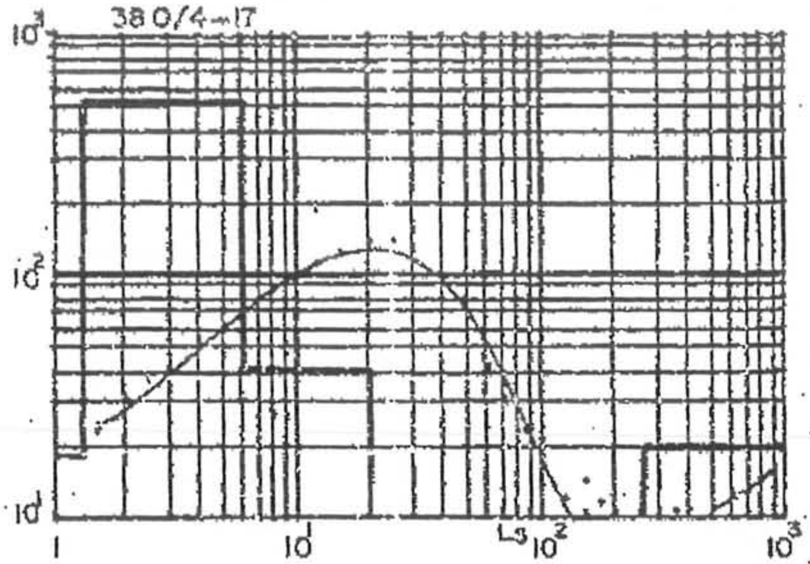
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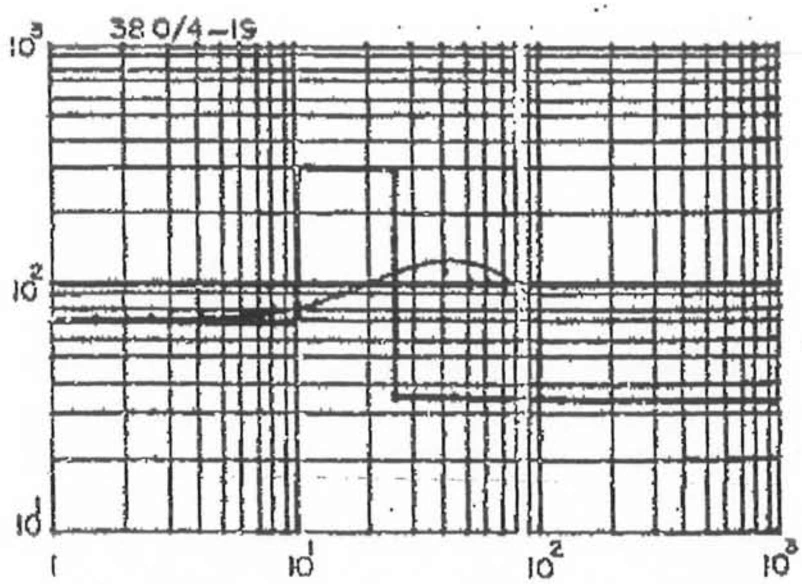
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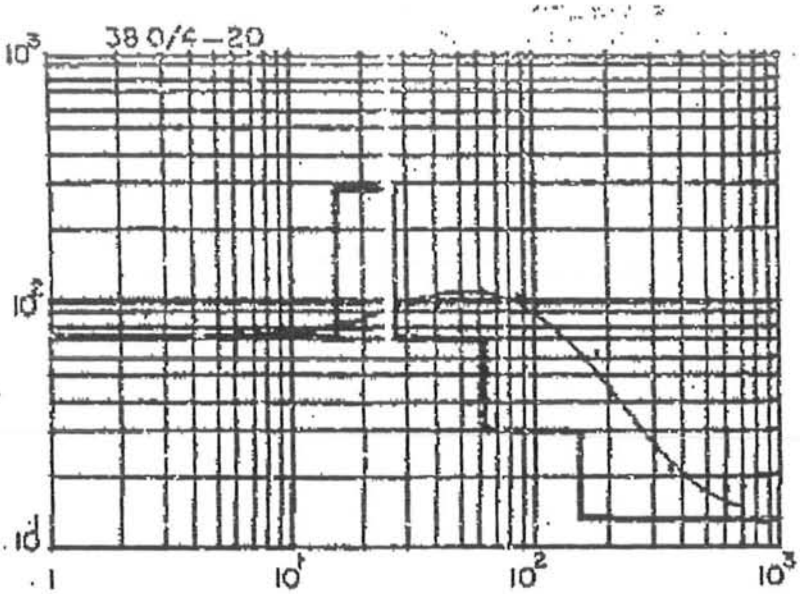
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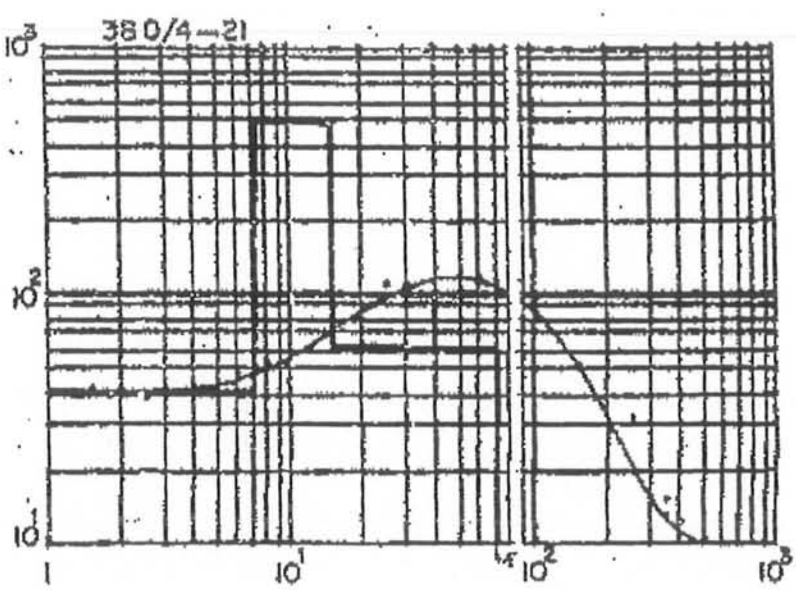
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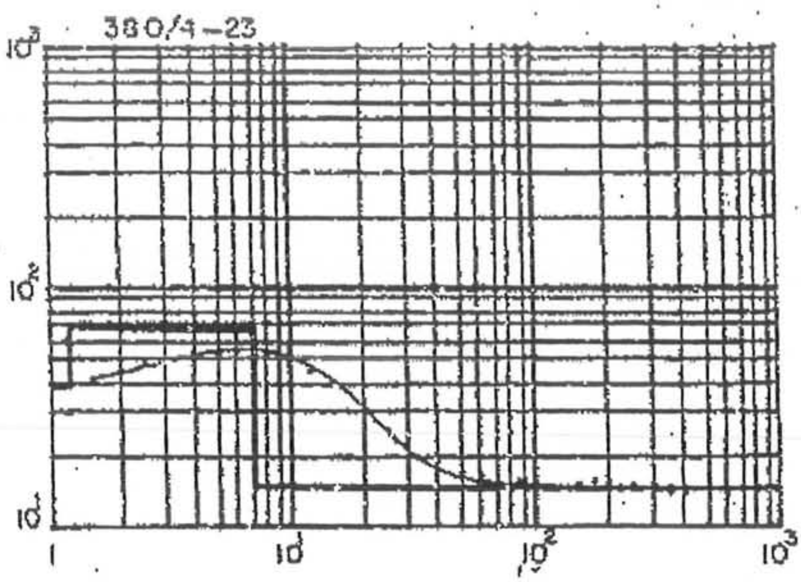
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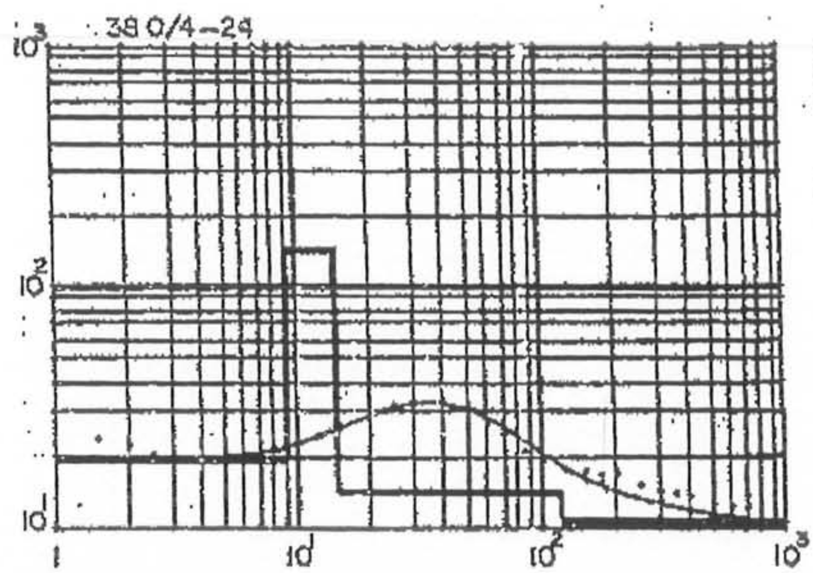
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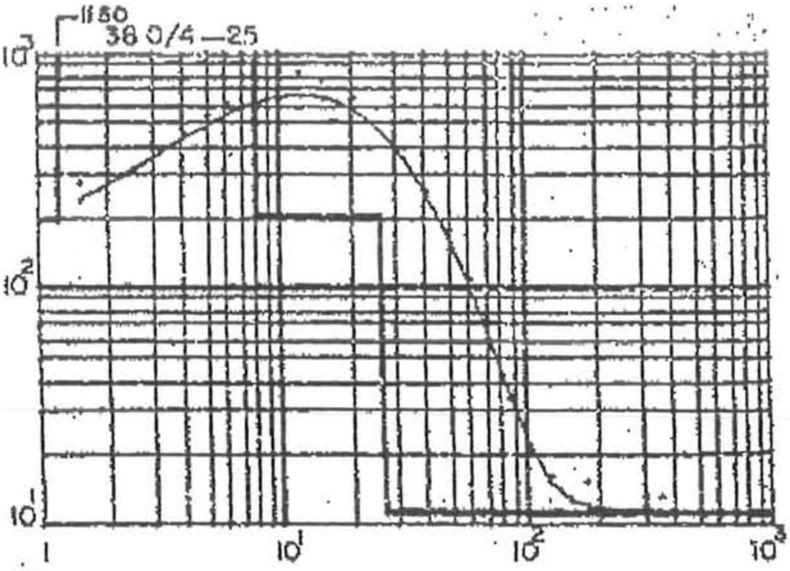

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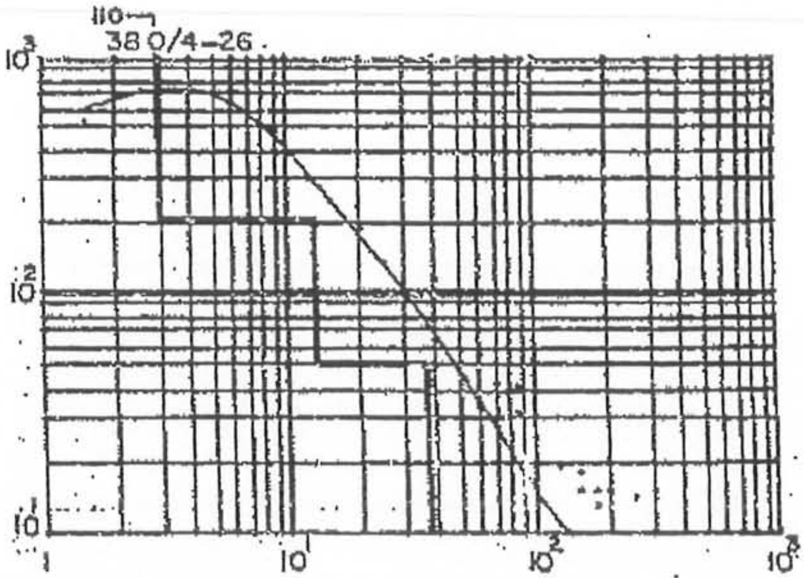

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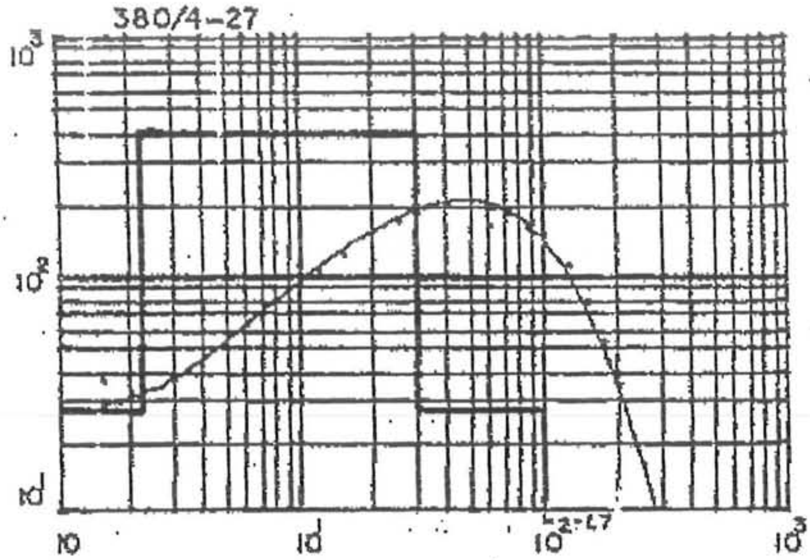

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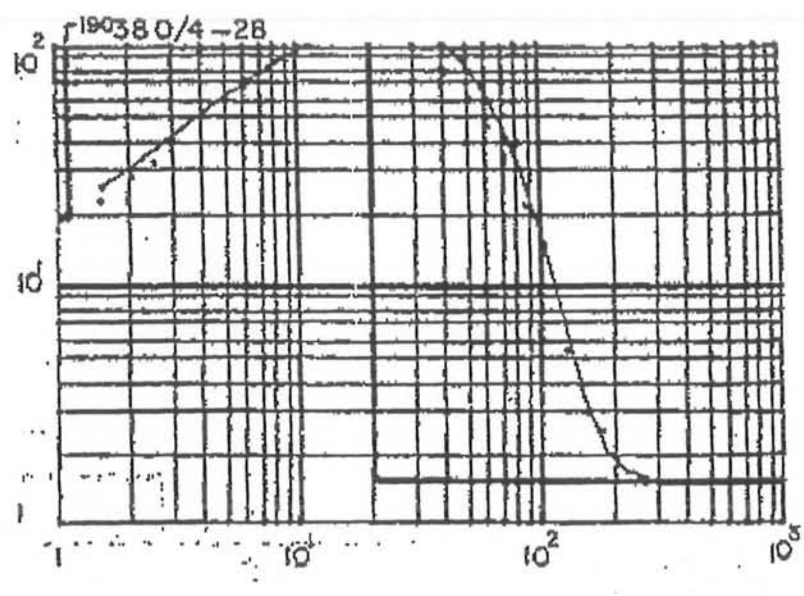

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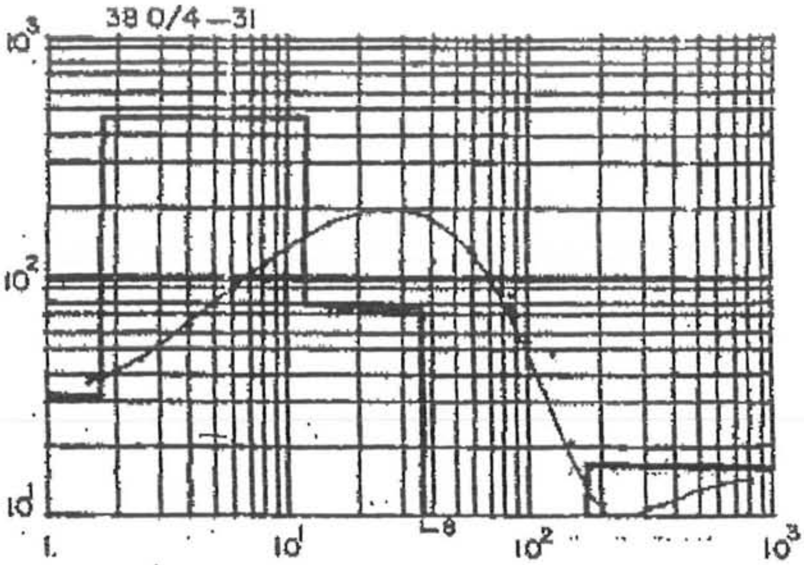
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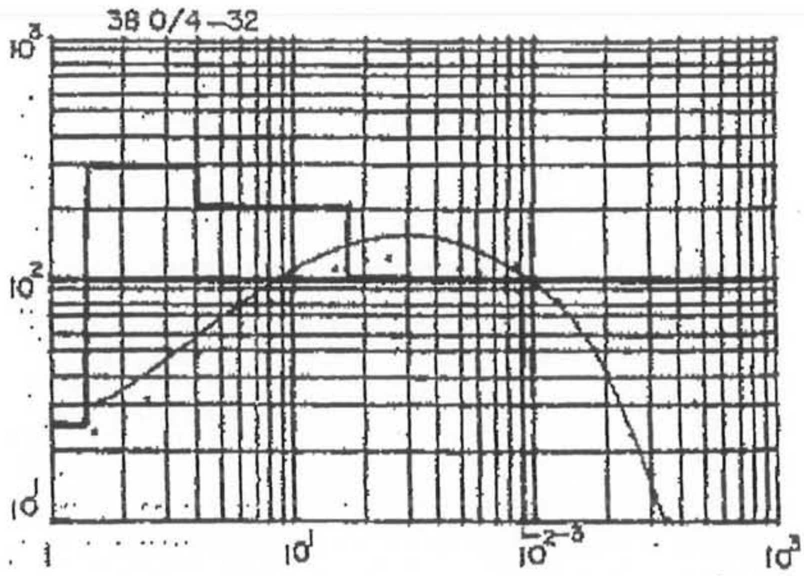
└8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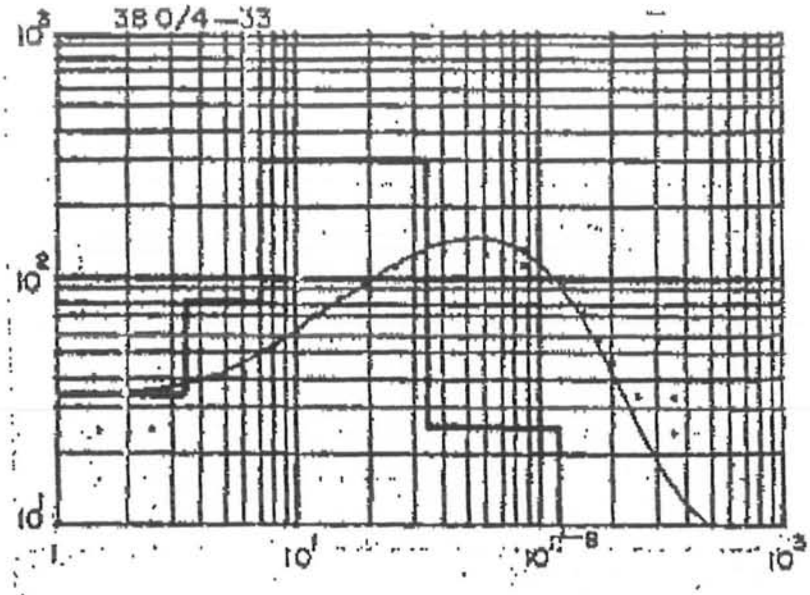
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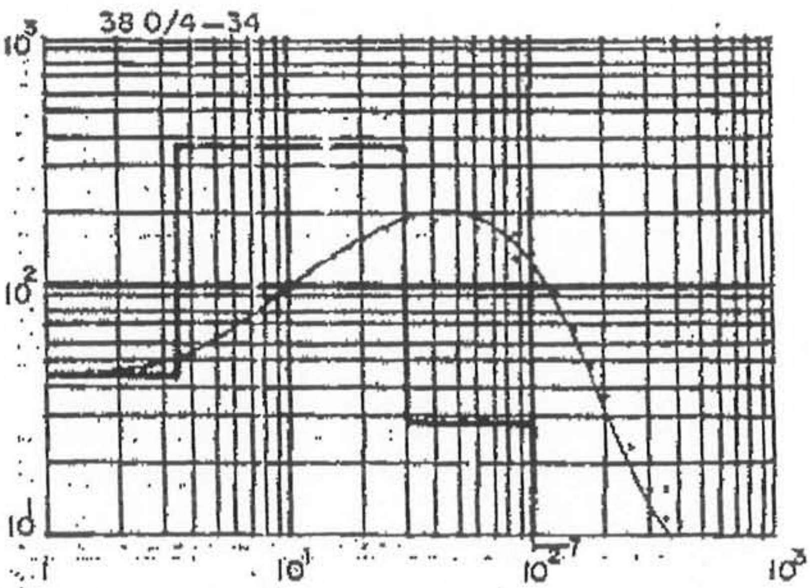
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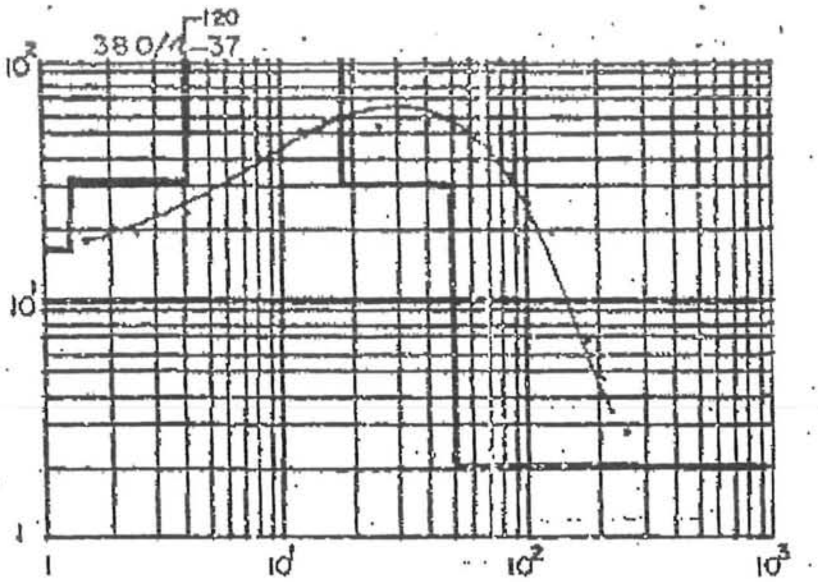
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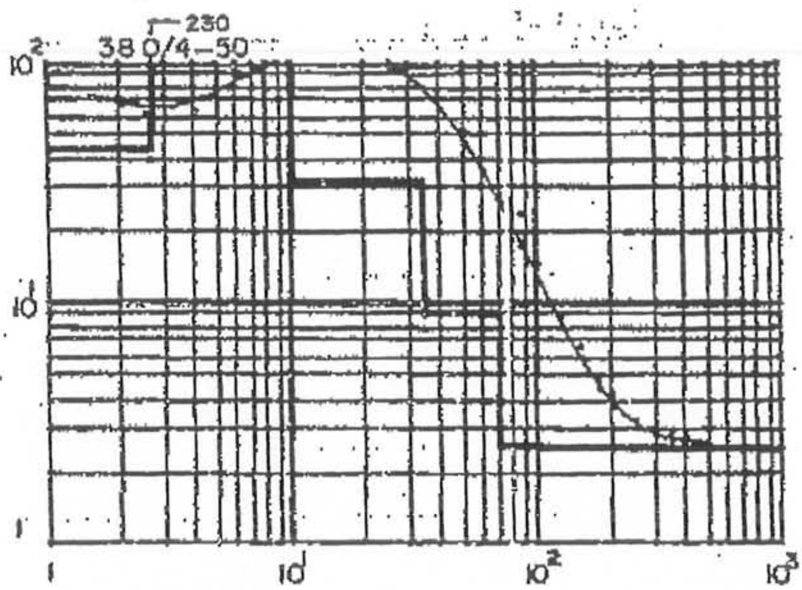
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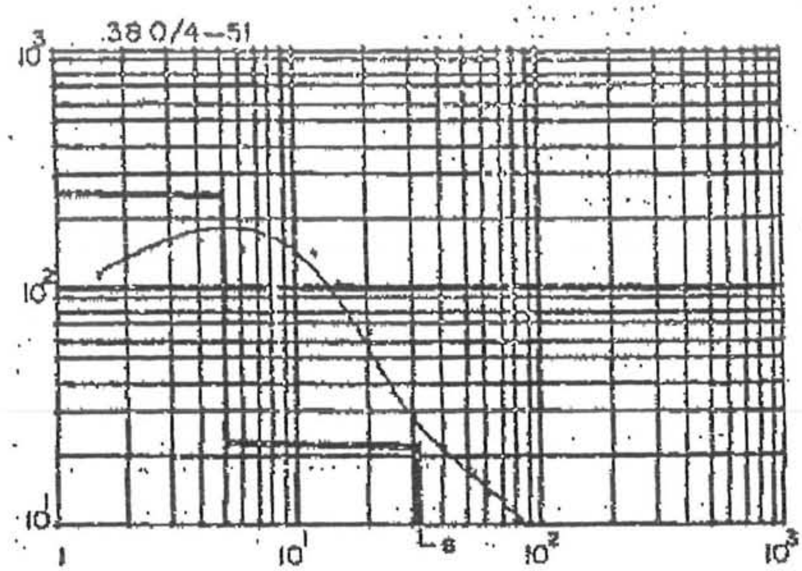
10²
10³


380/4—51
10^3
10^2
10^1
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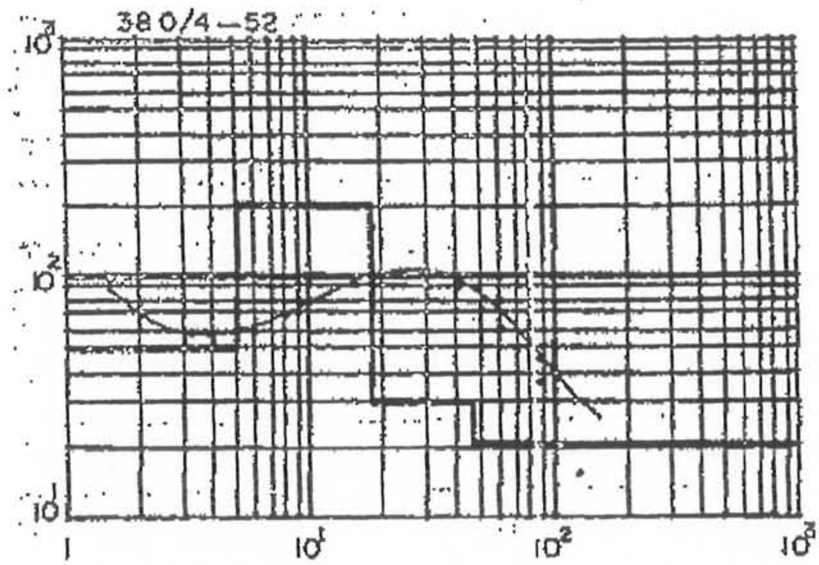
10^1
10^2
10^3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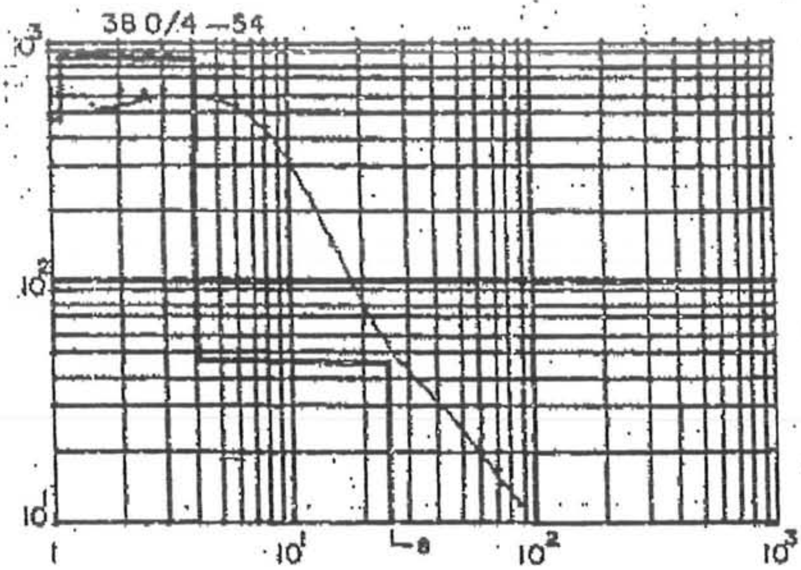
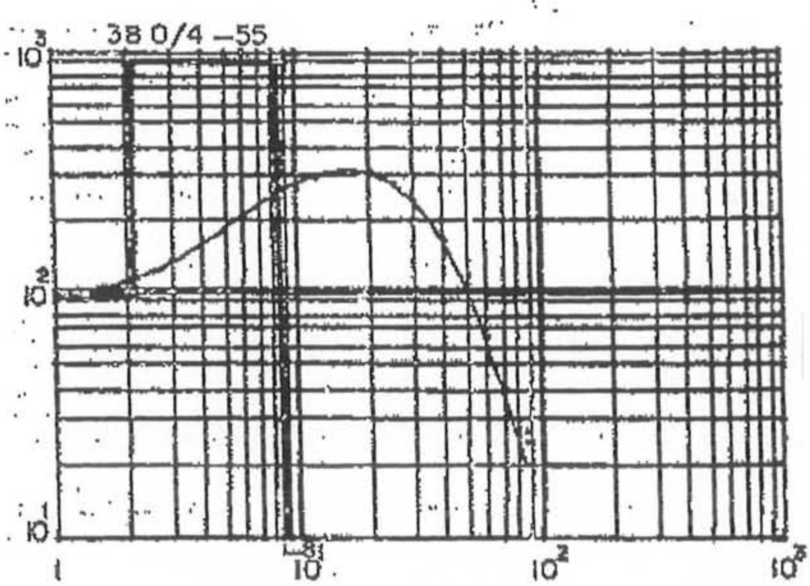
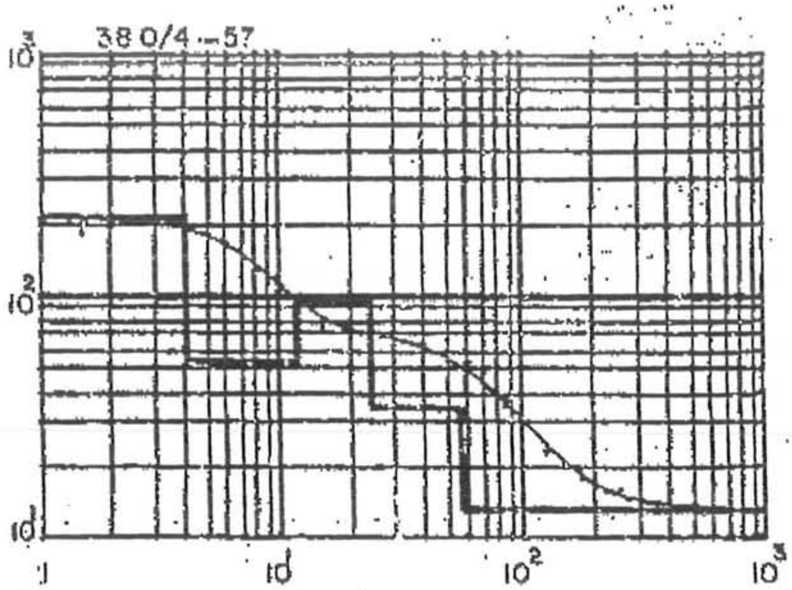
10^2
10^1
1
10^1
10^2
10^3



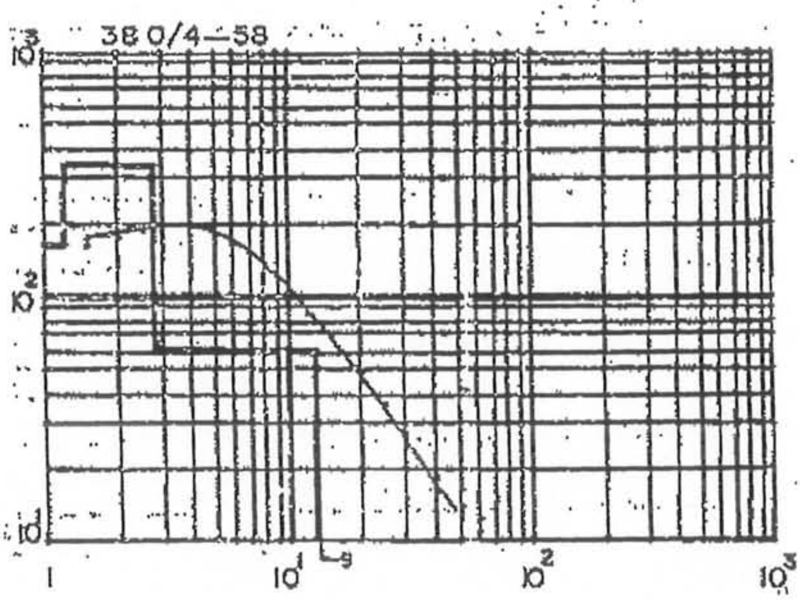
38 0/4 —54
10^3
10^2
10^1
1
10^1
L8
10^2
10^3



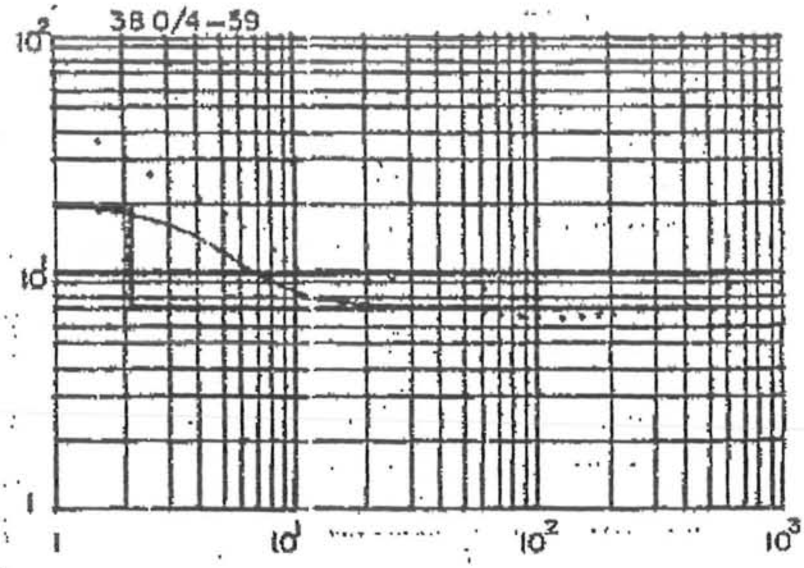
38 0/4 —55
10^3
10^2
10^1
1
10^1
10^2
10^3



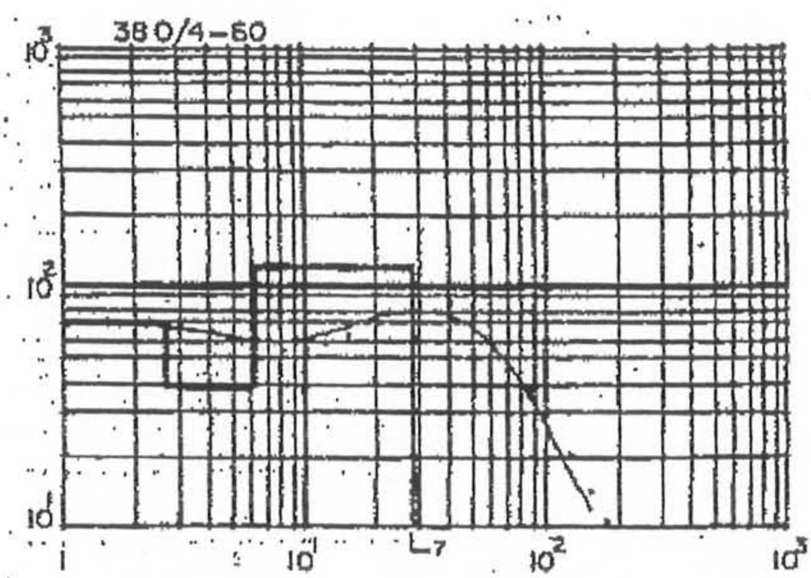
38 0/4-57
10^3
10^2
10^1
1
10^1
10^2
10^3



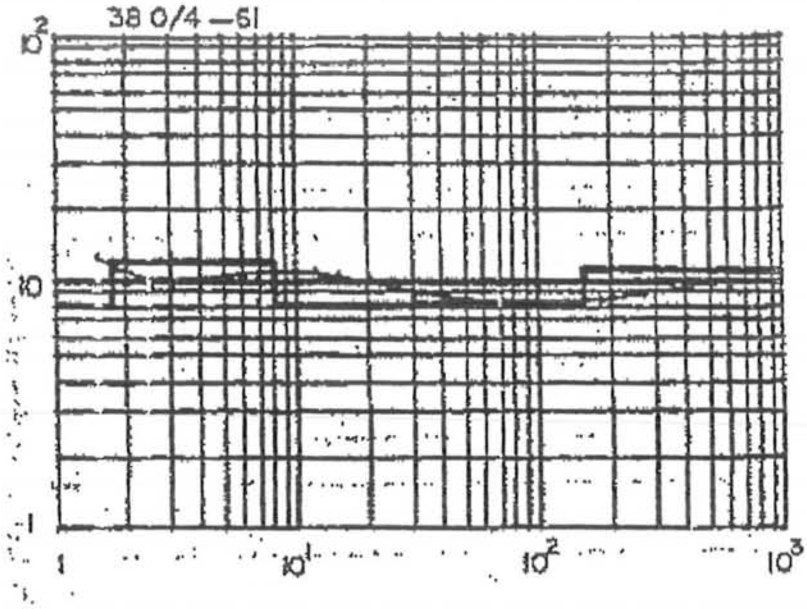
38 0/4-58
10^3
10^2
10^1
1
10^1
10^2
10^3

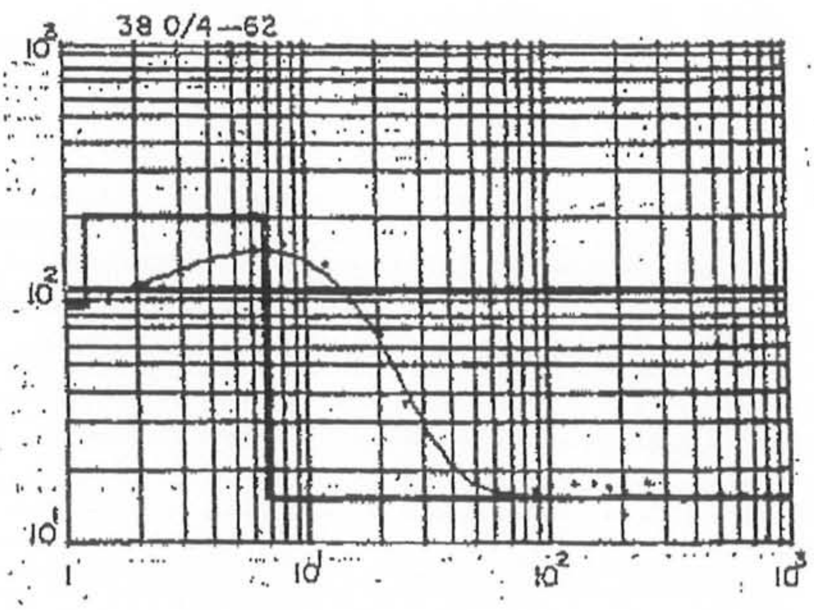


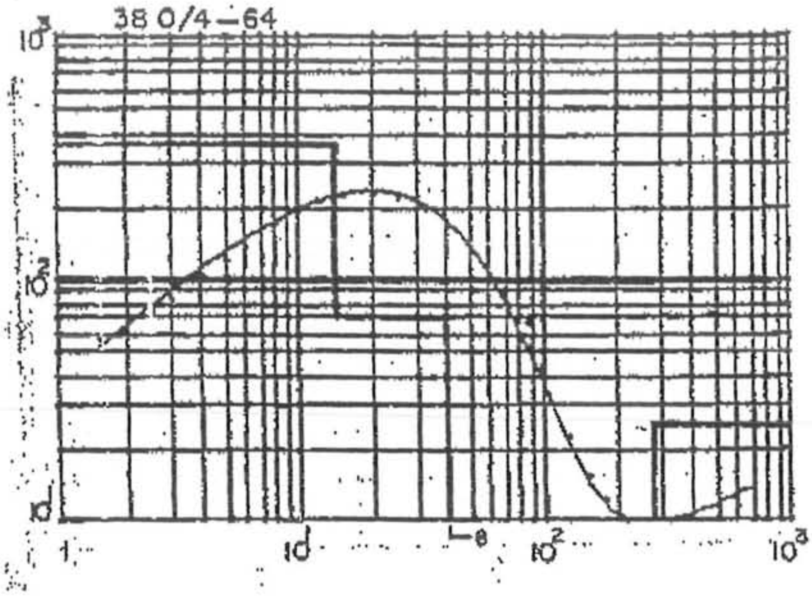
380/4-59
10²
10¹
1
1
10¹
10²
10³

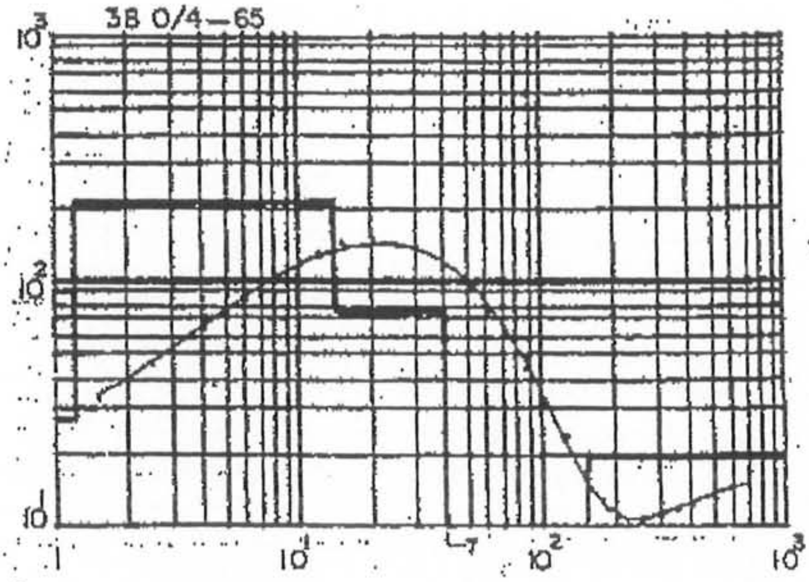


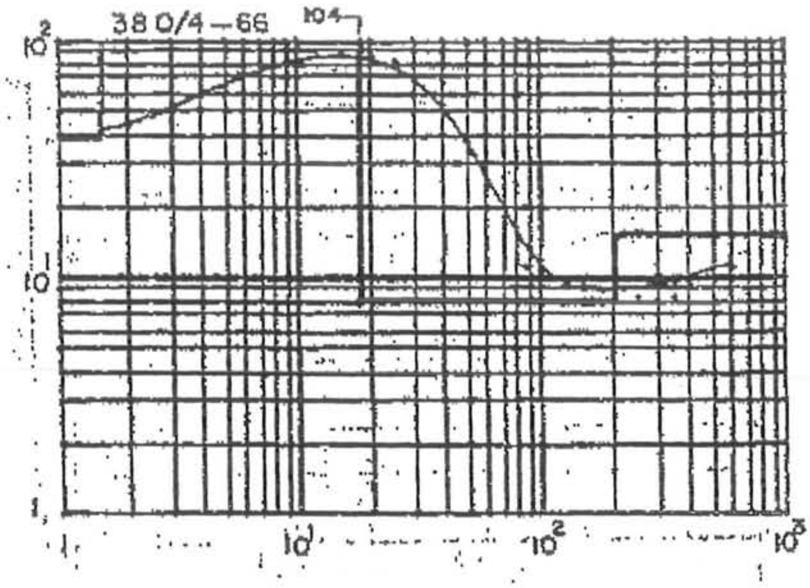
380/4-60
10³
10²
10¹
1
10¹
L7
10²
10³

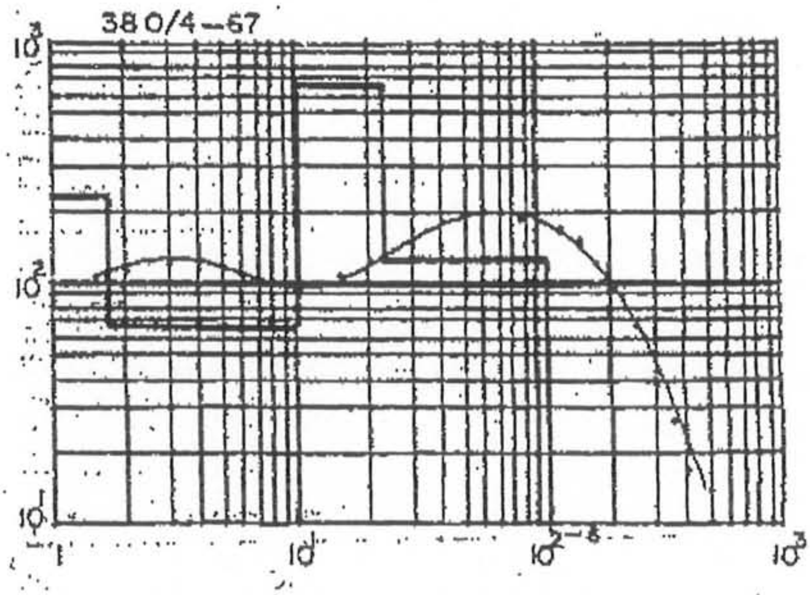

38 0/4 —61
10^2
10
1
1
10^1
10^2
10^3

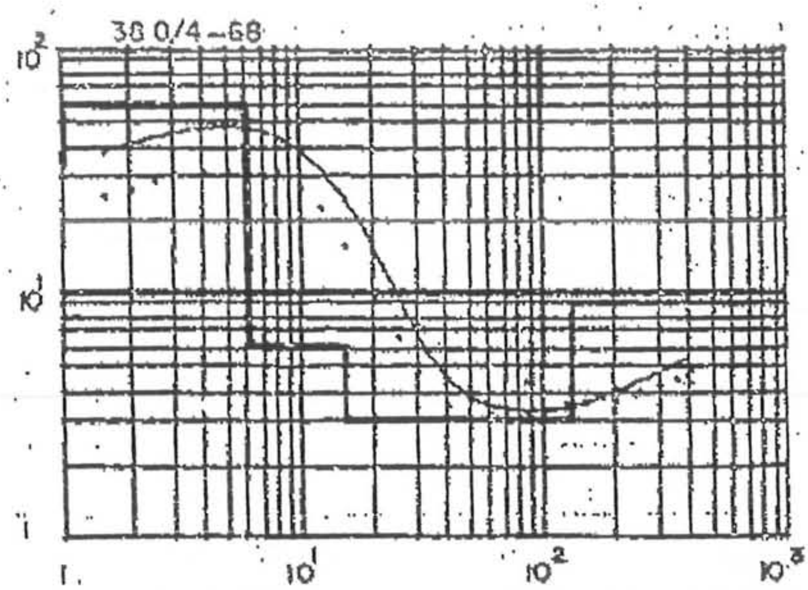

38 0/4 —62
10^3
10^2
10^1
1
10^1
10^2
10^3


38 O/4-64
10^3
10^2
10^1
1
10^1
10^2
10^3
└8

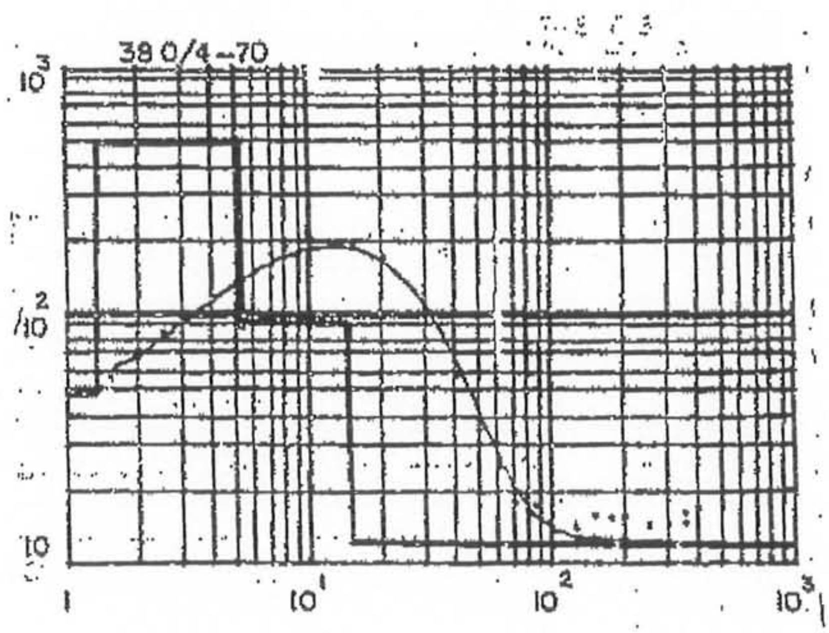

38 O/4-65
10^3
10^2
10^1
1
10^1
10^2
10^3
└7


38 0/4—66
10⁴
10²
10¹
1
10¹
10²
10³

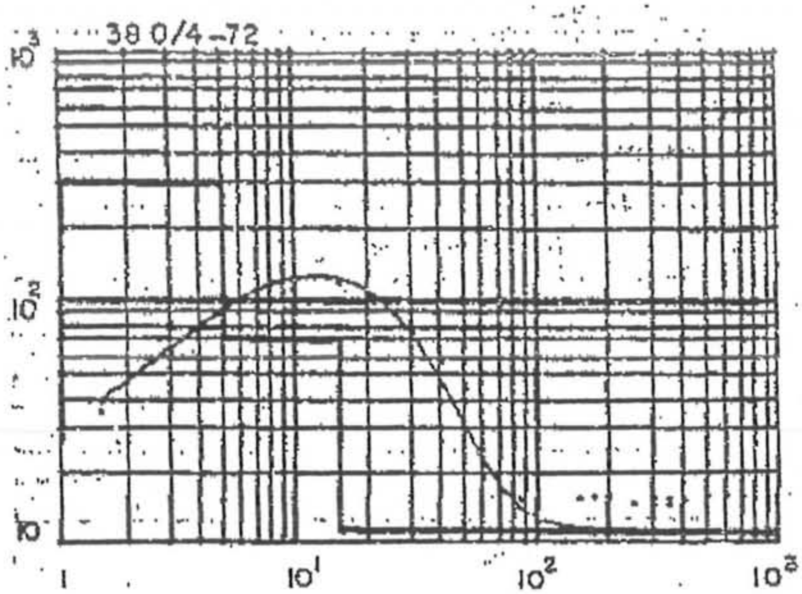

38 0/4—67
10³
10²
10¹
1
10¹
10²
10³

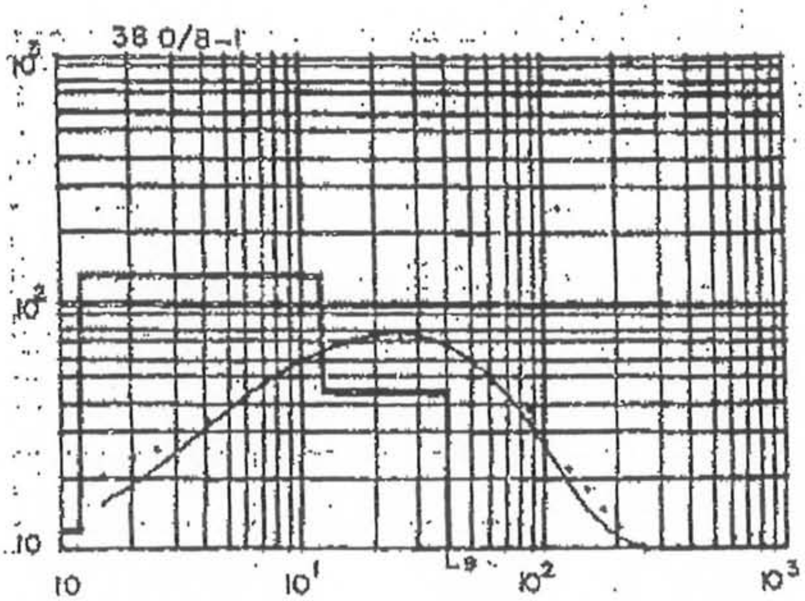


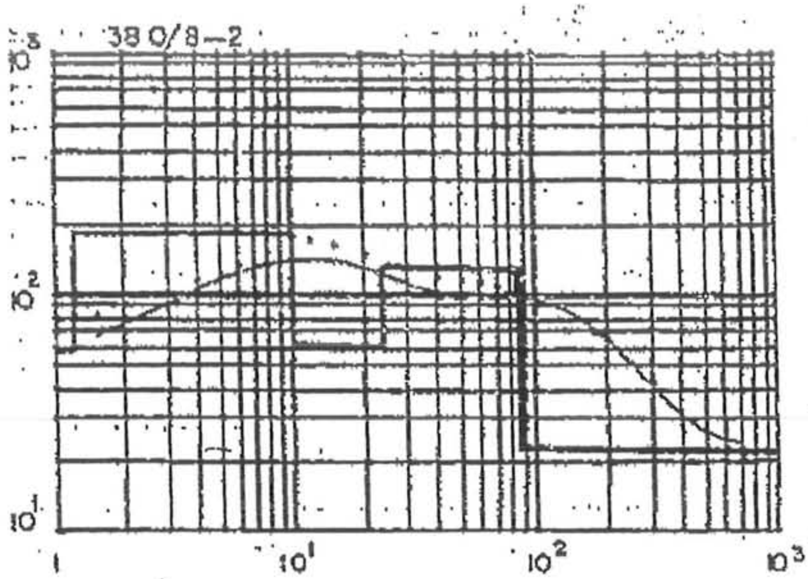
38 0/4-68
10^2
10^1
1
1
10^1
10^2
10^3

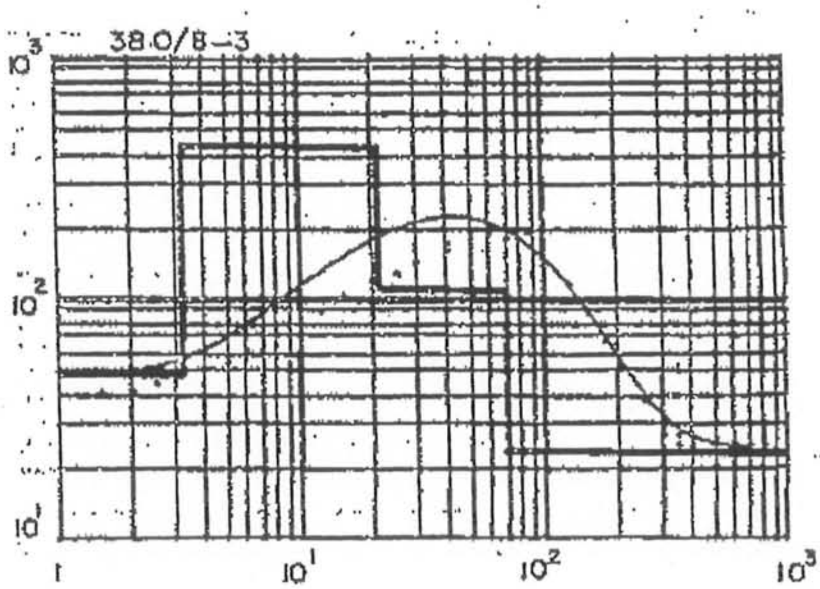


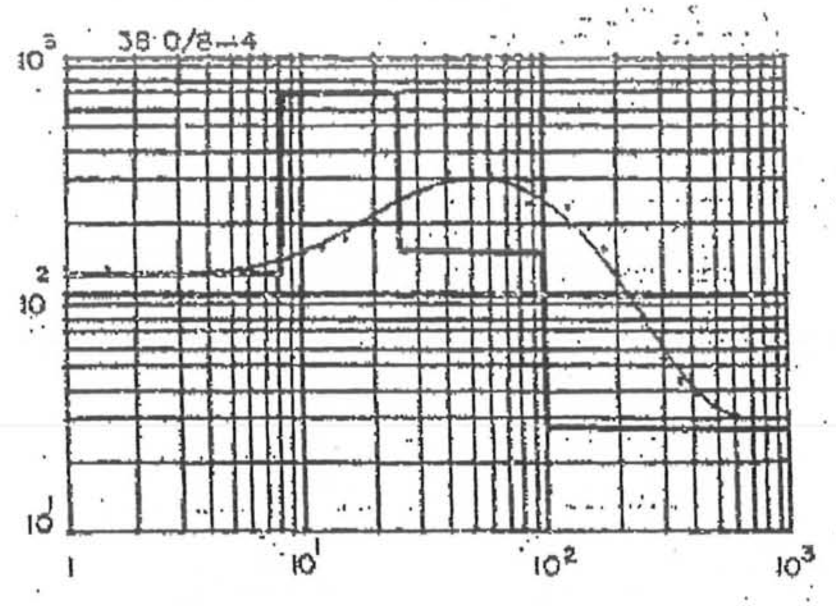
38 0/4-70
10^3
10^2
10
1
10^1
10^2
10^3

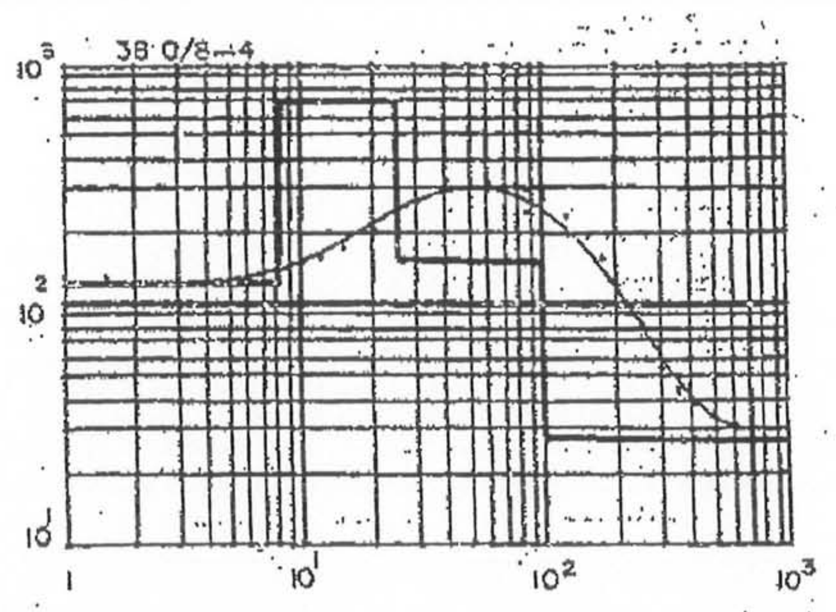

38 0/4-72
10^3
10^2
10
1
10^1
10^2
10^3

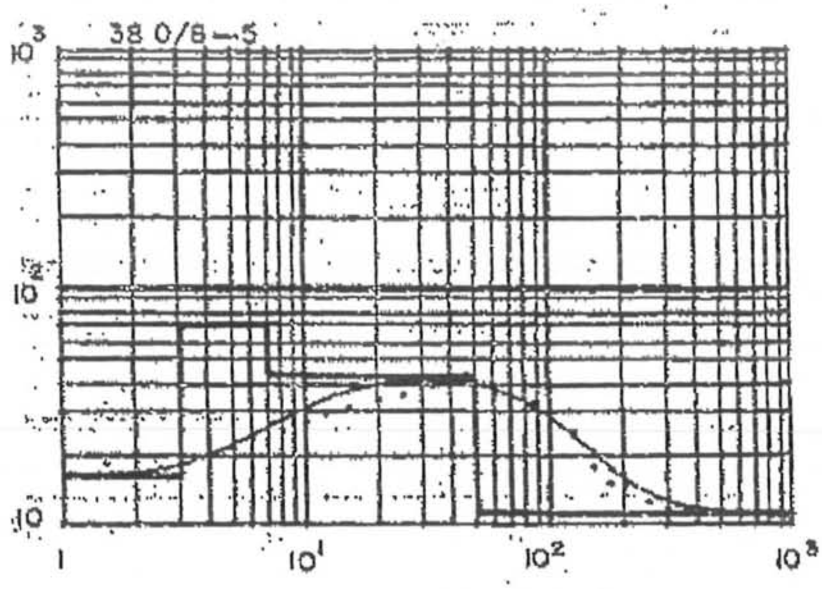

38 0/8-1
10^3
10^2
10
10
10^1
10^2
10^3

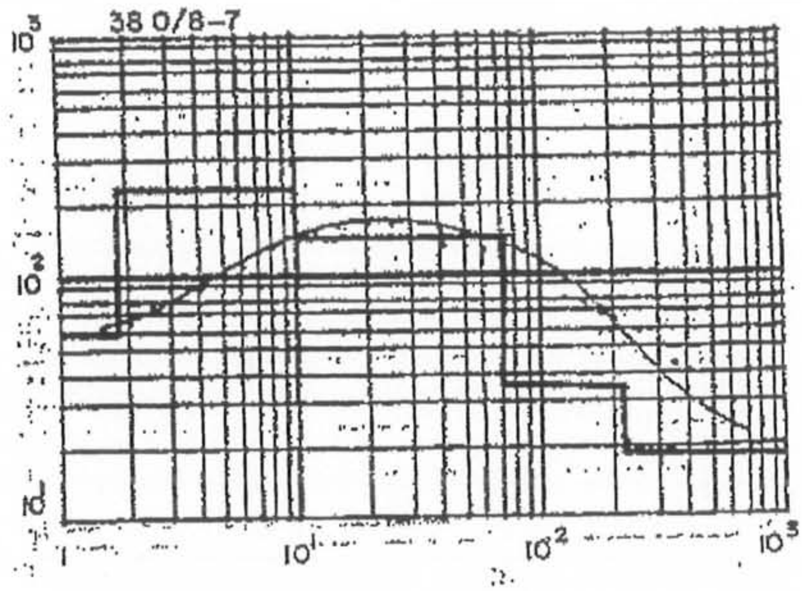

38.0/8-2
10^3
10^2
10^1
1
10^1
10^2
10^3

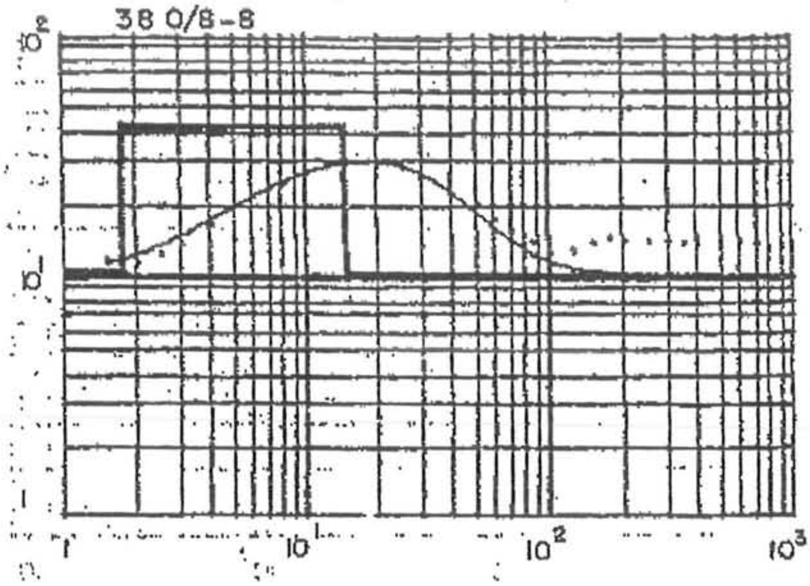

38.0/8-3
10^3
10^2
10^1
1
10^1
10^2
10^3

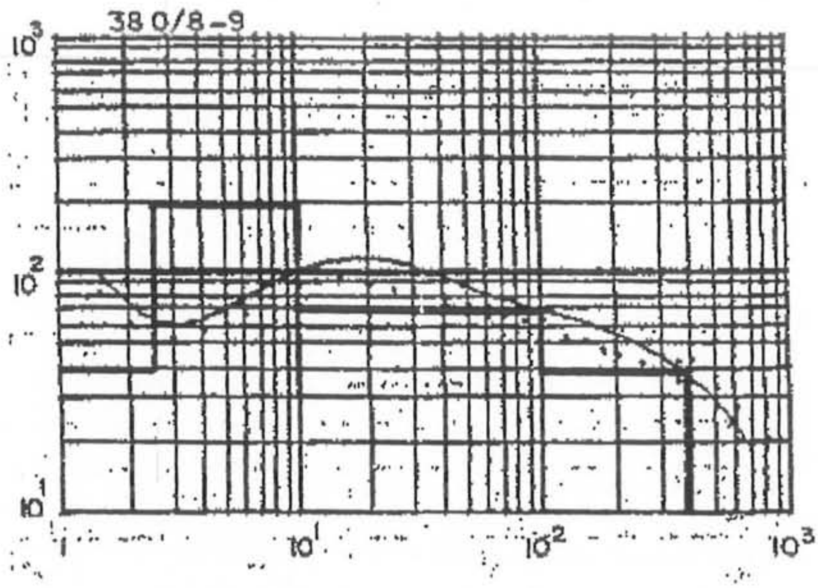

38·0/8→4
10^3
10^2
10^1
1
10^1
10^2
10^3

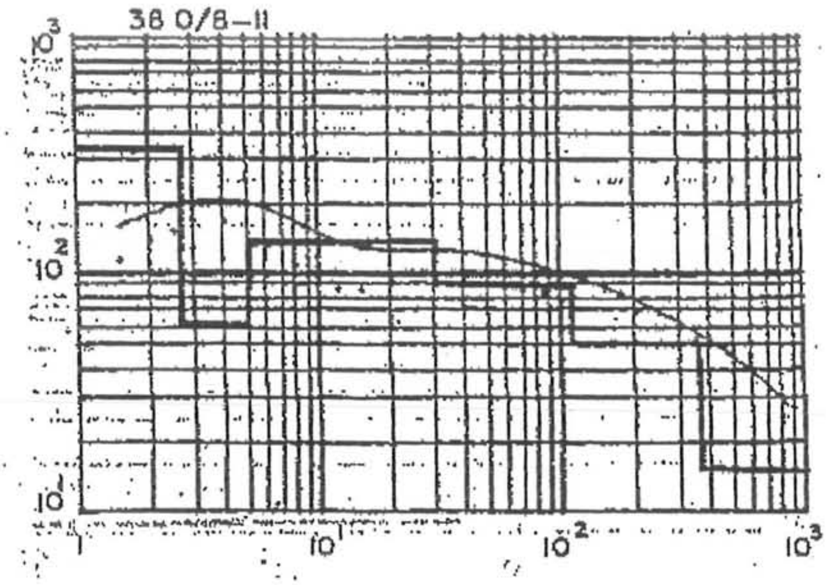

38·0/8→4
10^3
10^2
10^1
1
10^1
10^2
10^3


38 0/8-5
10^3
10^2
10
1
10^1
10^2
10^3

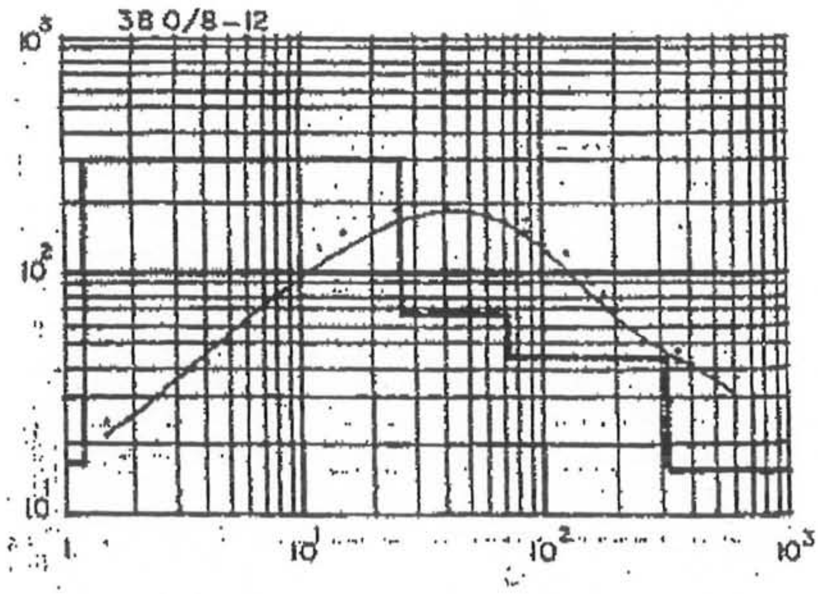

38 0/8-7
10^3
10^2
10
1
10^1
10^2
10^3


38 0/8-8
10²
10¹
1
1
10
10²
10³

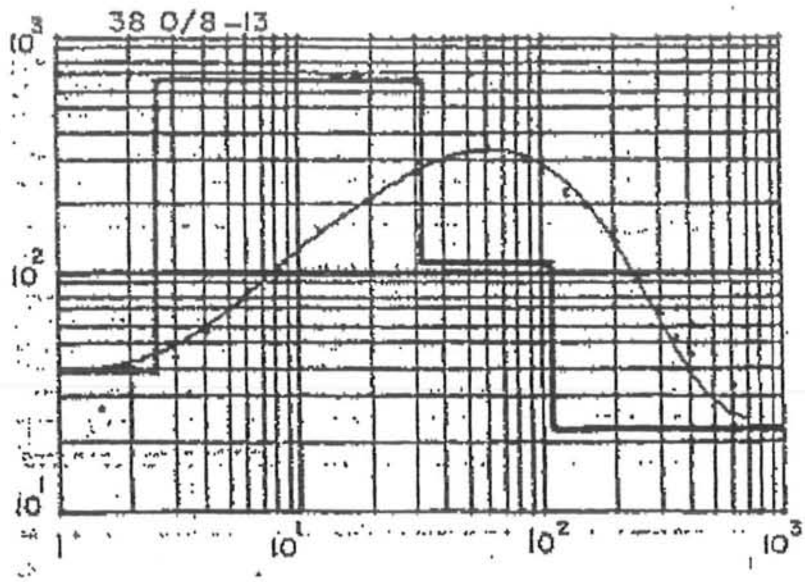

38 0/8-9
10³
10²
10¹
1
10¹
10²
10³

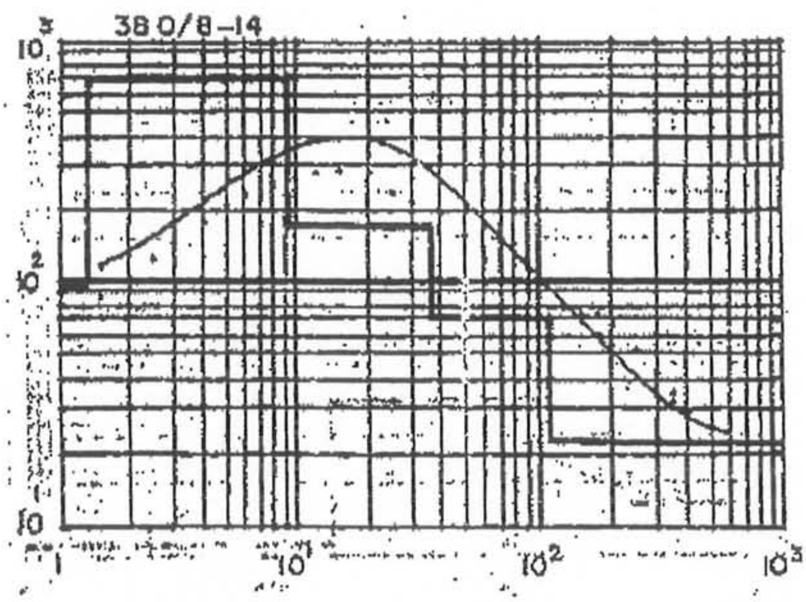


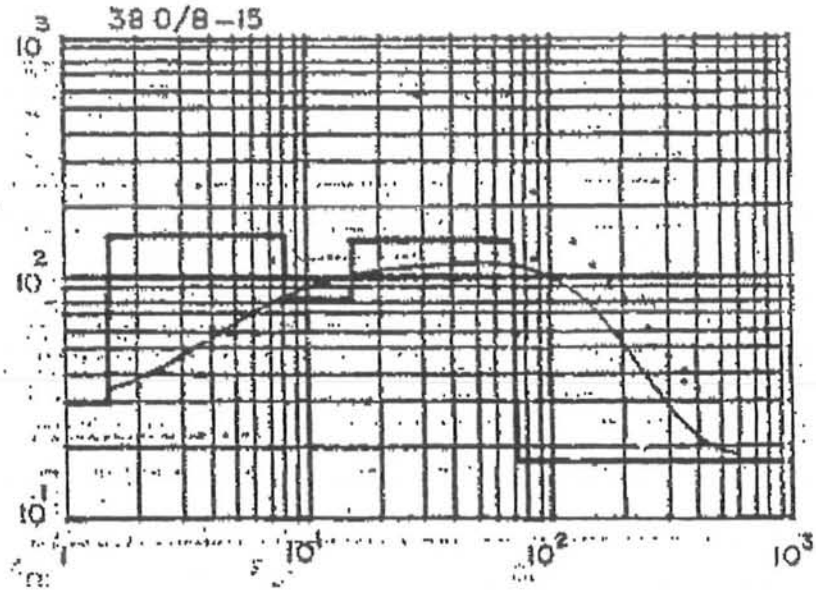
38 0/8-11
10^3
10^2
10^1
1
10^1
10^2
10^3



38 0/8-12
10^3
10^2
10^1
1.
10^1
10^2
10^3


38 0/8-13
10³
10²
10¹
1
10¹
10²
10³


38 0/8-14
10³
10²
10
1
10¹
10²
10³



38 0/8–15
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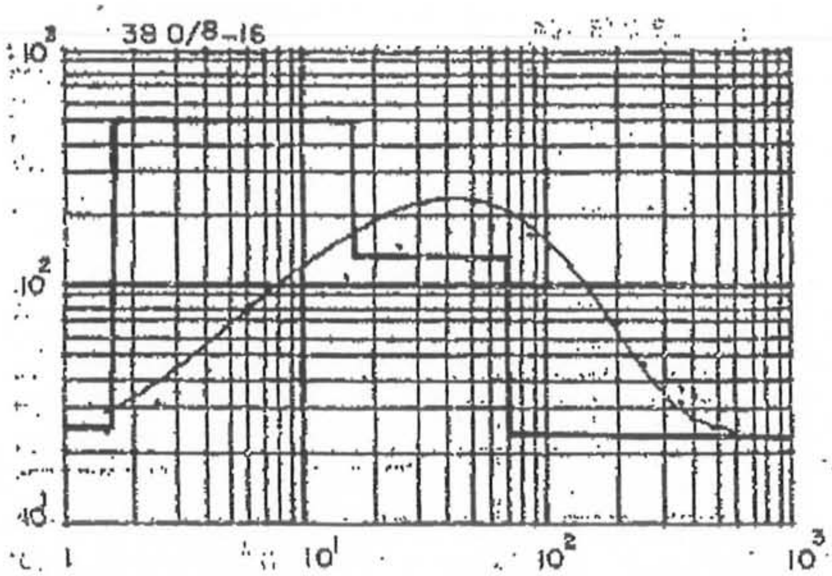
10^1
10^2
10^3



38 0/8–16
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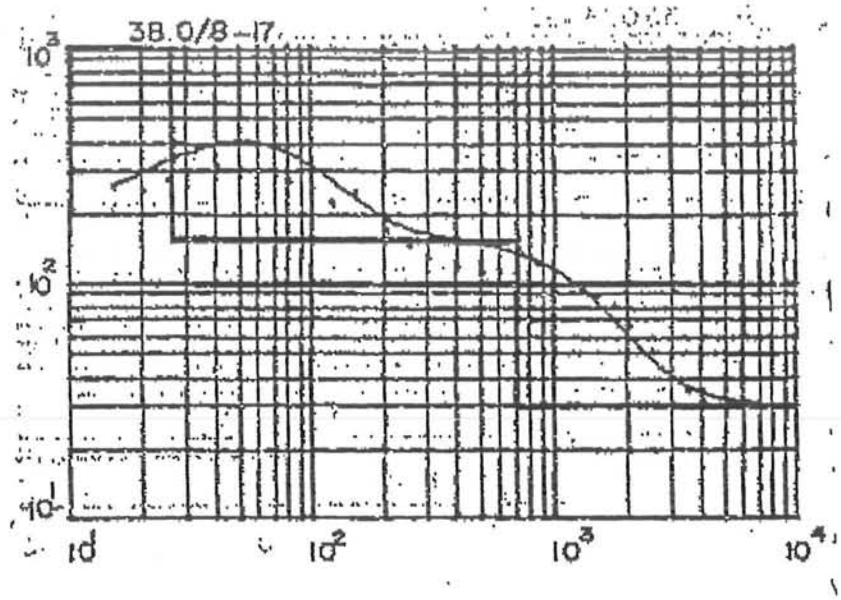
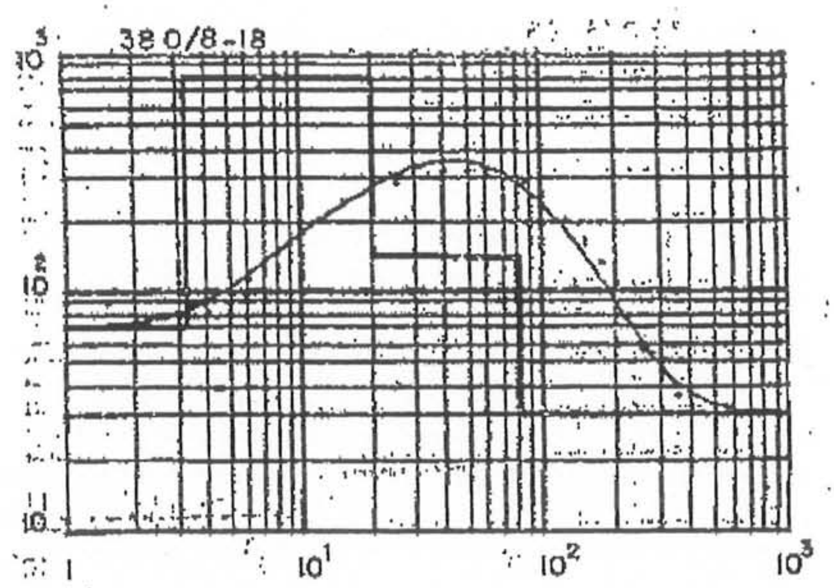
10^2
10
1
10^1
10^2
10^3


38.0/8-17
10^3
10^2
10^1
10^1
10^2
10^3
10^4


38.0/8-18
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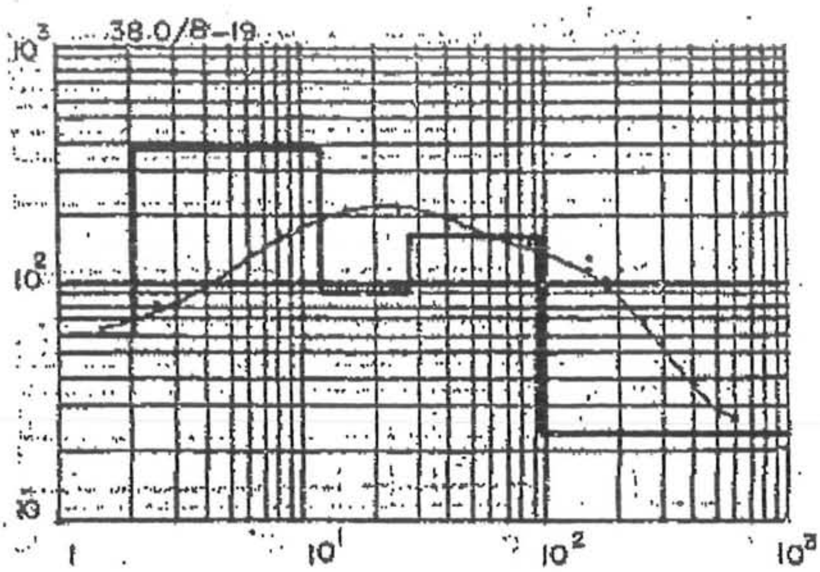
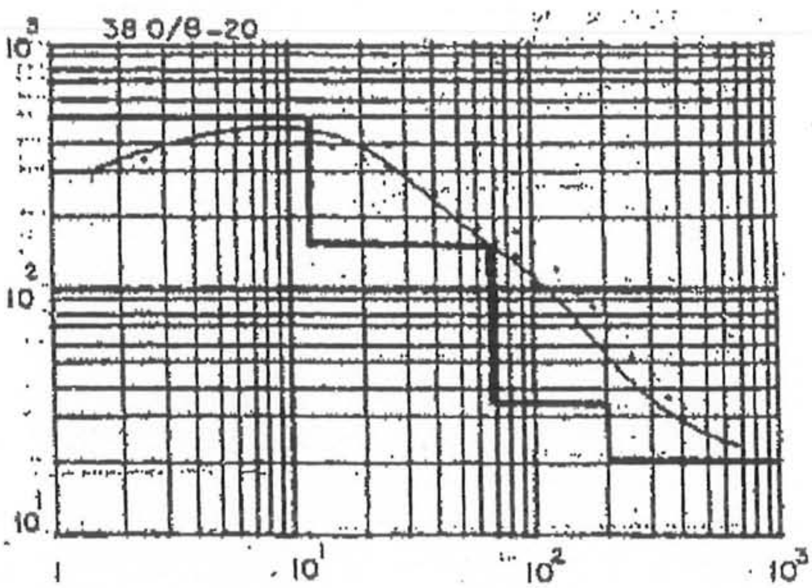
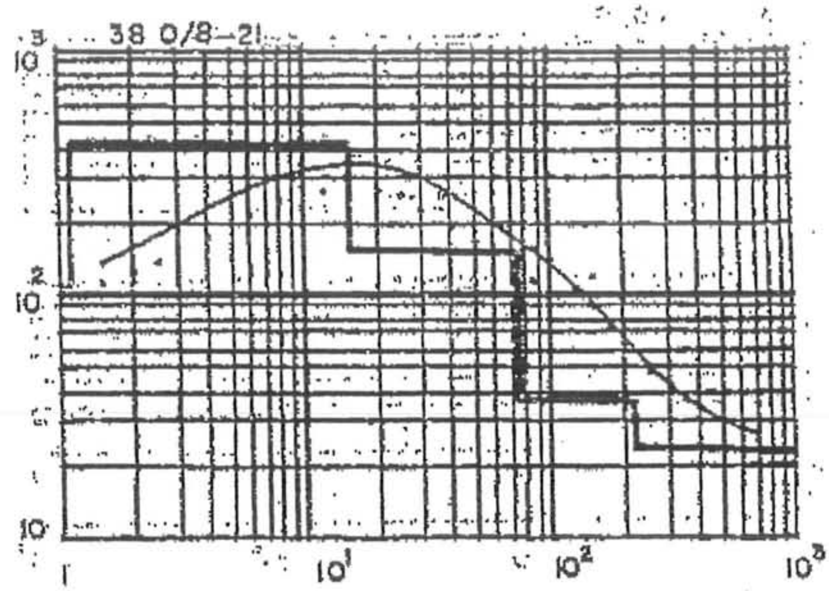
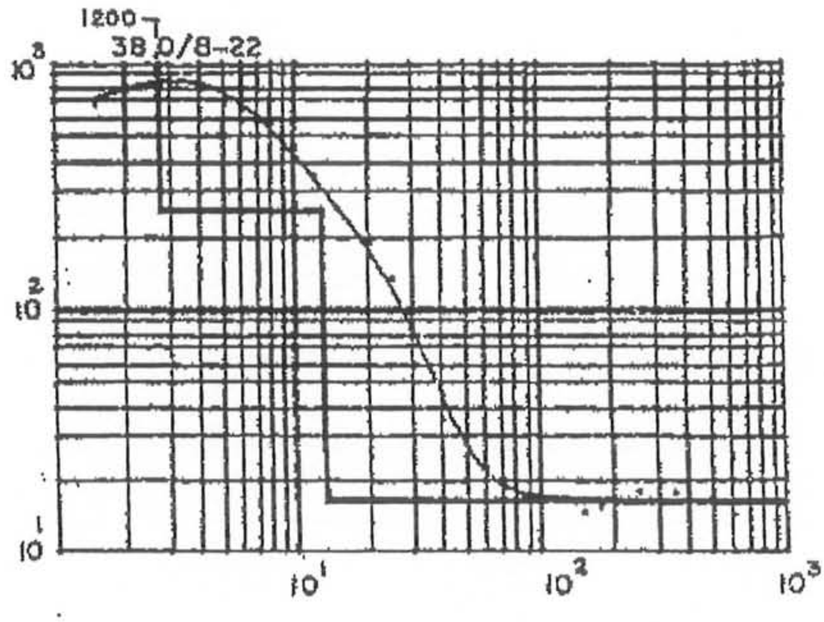
10^2
10
1
10^1
10^2
10^3


38.0/8-19
10^3
10^2
10
1
10^1
10^2
10^3

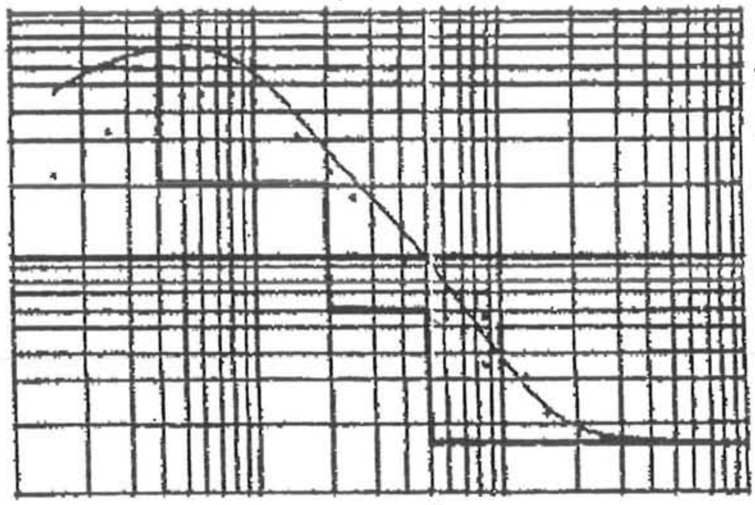

38 0/8-20
10^3
10^2
10^1
1
10^1
10^2
10^3

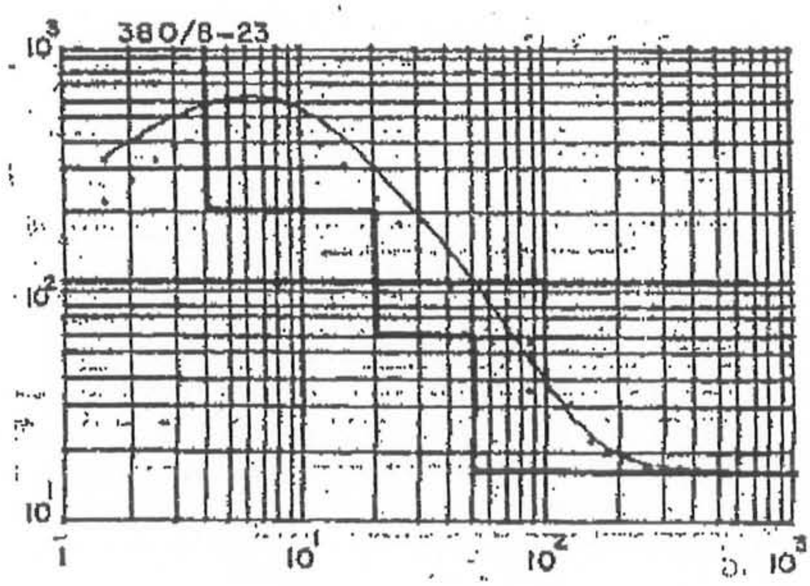


38 O/8-21
10
10
10
1
10
10
10

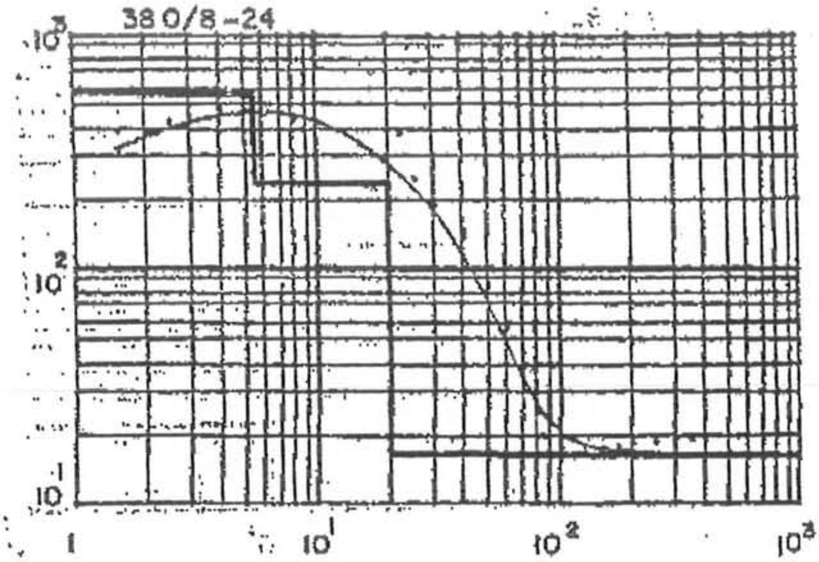


1200
38 O/8-22
10
10
10
10
10
10

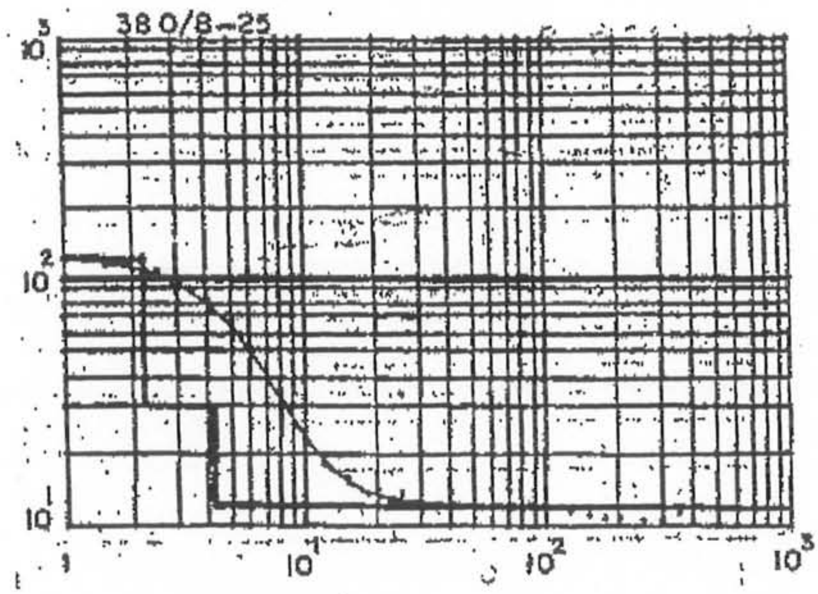




380/8-23
10³
10²
10¹
1
10¹
10²
10³



38 0/8-24
10^3
10^2
10^1
1
10^1
10^2
10^3



38 0/8-25
10^3
10^2
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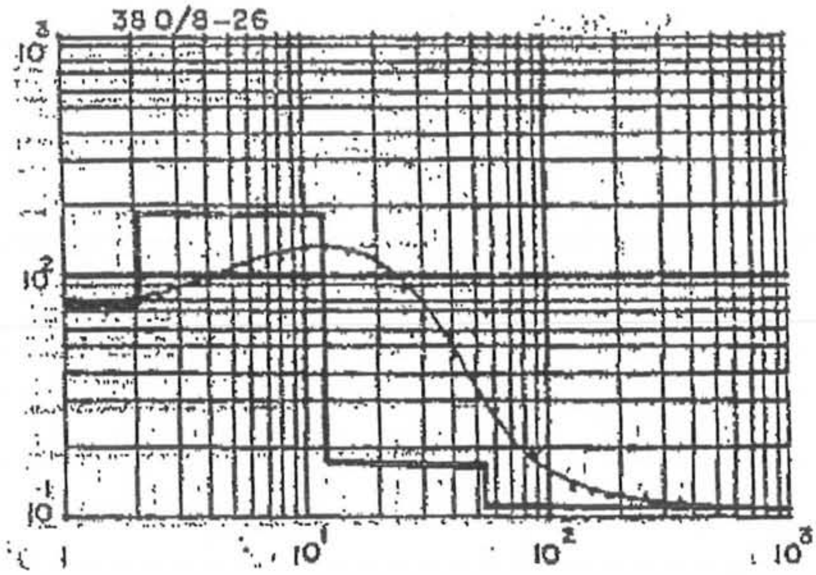
1
10^1
10^2
10^3



38 0/8-26
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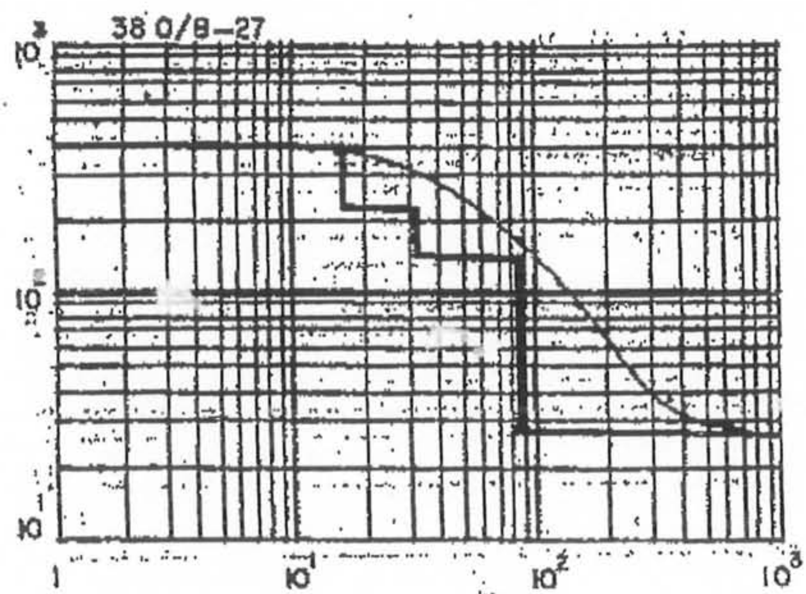
1
10^1
10^2
10^3



38 0/8-27
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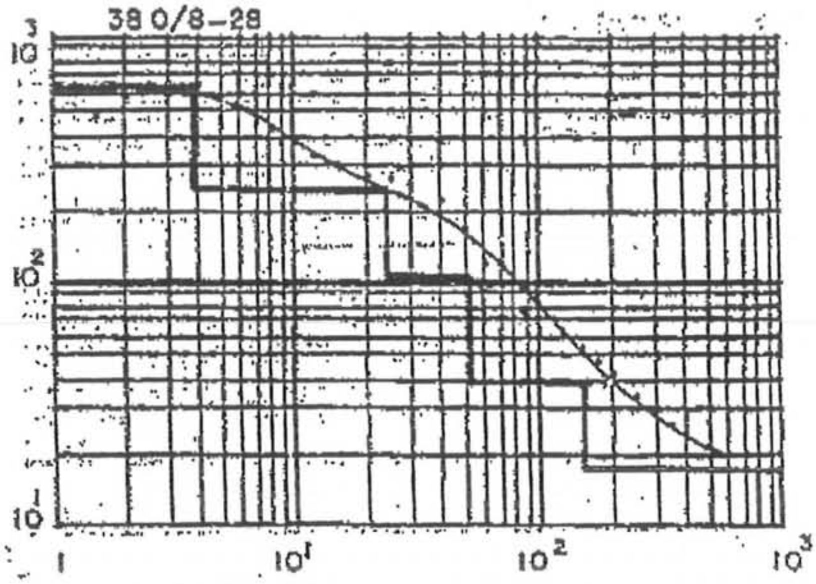
10^2
10^1
1
10^1
10^2
10^3



38 0/8-28
10^3
10^2
10^1
1
10^1
10^2
10^3

Figure: C-1

HYDROGEOLOGY DIRECTORATE		WAPDA PESHAWAR	
area : KARAK village : Dohda Khel district : KARAK GWL ordered by: WAPDA operator : IMTIAZ interpretation : IMTIAZ	GWL No.: 1982-1-12 date : 5-5-1982 SP: spontaneous potential sn/SN: short normal (20/40 cm) ln/LN: long normal (100/200 cm) ρ_{e} mud = 12 Ωm ; ρ_{m} mud = 11 Ωm	mapsheet : 38 o/4 co-ordinates: y/x grid borehole No.: KR-WA-4 owner's No. : GWL 1982-1-12 drilling system: ST. FLUSH depth: 152 m diam.: 18cm	caliper: diameter natural gamma radiation: logging speed: 3 m/min time constant: 5 s sensitivity : 4.7 legend Peshawar 1981