Application of Electrical Resistivity Method to Investigate Sub-surface Geology with Special Reference to Hafizabad Reclamation Area.

By

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Introduction

The land of West Pakistan is faced with two major problems of great magnitude and intensity, complete solution to which has not so far been found because the study of the problems is still in the research stages. These problems are salinity and water-logging. In some areas of the former Punjab, which are mainly irrigated by canals, a rise in the water-table has been observed owning to seepage through canals and irrigation by canal waters. Earth behaves just like an empty bowl into which water is poured. A stage is reached when there is no room for more water and if added, it overflows. If water be added to the underground reservoirs and there is no way to take this water out, a stage may reach when the sub-surface reservoir is completely filled and the water appears on the surface ; thus causing water-logging. This rise in water level in the ground may also bring some salts, causing the salinity effect on surface of the soil.

This rise in the sub-soil water-table and in some places the appearance of water on surface has been mainly due to :—

(*i*) Rainfall ;

(*ii*) Canal irrigation system ;

(*iii*) Flooding by rivers ;

(*iv*) Soils in lower areas having low permeability.

For reclamation of land from water-logging and salinity effects, it is necessary to know the sub-surface geology of the area under reclamation so as to know the main controls on the movement of the sub-surface fluids.

Electrical Resistivity survey was conducted in Hafizabad Reclamation Area for the purpose of delineating the sub-surface geology. The survey was conducted by the author in the month of January, 1958 along with the electrical resistivity survey along Rechna Test Line-C. Such electrical resistivity surveys are a part of the investigations by the Ground Water

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Development Organization, which is dealing with the investigations and survey for evaluation of the Ground Water resources of the previous Punjab with a view to control the Ground Water levels in the water-logged and saline area as well as the efficient development and utilization of available Ground Water supplies.

The Hafizabad area under investigation is located between the Lower Chenab Canal (from near R.D. stone 105 to R.D. stone 163) and Kot Nikka Branch (upto R.D. stone 60) and the area lying on the right side of the Kot Nikka Branch. The exact location map with the resistivity stations marked on it is shown in fig. 1.

The area investigated is mainly saline (thur) and water-logged. There are quite a good number of drains running in the area. The surface material of the area may roughly be called loams, silt and sand loams. The distribution of surface salinity as observed and as picked up from aerial photograph mosaics is approximately shown in fig. 2.

Earth Electrical Resistivity Technique :

Geophysics offers indirect aid to geologist and mining engineer such as the discovery of faults where one region has moved up or down or sideways with respect to another region ; the detection of dikes thrust up by igneous action ; the location of the depths to 'discontinuities' or 'material changes'; the finding of the concavity of an underground layer or syncline, of its convexity in the anticline; in short, the elucidation of many of the complexities beneath the earth which the geologist has so patiently and skilfully deduced from observations of out-crops and sections, or from the interpretation of fossil remains and of chemical constituents. The geophysicist can only detect a discontinuity where one formation differs sufficiently from another.

The various methods of geophysics used to detect these discontinuities of the underground are Magnetic, Electrical, Electromagnetic, Gravitational, Siesmic and a few others like Sound Reflection, Radioactive Measurements and Temperature gradients.

Electrical method pertaining to earth resistivity is discussed here.

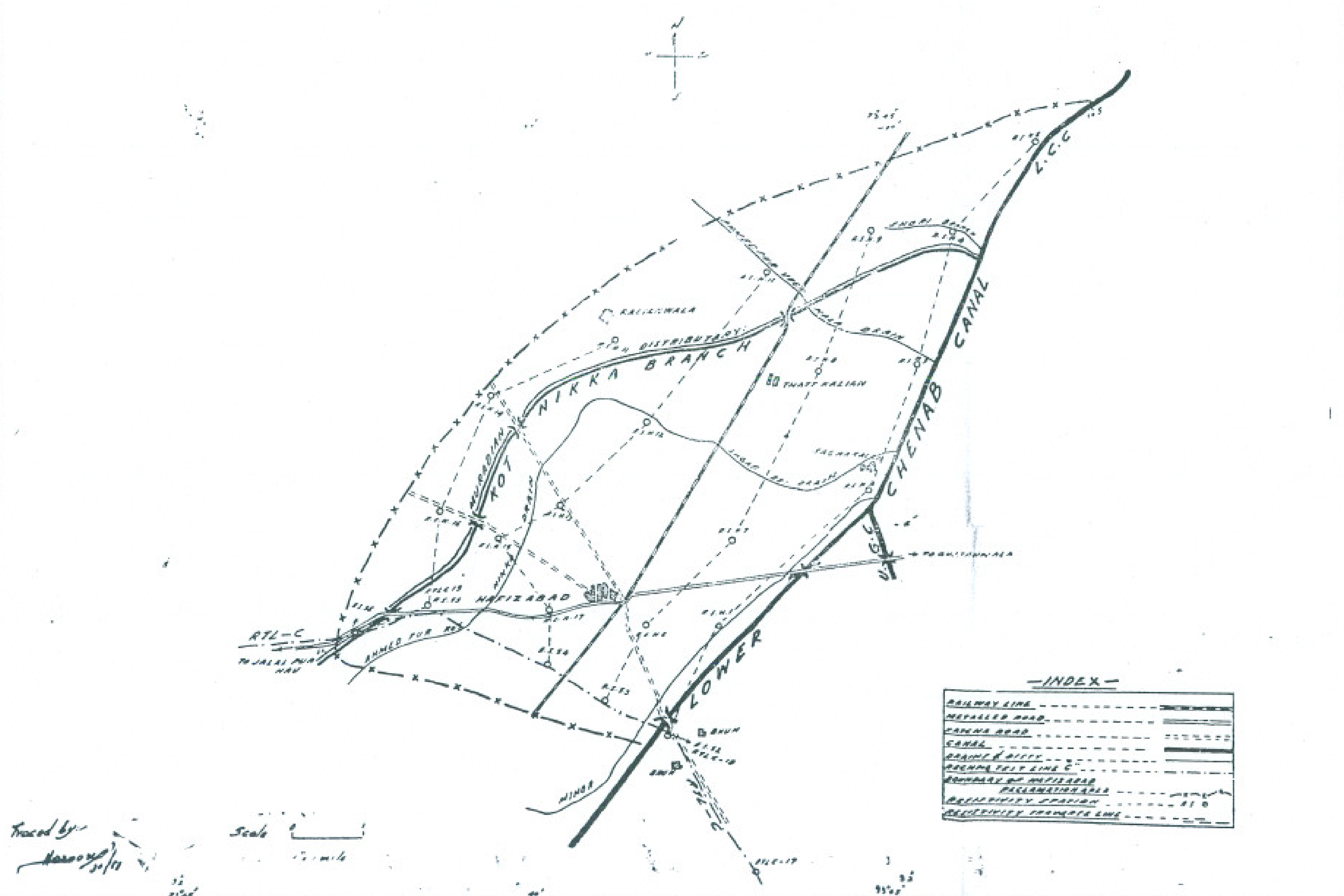
Electrical and telegraphic engineers have long been familiar with the fact that the earth acts as a conductor for electric currents ; and have recognized the importance of the nature of soil in which a ground contact was made. Since different strata, ores, etc., usually have characteristic electrical resistivities, the importance of such measurements is evident. The basis of the measurement is the well known law :

$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}}$$

and although both voltage drop and current are usually small in earth circuits, there appears to be no difficulty in measuring these quantities, and deducing the resistance as the ratio of the two.

-FIG: 1-

LOCATION MAP OF HAFIZABAD RECLAMATION AREA SHOWING RESISTIVITY STATIONS & A PORTION OF RECHNA TEST LINE C'



-FIG: 2-

PLAN OF HAFIZABAD RECLAMATION AREA SHOWING SALINITY (Thur) EFFECTS AT SURFACE BASED ON THE AERIAL PHOTOGRAPHIC MOSAICS OF TOPO SHEETS 43 H/12, 43 H/16

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If at the surface of the (homogeneous and isoropic) ground of the conductivity G, an electric current 'I' is introduced by means of two point electrodes, C_1 and C_2 and if the current flows from C_1 to C_2 the potential at the potiential at any point P_1 on the surface is

$$V_{P_1} = \frac{I}{2\pi G}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (I)$$

where r_1 and r_2 are the distances of the point P_1 from the electrodes C_1 and and C_2 respectively. The potential difference between two points P_1 and P_2, which have distances r_1, r_2 and R_1, R_2 respectively from the electrodes is

$$V_{P_1} - V_{P_2} = V = \frac{I}{2\pi G}\left(\frac{I}{r_1} - \frac{1}{r_2} - \frac{I}{R_1} + \frac{1}{R_2}\right)$$

Hence the resistivity

$$\rho = \frac{1}{G} = 2\pi \frac{V}{I} \frac{1}{\left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{R_1} + \frac{1}{R_2}\right)} \quad \ldots\ldots\ldots\ldots (2)$$

The equation holds for any position of the current electrodes C_1 and C_2 and the search electrodes P_1 and P_2, and does not change when current and potential electrodes are interchanged. Differences in the position of the search electrodes with respect to the current electrodes give rise to various resistivity methods. By selecting definite dispositions, it is possible to simplify the field procedure or to give the expression for resistivity a form that will simplify the interpretation of the results.

The electrode system often applied and the one used by the author is that of Wenner-Gish-Rooney. In the Wenner-Gish-Rooney method the two potential electrodes are placed on a line with two current electrodes, so that all the four electrodes are situated at equal distance from one another. This is shown in fig 3, with 'a' as the distance between the electrodes. In this configuration,

r_2 and R_1 = 2a.

Then the expression for the resistivity, from equation (2) is

$$\rho = 2\pi \ a \ \frac{V}{I} \quad \text{.........(3)}$$

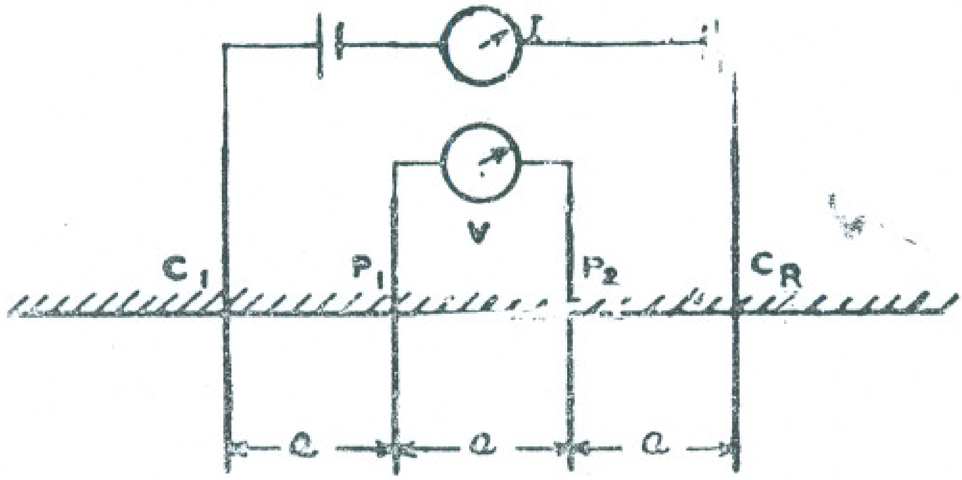


FIG NO 3

If the earth is not homogeneous electrically as is illustrated in fig. 4. the formula no longer gives the true resistivity of any actual formation. The resistivity, as calculated by it, is actually influenced by the actual resistivities of all formation down to the maximum effective depth of penetration. In such a case, 'ρ' value determined according to equation (2) forms the measured V/I ratio and from the factor in brackets dependant on Electrode geometry is known as the apparent resistivity ρ_a.

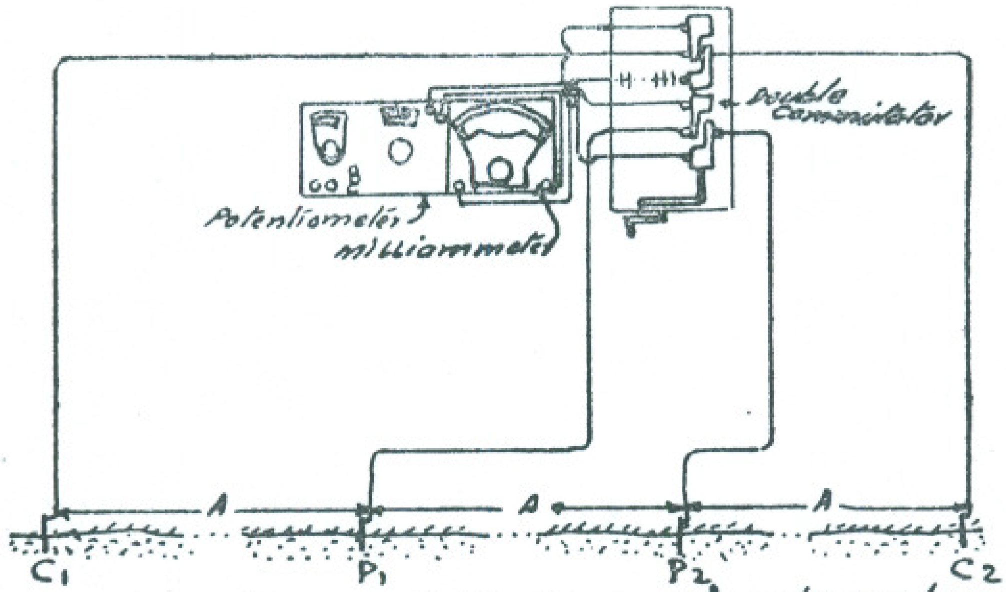
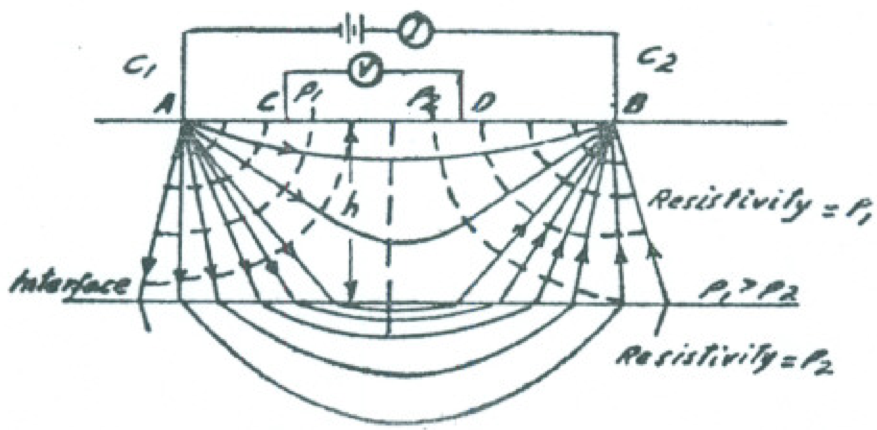


Fig Diagram of Gish-Rooney apparatus and ground connexions for earth-resistivity measurements

In practice, the apparent resistivity ρ_a is measured for a number of different separations of the current electrodes. In a homogeneous earth the

ρ_a would be the same regardless of the electrode separation. In the two layer case of fig. 4, the ρ_a would be very nearly ρ_1 for very short separations, but it would decrease with electrode separation, as shown in fig. 5 since a larger and larger proportion of the total current between the electrodes would pass through the low-resistivity deeper medium. As the separation becomes larger compared with h, the proportion of the current passing through the upper layer becomes negligible and the ρ_a approaches ρ_2.

FIG NO: 4



LINES OF CURRENT FLOW BETWEEN ELECTRODES A & B IN TWO-LAYERED EARTH WITH HIGHER CONDUCTIVITY IN DEEPER LAYER

Equiptment and Field Procedure :

A Gish-Rooney double commutator type Geohmeter is used to measure the resistivities of the sub-surface material. Since the mineral contents and more especially the water contents of a geological formation will greatly influence its electrical resistivity, the formation may often be distinguished and located by a series of resistivity measurements. In normal operation, the instrument sends a measured current into the earth through the outer electrodes hammerdriven into the ground. The resulting potential difference is measured between the intermediate pair of electrodes by a potentiometer. The current is supplied for the purpose by dry batteries. It is desirable that the resistance of electrode to earth should be the minimum possible. The resistance between electrode and earth is lowered by pouring water around the electrode, in other words by making a good contact of electrodes with the earth.

Over the area surveyed, a series of traverse lines were layed out as shown in fig. 1. Each determination of resistivities at a station involved positioning the four electrodes at the selected equidistant points along the line of traverse with the station at the centre, connecting the outer electrodes to the current supply units and the inner electrodes to the potential measuring system as shown in fig. 6. The current from the batteries passes first through an ammeter and next through a commutator which transforms, into alternating direct current of frequency 16 CPS before it reaches the terminals connected to the outer electrodes.

The current is alternated at a low frequency so that the contact potentials at the electrodes which are usually developed be eliminated. The current passing through the ground developes a potential field in the ground (see fig. 4). The potential difference between the inner electrode is measured by the potential measuring device. Thus, the quantities V & I are measured and from the equation $\rho_a = 2\pi a \frac{V}{I}$, ρ_a the apparent resistivity calçulated

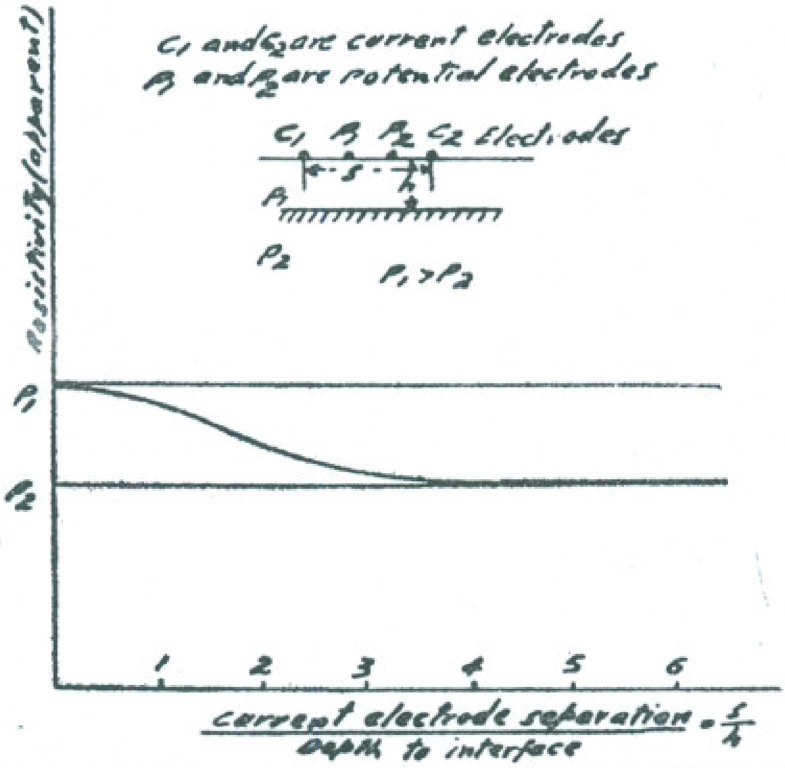


FIG: 5

APPARENT RESISTIVITY AS FUNCTION OF ELECTRODE SEPARATION FOR TWO-LAYER CASE ILLUSTRATED.

for each electrode spacing interval 'a'. The 'ρ_a's are then tabulated, in correlation with the positions of the stations and the spacing intervals.

The units of various quantities measured are as :—

ρ_a = apparent resistivity in ohms/cm.

a = electrodes separation in feet.

V = potential in milli-volts between the two inner potential electrodes.

I = Current in milli-amperes measured between the two outer current electrodes.

Method of Interpretation

Many methods to interpret the Field Earth Electrical Resistivity data have been devised. Among these are the Tagg's two layer theoretical method, Roman's two layer method, Wetzel-McMurry three layers theoretical curves, empirical methods and a few others. The method used by the author is that of Wetzell-McMurry three layer standard curves and Roman's two layer curves. No empirical method has been employed since it is considered that an uncertain amount of error may creep in by way of personal judgement. The Wetzel and McMurry curves and the Roman curves are three layer and two layer theoretical apparent resistivity *vs* electrode separation curves drawn for certain assumed resistivity relationships and depths of the sub-surface layers. A large number of curves have been drawn by Wetzel and Mc Murry and Roman for various possible resistivity relationships between the layers and for various depths on log-log paper. Some of these are shown in fig. 7.*

The field data were plotted on log-log paper and compared with the standard curves. When a perfect or good match was obtained, the interpretation became complete. At certain places the matching with one particular electrode separation was found to be difficult and thus the matchings in parts were interpreted.

True resistivity values obtained of different layers by matching the field resistivity curves with the theoretical curves have been presented in figs. 8 (a, b, c, d, e) in the form of vertical columns. These resistivity values are then converted into the sub-surface material and are shown in figs. 9 (a, b, c, d, e). To transform the resistivity values into the lithology help is taken from the resistivity measurements made on the actual sites of test holes drilled in the area and comparing the values with actual changes in formation. In this particular area the interpretation and correlation is based on the data of test holes RTLC-18 and RTLC-19 drilled on the south east side of the area (see fig. 1). The values of resistivity of the various formations at these test holes are given in the Table 1 below. These test holes are a part of the Rechna Test Line-C. Interpretation upto 400—500 feet depth has been attempted.

Table 1

Showing Resistivity Magnitudes of Various Formations at RTLC 18, 19

Formation	Resistivity Ohm/cm.	
	RTLC-18	RTLC-19
Sands (Fine-Medium)	10,000	2,500—19,600
Sands (Medium-coarse)	13,000—30,000	59,500
Silty sands (fine-medium)	—	3,200
Silty sands (medium-coarse)	—	7500
Silty clay	1,000—1,300	196—2,500
Clay	1,000—1,300	—

*For use of these theoretical curve a reference may be made to literature, referance 3 given at the end of this paper.

The correlation and interpretation at resistivity stations RSH 1, 2, 3, 4, 5 is done on the basis of formation at RSC 52. Similarly the resistivity values at stations RSH 6, 7, 8, 9 on the basis of RSC 53. at stations RSH 10, 12, 13, 15, 17 on the basis of RSC 54 and those at RSH 16, 14,11 on the basis of RSC 56,55 have been interpreted and correlated. Among resistivity stations RSC 52, 53, 54, 55, 56, the stations RSC 52 and RSC 55 are just at test drill holes RTLC-18 and RTLC-19 respectively. The geologic information of these test holes was available as a result of test drilling data. (For location of the various resistivity stations a reference may please be made to fig. 1).

Analysis of Data

In all 22 electrical resistivity profiles were run in the area upto a depth of 500 feet each. Due to the water-logging and salinity effects at the surface and other disturbing factors like Lower Chenab Canal and the drains, slight variations in the shape of the curves of apparent resistivity *versus* electrode separation have been noticed. The resistivity curves were drawn from the field data of the apparent resistivity values of various fixed electrode intervals at the resistivity stations. The results of the field data are tabulated in Table 2.

From this data it may be noticed that :—

(a) Apparent resistivity values at Station $RSH_{1, 2, 3, 4, 5}$, are high. Out of these the values at stations $RSH_{1,3,4}$, are low at the top and are in the range 993—1,914 ohm-cm. While those at $RSH_{2, 5}$ are quite high and of the order of 4,850 and 4,070 ohms cm respectively.

At stations $RSH_{1, 3, 4}$ the value of ρ_a at top are low ; this may be due to the facts :

(*i*) The top soil is silty clay.

(*ii*) Salinity (thur) is high at the top.

(*iii*) Water-table is near the surface.

ρ_a at $RSH_{2, 5}$, may be comparitively high at top due to the dry coarser texture at the top soil.

The values ρ_a at these five resistivity stations are high at the deeper formations (say after 30 feet) this may be due to :

(*i*) The seepage water of the Lower Chenab Canal being fresh water might be causing some leeching effects;

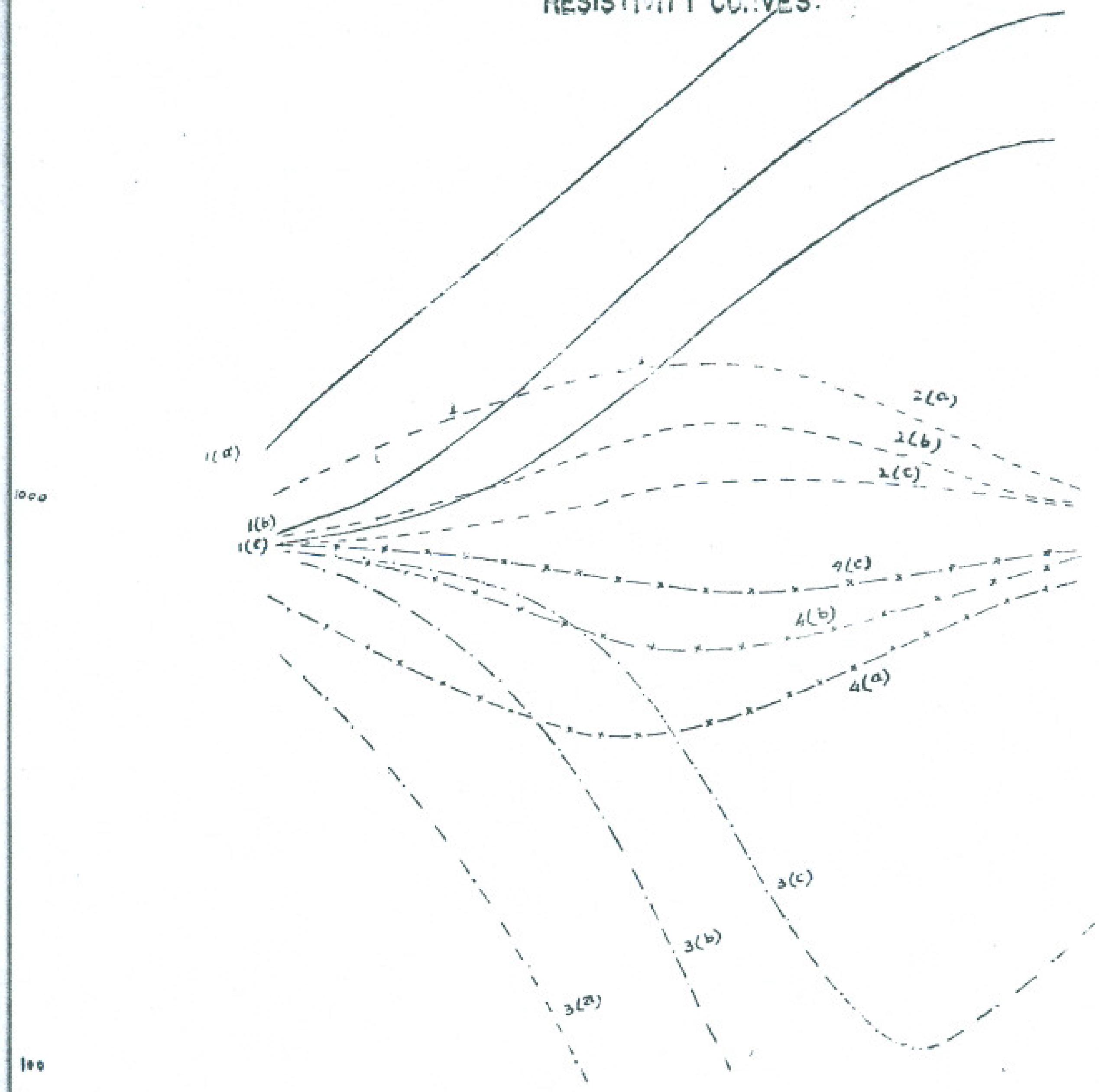
(*ii*) The fresh water present in the aquifers ; and

(*iii*) Comparatively coarser material present ;

(b) The apparent resistivity values at resistivity stations $RSH_{7, 10, 12, 13, 14, 16, 17}$..start from low values and then the trend is upward

SOME THEORETICAL 3-LAYER WETZELL McMURRY RESISTIVITY CURVES.

FIG NO. 7



CURVES: (1) —— $\rho_1 : \rho_2 : \rho_3 :: 1:100:1$

1(a) —— $\rho_1 = 1000$; $\rho_2 = 100000$; $\rho_3 = 1000$
$H_1 = 2$; $H_2 = 8$

1(b) —— $\rho_1 = 1000$; $\rho_2 = 100000$; $\rho_3 = 1000$
$H_1 = 4$; $H_2 = 8$

1(c) —— $\rho_1 = 1000$, $\rho_2 = 100000$; $\rho_3 = 1000$
$H_1 = 6$; $H_2 = 8$

CURVES (2) - - - $\rho_1 : \rho_2 : \rho_3 :: 1:3:1$

2(a) - - - - $\rho_1 = 1000$; $\rho_2 = 3000$; $\rho_3 = 1000$
$H_1 = 2$; $H_2 = 8$

2(b) - - - - $\rho_1 = 1000$; $\rho_2 = 3000$; $\rho_3 = 1000$
$H_1 = 4$; $H_2 = 8$

2(c) - - - - $\rho_1 = 1000$; $\rho = 3000$; $\rho_3 = 1000$
$H_1 = 6$; $H_2 = 8$

CURVES (3) -·-·- $\rho_1 : \rho_2 : \rho_3 :: 1 : \frac{1}{100} : 1$

3(a) -·-·- $\rho_1 = 1000$; $\rho_2 = 10$; $\rho_3 = 1000$
$\rho_1 = 2$; $H_2 = 8$

3(b) -·-·- $\rho_1 = 1000$; $\rho_2 = 10$; $\rho_3 = 1000$
$H_1 = 4$; H_2 8

3(c) -·-·- $\rho_1 = 1000$; $\rho_2 = 10$; $\rho_3 = 1000$
$H_1 = 6$; $H_2 = 8$

CURVES (4) -x-x- $\rho_1 : \rho_2 : \rho_3 :: 1 : \frac{1}{3} : 1$

4(a) -x-x- $\rho_1 = 1000$; ρ_2 333 $\rho_3 = 1000$
$H_1 = 2$; $H_2 = 8$

4(b) -x-x- $\rho_1 = 1000$; ρ_2 333; $\rho_3 = 1000$
$H_1 = 4$; $H_2 = 8$

4(c) -x-x- $\rho_1 = 1000$; $\rho_2 = 333$; $\rho_3 = 1000$
$H_1 = 6$; $H_2 = 8$

afterwards about 50 feet. Afterwards the curves are nearly flat with slight variations in them. The low values at the top may be due to high salinity, water-logging, effect of quality of water and the presence of finer material, silts and clays being also present in the formation.

(c) The values of ρ_a at station RSH_6 start at 3,121 ohms-cm and then after nearly 50 feet the curve is approximately flat. The high values at the presence ofKankar of 4-5 m.m. size in dry sandy silt seen at the surface.

(d) The values of ρ_a at resistivity stations $RSH_{8,\ 9}$ are respectively equal to 2,005 and 3,560 ohms-cm at 5 feet interval in the electrode separation. Values rise and after nearly 50 feet the curves are almost flat. The formations at the top at these stations are silty clay and silty sand respectively. The values of ρ_a are slightly high at the top, this may be due to the effect of the nearby drains.

By having a general look at the apparent resistivity curves and the true resistivity values it may be seen that :

(*i*) Curves of profiles No. RSH_7 and RSH_8 follow closely upto nearly 3,000 feet, but after this that of No. 8 has downward trend at 360′. The true resistivity values at these two stations also follow approximately the same pattern. The true resistivity value of No. 7 have limits 1,000 to 14,700 ohms-cm and those at No. 8 have limits 430 and 12,900 ohms-cm.

(*ii*) Curve No. RSH_9 has low trend at 160 feet to 250 feet, where the true resistivity value is 1,870 ohms-cm. After 340 feet it is wavery which may be due to interclations of high and low resistivity formations.

(*iii*) Curve $Nos._{6,10,12,13,14,15,16,17}$ have nearly the same shape with slight variations at different depths. The highs and lows in the true resistivity values at these stations are summarized below :

Resistivity Station	*True Resistivity Values* *Lowest*	*(ohms/cm).* *Highest*
RSH_6	2,800	12,000
RSH_{10}	530	16,500
RSH_{12}	1,050	6,300
RSH_{13}	1,340	26,500
RSH_{14}	1,300	19,000
RSH_{15}	1,533	25,000
RSH_{16}	110	17,000
RSH_{17}	420	20,000

(*iv*) Curves No. $RSH_{1,2,3,4,5}$ have nearly alike shape of gradual rise and then general downward trend after 270 feet. The true resistivity values at these stations are in the ranges 750-75,000, 3,500-36,000, 1750-17500, 995-31,000 and 3,300-52,000 ohms-cm respectively.

The true resistivity values at the various resistivity stations as drived from the apparent resistivity curves on log-log paper with the help of standard curves of Wetzel-McMurry have been entered in the vertical columns of figs. 8 (a, b, c, d, e.).

The true resistivity values thus obtained have been correlated in a manner that low resistivity formations are connected together, medium resistivity formations together and those of high values separated from other formations. In correlation, efforts were made to follow the following limits of resistivity ranges :

0-3,000 ohms-cm ;

3,000-6,000 ohms-cm ; and

above 6000 ohms-cm ;

The limit 0 -3,000 ohms-cm has, however been broken into two at some places where found necessary. A good idea about the correlation can easily be had from figs. 8 (a, b, c, d, e).

The true resistivity values obtained and correlated in figs. 8 (a,b,c,d,e) are then transformed into the form of lithology. The adoption of the resistivity values to the particular material is done on the basis of portion of Rechna Test Line-C between test holes RTLC- 18 and RTLC-19. The true resistivity of the various formations at these test hole sites has already been shown above (Table 1).

The resistivity values of the particular formations found in this area on this basis are given below :—

Material	*Resistivity Range in ohms-cm*
Sands	2,300—58,700
Silty Sands	I,500—7,500
Silty Clay	1,000—2,900
Clay	230—2,700

It may,however, be pointed out that the resistivity of sub-surface formation is a complex function of so many factors such as material, water quality (moisture content) , grain size, assortment etc., and that no rigid rule can be fixed to define the particular material. Only due to experience and the data of the drilling on C—line, the above demarçation in values to define the material of this area could be made,

CROSS SECTION SHOWING FORMATION AS PICKED UP THROUGH ELECTRICAL RESISTIVITY SURVEY IN HAFIZ ABAD RECLAMATION AREA

FIG. a

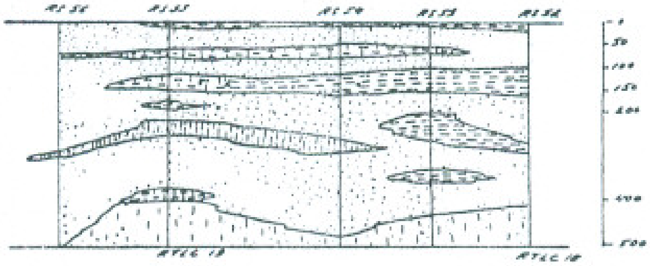
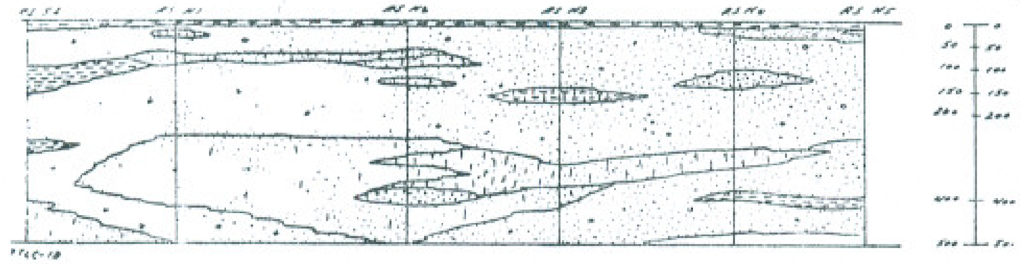


FIG. b



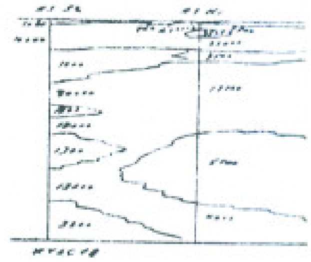
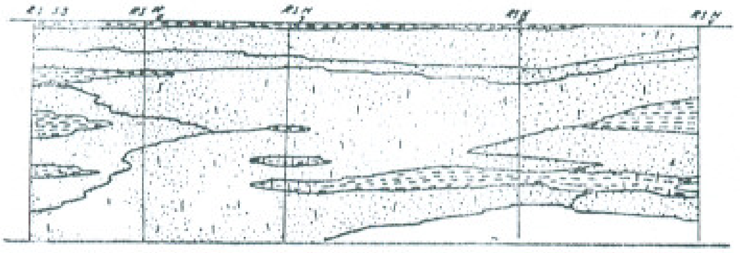


FIG. c



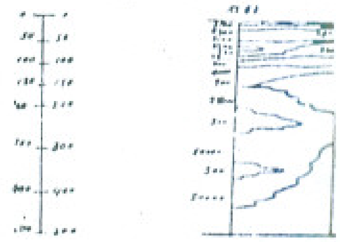


FIG. d

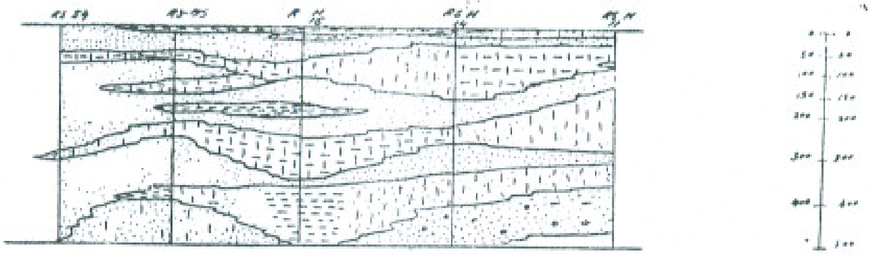
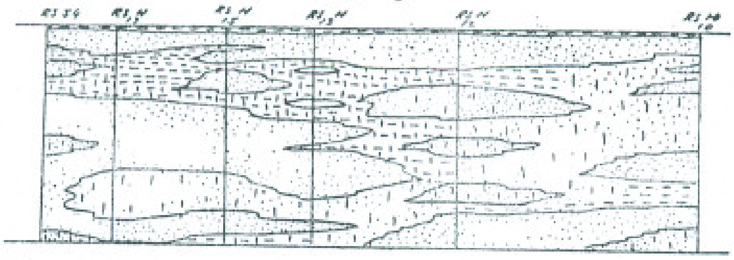
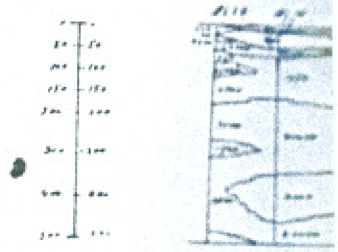


FIG. e





-: INDEX :-

- CLAY
- SILTY CLAY
- SILTY SAND
- SAND
- SAND WITH GRAVEL

SCALE

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...HING FORMATION AS PICKED UP THROUGH
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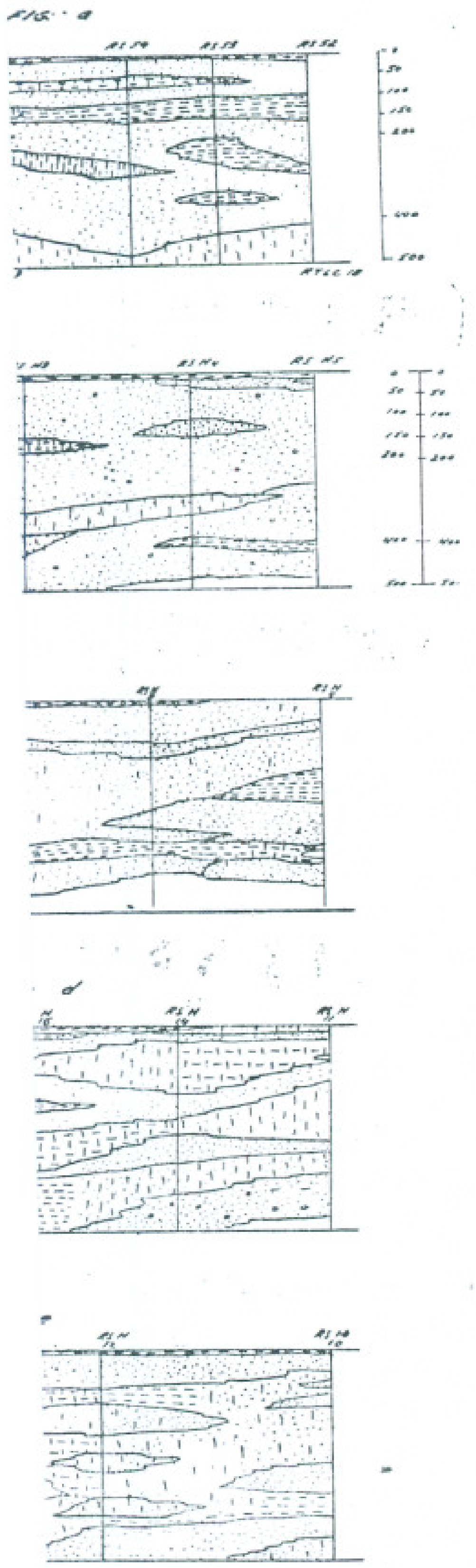
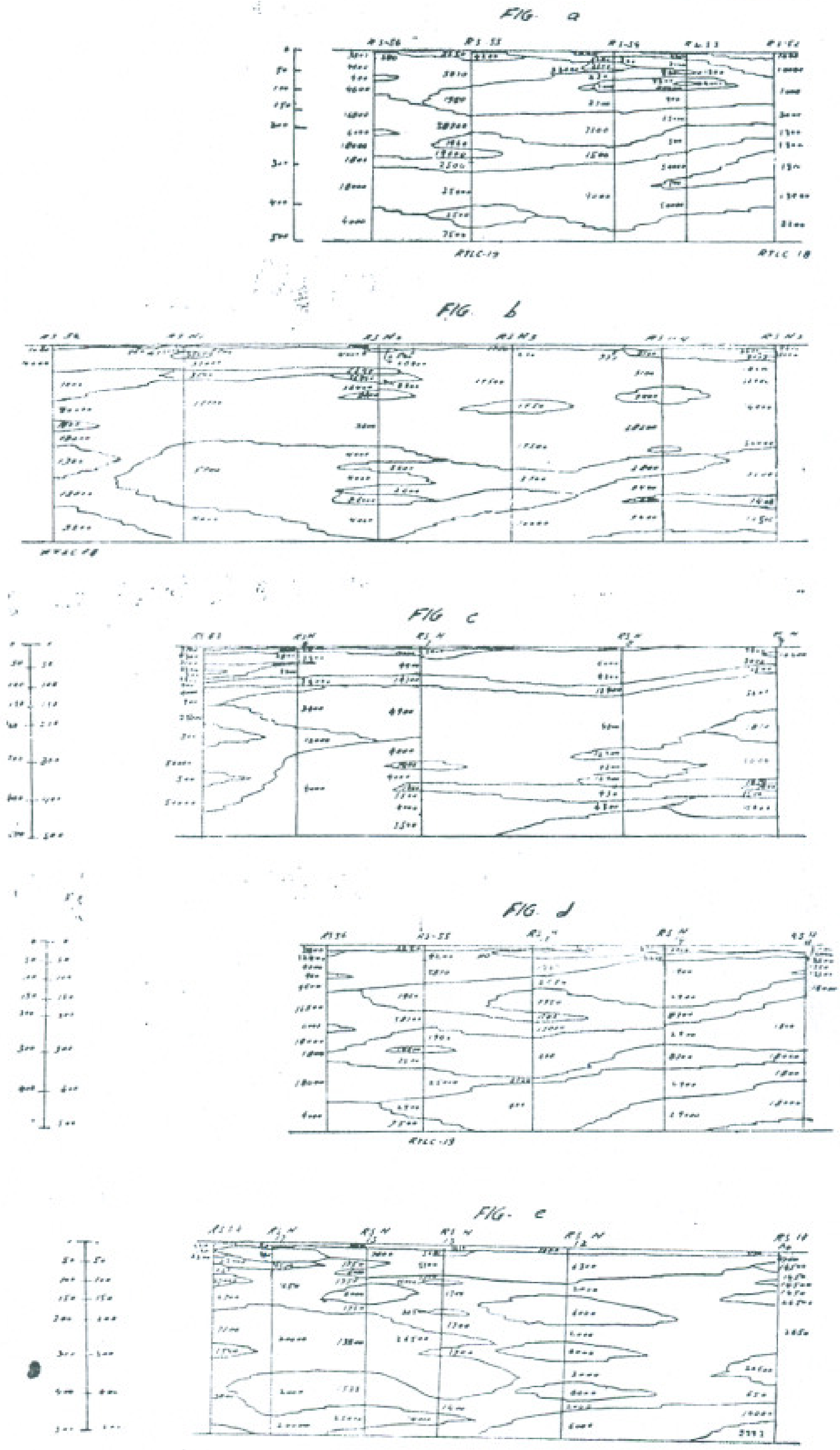


CROSS SECTION SHOWING RESISTIVITY VALUES OF VARIOUS SUBSURFACE FORMATION IN HAFIZ ABAD RECLAMATION AREA



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The correlation of the lithology on the basis of resistivity values is clearly shown in figs. 9 (a,b,c,d,e). To have a better three dimentional idea a panel diagram of the sub-surface formation of the area at the various resistivity stations has been made and is attached (fig. 10).

Conclusion :

From the discussion of the data obtained and the panel diagram it may be concluded that :—

(a) The sub-surface formation along resistivity stations $RSC_{52,53,54,55,\text{ and }56}$ is made up of sands, silty clays and silty sands in layers. This portion is a part of the Rechna Test Line-C between test hole RTLC-18 and RTLC-19.

(b) The sub-surface formations along resistivity stations $RSC,_{1,2,3,4,5,6,7,8,9,}$ are built up of sands, silty sands with clays at stations $RSH_{7,8,9}$ say at 360′, 330′ and 170′—250′, 350′—400′ respectively At stations $RSH_{2,3,4}$ sandy silts are also present after 300 feet. Sands, however, dominate the formation between stations $RSC_{52,53}$ $RSH_{1,2,3,4,5,6,7,8,9}$.

(c) The sub-surface formation at resistivity stations $RSC_{54,55,56}$ $RSH_{10,11,12,13,14,15,16,17}$ is complicated. The formation is composed of sands, silts, silty clays, clay and silty sands in different layers. The resistivity values here are not too high. At the stations RSC_{54} $RSH_{17,15,13,12,10}$ silty clay and silty sands dominate as the formation here is more conductive.

(d) The electrical resistivity method of Geophysical Exploration for the detection of sub-surface formation is very useful. It is correct that no fine description of the formations as regards their grain size distribution can be given, but nevertheless it cannot be denied that this method gives a very fair idea of the sub-surface formations. Besides the lithology the method is helpful in finding out the saline and non-saline sub-surface zones, as here the resistivity will be low and high re spectively. The method of interpretation applid also seems to be very much helpful as it is quite quick and accurate.

A PAPER ON

Application of Electrical Resistivity Method to Investigate Sub-surface Geology with Special Reference to Hafizabad Reclamation Area.

By

Maqsood Ali Shah Gilani

ABSTRACT

Water-logging and salinity are directly connected to the movement of ground water. In order to solve the acute problems of water-logging and salinity in a certain area it is very necessary to know the sub-surface geology because, flow of groundwater is controlled by its sub-surface geology. Th e Ground Water Development Organization is conducting extensive survey in West Pakistan to exptore sub-surface geology. The present work was done in Hafizabad Reclamation Area for the same purpose, using Earth Electrical Resistivity Method.

In the paper the technique of the method and the interpretation of the field data obtained using 2-layer 'Roman' and 3-layer 'Watzeland Mc Murry' theoretical curves are discussed. It is concluded that Electrical Resistivity Method is very useful in investigating the sub-surface geology and the sub-surface saline and non-saline formations. Also it is very helpful to use theoretical curves for interpretation of resistivity field data as their use has been found to be quite quick and accurate.

DIAGRAM SHOWING LITHOLOGIC CONDITIONS IN HAFIZABAD
EA BASED ON ELECTRICAL RESISTIVITY SURVEY.

VERTICAL SCALE 1" = 200 Feet . HORIZONTAL SCALE 2" = 1 Mile.

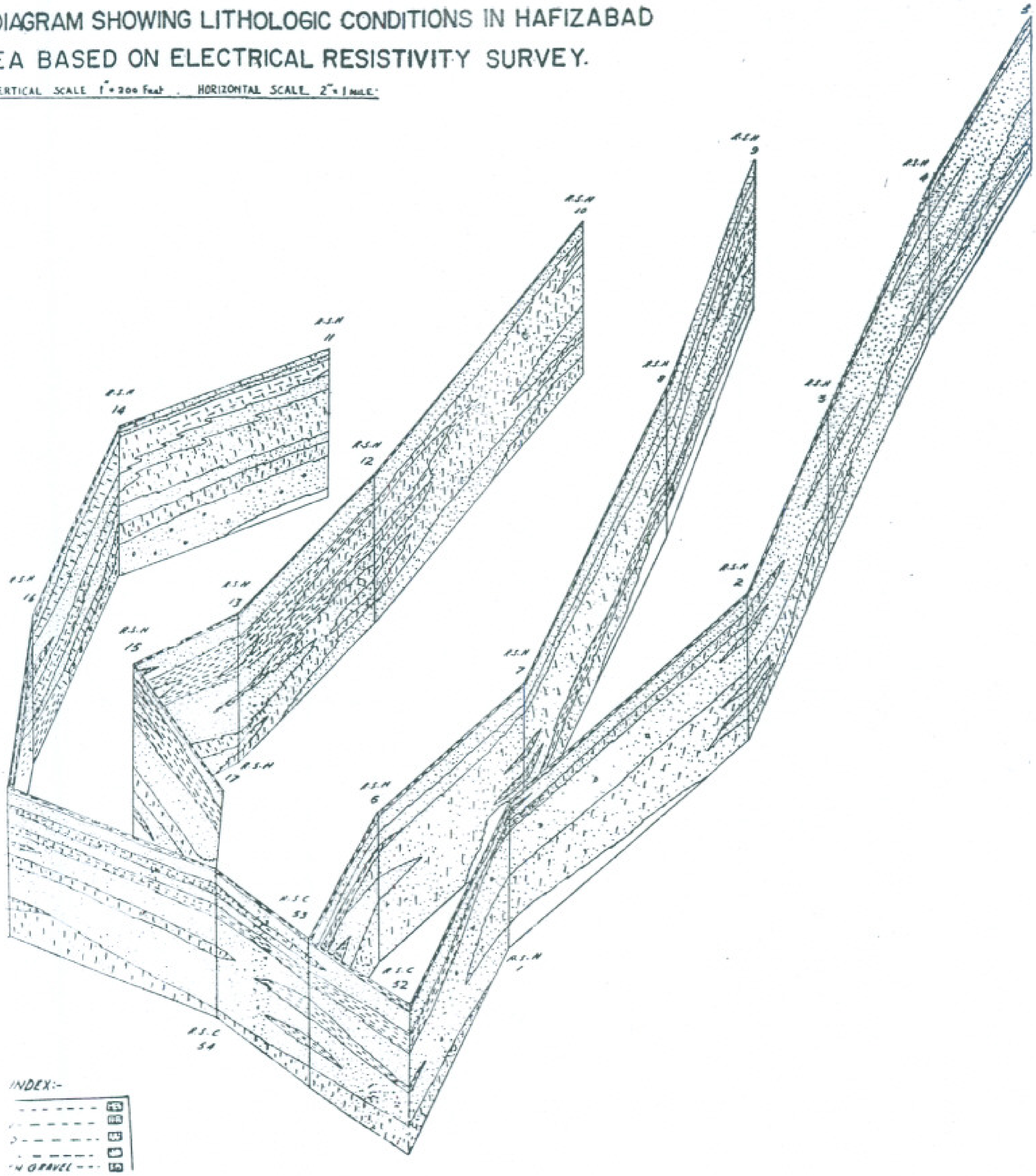
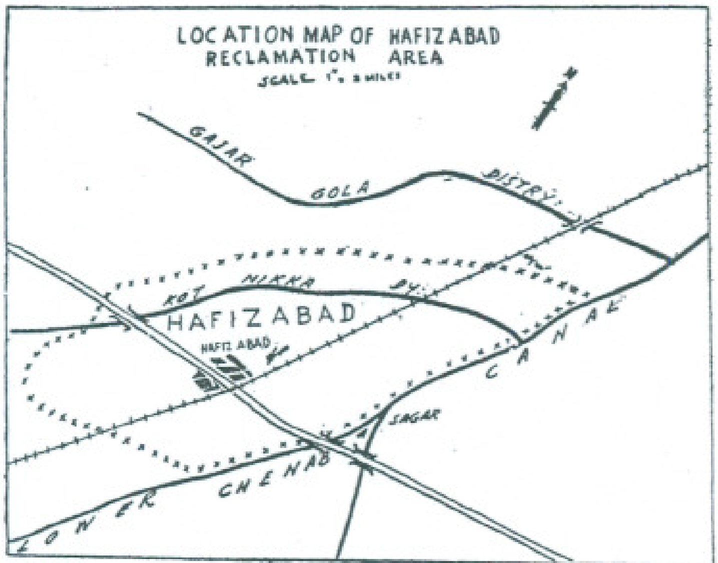


FIG NO: 10. PANEL DIAGRAM SHOWING LITHOLOGIC CONDITIONS I
RECLAMATION AREA BASED ON ELECTRICAL RESISTIVITY S

VERTICAL SCALE 1" = 200 Feet . HORIZONTAL SCALE 2" = 1 MILE.



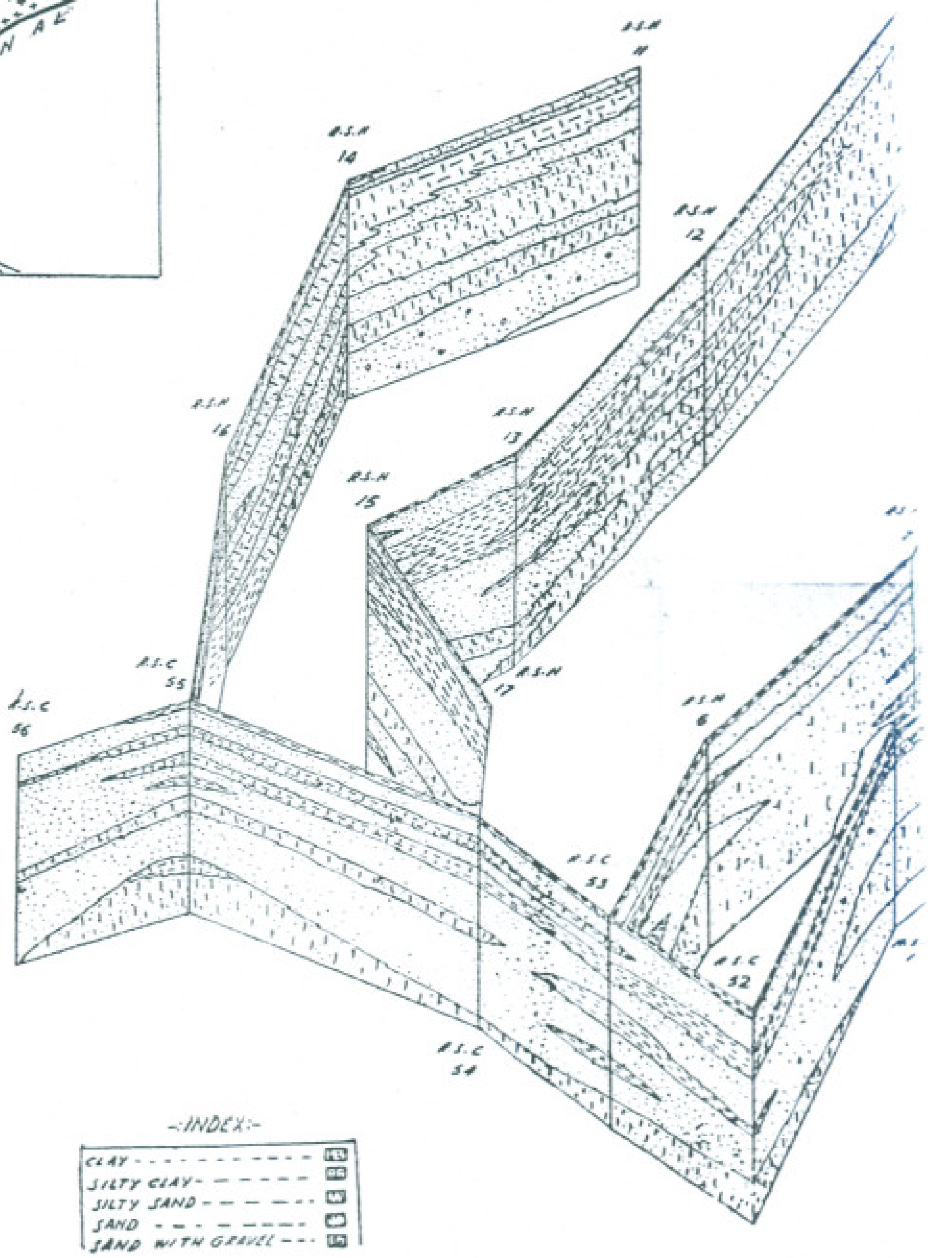


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Table

Showing Values of Apparent

S.No.	Electrode Separation 'a' in feet.	Values ef Apparent Electrical									
		RS C 52	RS C 53	RS C 54	RS C 55	RS C 56	RS H 1	RS H 2	RS H 3	RS H 4	RS H 5
1.	5	1050	3680	1495	2570	4250	1069	4850	1914	993	4070
2.	10	1801	4680	2200	3080	5250	1769	7400	2540	1719	6070
3.	20	3050	5420	2540	3520	5370	3800	9640	4260	2795	10299
4.	30	3910	5750	2670	3625	5300	4320	12620	5850	3640	11460
5.	40	4490	5375	2830	3900	5060	5000	13100	7248	4780	13750
6.	50	5470	4898	2880	4155	4945	5785	14180	8300	5995	14095
7.	60	6190	4920	3050	4405	5045	6400	14790	9300	6752	14800
8.	70	6660	4445	3010	4575	5010	6880	14400	10050	7745	15380
9.	80	7000	4610	2985	4799	4750	7495	15000	10710	8550	15495
10.	90	7075	4655	3095	4780	5240	7610	14700	10850	9220	15960
11.	100	7290	4950	3205	4960	6460	8120	15000	11420	9648	16350
12.	120	7515	4209	3255	4860	6520	8745	15600	12000	10195	16610
13.	140	7015	3922	3360	4750	6910	9415	14420	12700	10860	17030
14.	160	7070	3780	3340	4810	6960	9475	14200	12475	11295	17030
15.	180	7608	4120	3439	4888	7400	9800	14600	12920	11720	17400
16.	200	7750	4200	3475	5146	7545	9700	14500	13160	12100	17000
17.	220	7305	3800	3605	5448	7550	9684	15400	13395	12360	17200
18.	240	7590	3450	3860	5303	7855	10350	15050	13450	12700	17215
19.	260	7620	3180	3982	5140	8215	10110	15420	13660	14200	17950
20.	280	7445	3342	4035	5360	8455	10270	15500	13750	13350	17340
21.	300	7120	3720	3912	5260	8020	10300	15550	13890	13680	17100
22.	320	6890	3990	3920	5160	7850	10210	14780	13820	13410	16520
23.	340	6851	4075	4065	5200	7800	10475	14800	13600	13410	16110
24.	360	6955	3800	4040	5300	7755	10200	14760	13380	13750	15800
25.	380	7055	4018	4210	5652	7800	10110	14360	13515	13910	15595
26.	400	7200	4230	4230	5800	8100	10175	15820	13200	13690	15600
27.	420	7180	4690	4365	5810	8350	9940	15000	13510	13690	14720
28.	440	7000	4705	4500	5660	7745	9990	14550	13000	13700	14200
29.	460	6650	4615	4610	5300	7860	9855	13670	12890	13760	14050
30.	480	6425	4790	4730	5375	7815	9960	13370	12700	13875	13600
31.	500	6255	4840	4705	5360	7545	9848	13000	12760	14000	14050

2

Resistivity at Various Stations

Resistivity at Stations in ohms-cm

RS H 6	RS H 7	RS H 8	RS H 9	RS H 10	RS H 11	RS H 12	RS H 13	RS H 14	RS H 15	RS H 16	RS H 17
3121	1582	2005	3560	715	2660	1650	1559	1310	2400	1280	517
3840	2486	2485	3855	1128	2380	2528	1966	1560	3570	1998	840
4040	3970	3255	4750	1800	2080	3445	2265	1922	4850	3240	1590
4230	4960	3610	4990	2220	2580	3705	2620	2200	5440	3750	2105
4400	4860	3940	4820	2515	2885	3850	2795	2460	5900	4180	2503
4645	5160	4160	4675	2860	3115	3940	2998	2745	5780	4510	2742
4800	5710	4250	4975	3045	3165	4015	3140	2920	6370	4898	3150
4800	5320	4500	5105	3130	3020	4000	3080	2910	6310	4930	3280
4780	5255	4750	5075	3100	3060	4010	3145	2952	6395	4925	3450
4950	5400	4855	5250	3220	2825	4155	3260	2982	6960	5025	3528
5380	5500	4940	5110	3205	2985	4050	3285	3020	6115	4920	3600
4951	5730	5080	4960	3300	3370	3939	3050	3095	6125	4950	3708
5040	5810	5130	4710	3480	3500	3900	3330	3300	6000	4940	3655
4960	5720	5170	4690	3700	3660	4045	3355	3240	6090	5055	3590
4910	5740	5145	4525	3930	3820	4145	3835	3443	5680	5155	3710
4750	5640	5145	4500	4160	4030	4320	3860	3560	5660	4725	3880
4745	5795	5260	4480	4260	4103	4348	3785	3520	5600	4915	3950
4850	5630	5190	4400	4290	4150	4300	3860	3550	5620	5090	4100
4708	5800	5190	4400	4300	4170	4570	4160	3822	5710	5380	4115
4710	5950	5340	4420	4360	4260	4635	4070	3830	5885	5360	4225
4740	5930	5400	4552	4631	4355	4740	4140	3885	5810	5455	4395
4740	5450	5255	4710	4790	4530	4515	4220	3905	5810	5405	4500
4885	5610	5400	4895	4950	4580	4525	4390	4100	6008	5452	4510
4750	5805	5570	4608	5070	4570	4500	4580	4160	6000	5350	4500
4938	—	4958	4690	4895	4652	4685	4630	4240	5960	5550	4480
4840	5710	4875	4445	4390	4820	4945	4830	4205	5845	5575	4375
4770	5600	4850	4760	4520	5080	4800	5060	4250	5570	5480	4305
4955	5420	4950	5050	4720	5105	4895	4900	4410	5600	5365	4270
4805	5500	4865	5000	4800	5290	4950	5000	4493	5850	5215	4260
5092	5580	5260	4880	4790	5280	5000	4780	4555	6300	5205	4290
4940	5540	5720	4650	4700	4900	5010	4680	4610	6350	4920	4508

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