DELINEATION OF AQUIFERS BY ELECTRICAL RESISTIVITY METHOD

A DISSERTATION

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

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in

WATER RESOURCES DEVELOPMENT

By

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CANDIDATE'S DECLARATION

I do hereby declare that the dissertation entitled **"DELINEATION OF AQUIFERS BY ELECTRICAL RESISTIVITY METHOD"** is being submitted by me in the partial fulfilment of the requirements for the award of degree of **"Master of Technology** in **WATER RESOURCES DEVELOPMENT** ____________" and submitted in the Water Resources Development and Management Department, Indian Institute of Technology, Roorkee, is an authentic record of my own work, carried out during the period of third and fourth semester under the guidance of **Prof. Gopal Chauhan,** Professor and **Dr. Deepak Khare,** Associate Professor, Water Resources Development and Management Department, Indian Institute of Technology, Roorkee.

I certify that the matter embodied in this dissertation work is not submitted by me anywhere for any other award of degree/diploma.

Dated: 27, June, 2006
Place: IITR, Roorkee

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ABSTRACT

In our life, water play a vital role, especially fresh water is of utmost importance. The main sources of fresh water are lakes, rivers, streams and channels but this water may be contaminated not suites for intended use of water. Ground water is the main source of fresh and pure water; it can be directly used in drinking, agricultural and industrial purposes. So, it becomes of more importance to locate subsurface zones of fresh & pure water and even to locate a pin point (allocation of aquifers) for construction of a tube well either used for drinking, agricultural and industrial purposes.

Out of many geophysical methods, direct current (D.C.) resistivity survey is the most extensively used method to delineate aquifers i.e. availability of fresh water under subsurface of specified area. In present work an attempt is tried to identify aquifer layers underneath of selected sites in the study area. Resistivity surveys are conducted nearby a tube well, whose strata chart is known. These tube well are state public tube wells. These are deep wells and drilled up to around 100 m and installed for agriculture and these have discharge of 150 m^3/hour. Resistivity surveys are conducted at 41 sites in Roorkee block and Narsan block (the study area). Schlumberger electrode configuration is used in this work. The data are collected as apparent resistivity for Schlumberger electrode configuration. These data are interpreted by using IX-1D software, which gives layered model of VES in the graphical and analytical form. The analytical results contain resistivity of layers and their thicknesses and depth of layers from ground level. The results obtained from interpretation of sounding curves of VES are correlated with respective strata chart of nearby tube well. Analyzing result of VES and stratified layers of nearby tube well, geological interpretation of model is carried out. An analysis is also performed that

how for results obtained from interpretation of VES match with existing data. Results of some sites are very close to actual geological section and of some are approximate to strata charts of state tube wells.

This work is an attempt to verify that how closely results can be obtained from D.C. resistivity surveying and with what reliability this method can be used in future to locate water bearing strata from surface investigation and pin point for construction of a new tube well.

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CHAPTER-1

INTRODUCTION

1.1 GENERAL

Water is an essential commodity to mankind, and the largest available source of fresh water lies underground. The increased demands of water have stimulated development of underground water supplies. The main source of water on this earth is rainfall, a portion of this is penetrated into the ground surface, a portion of this is evaporated to atmosphere and remaining flows as runoff. The ground water is the largest source of fresh water on the earth excluding the polar icecaps and glaciers. The amount of water within 800 m from the ground level is over 30 times the amount of water in all fresh water lakes and resources, about 3000 times the amount in stream channels, at any one time. At present, nearly one fifth of all water used in the world is obtained from ground water resources.

As ground water becomes more important source of uncontaminated water, the methods for locating good aquifers must become more efficient. There are three popular geophysical methods to discover the ground water; each method has its own advantages and limitations. First method is to drill a test hole, this method is the most accurate method but it is costly affair to drill a test hole every time and at every place. Third method is aerial or remote sensing method, it is least costly method and gives knowledge of the largest area of all the three methods but depth of investigation is limited to shallow depth, in this method; maps classifying an area into good, fair and poor ground water yields can be prepared.

Whilst, second method have properties in between first and third method; these are electrical resistivity, seismic refraction, induced polarization, magneto telluric and electromagnetic methods.

1.2 GEOPHYSICAL EXPLORATION

It is important to understand the capabilities of the different geophysical methods, so that it may be possible to take full advantage of abilities of each method for subsurface investigations. These methods are a fairly inexpensive means of ground exploration and are very useful for correlating information between borings which, for reasons of economy, are spaced at fairly wide intervals. Geophysical data must be interpreted in conjunction with borings and by qualified, experienced personnel. Because there have been significant improvements in geophysical instrumentation and interpretation techniques in recent years, more consideration should be given to their use.

Applicable geophysical ground surface exploration methods include: (1) seismic methods, (2) electrical resistivity, (3) self potential (SP) methods, (4) electromagnetic (EM) method, (5) magnetotelluric (MT) methods. Information obtained from seismic surveys includes material velocities, delineation of interfaces between zones of differing velocities, and the depths of these interfaces from ground level. The electrical resistivity survey is used to locate and define zones of different electrical resistivities such as pervious and impervious zones or zones of low resistivity such as clayey strata. The resistivity method requires a resistivity contrast between materials being located, while the seismic method requires contrast in wave transmission velocities. Furthermore, the seismic refraction method requires that any underlying stratum transmit waves at a higher velocity than the overlying stratum. Difficulties arise in the use of the seismic method if the surface terrain and layer interfaces are steeply sloping or irregular instead of relatively horizontal and smooth. Therefore, in order to use these methods, one must be fully aware of potential and limitations of them.

A resistivity survey measures variations in potential of an electrical field within the earth by a surface applied current. Variation of resistivity with depth is studied by changing electrode spacing. The data is then interpreted as electrical resistivity expressed as a function of depth.

Electromagnetic (EM) induction surveys use EM transmitters that generate currents in subsurface material. These currents produce secondary magnetic fields detectable at the surface. Simple interpretation techniques are advantages of these methods, making EM induction techniques particularly suitable for horizontal profiling. EM horizontal profiling surveys are useful for detecting anomalies. Self potential (SP) methods are based on change of potential of ground by human action or alteration of original condition.

1.3 DIRECT CURRENT RESISTIVITY METHOD

Direct current (DC) resistivity techniques (sometimes referred to as "electrical resistivity" or "vertical electric sounding") measure earth resistivity by driving a direct current signal into the ground and measuring the resulting potentials (voltages) created in the earth. From that data the electrical properties of the earth (the geoelectric section) can be derived and thereby the geologic properties are interpreted.

Two short metallic stakes (electrodes) are driven about 0.3 m into the earth to apply the current to the ground. Two additional electrodes are used to measure the earth voltage (or electrical potential) generated by the current (see Fig.1.1). Depth of investigation is the function of the electrode spacing. Greater the spacing between the outer current electrodes, deeper the electrical currents will flow in the earth, hence greater the depth of exploration. The depth of investigation is generally 20% to 40% of the outer electrode spacing, depending on the earth resistivity structure.

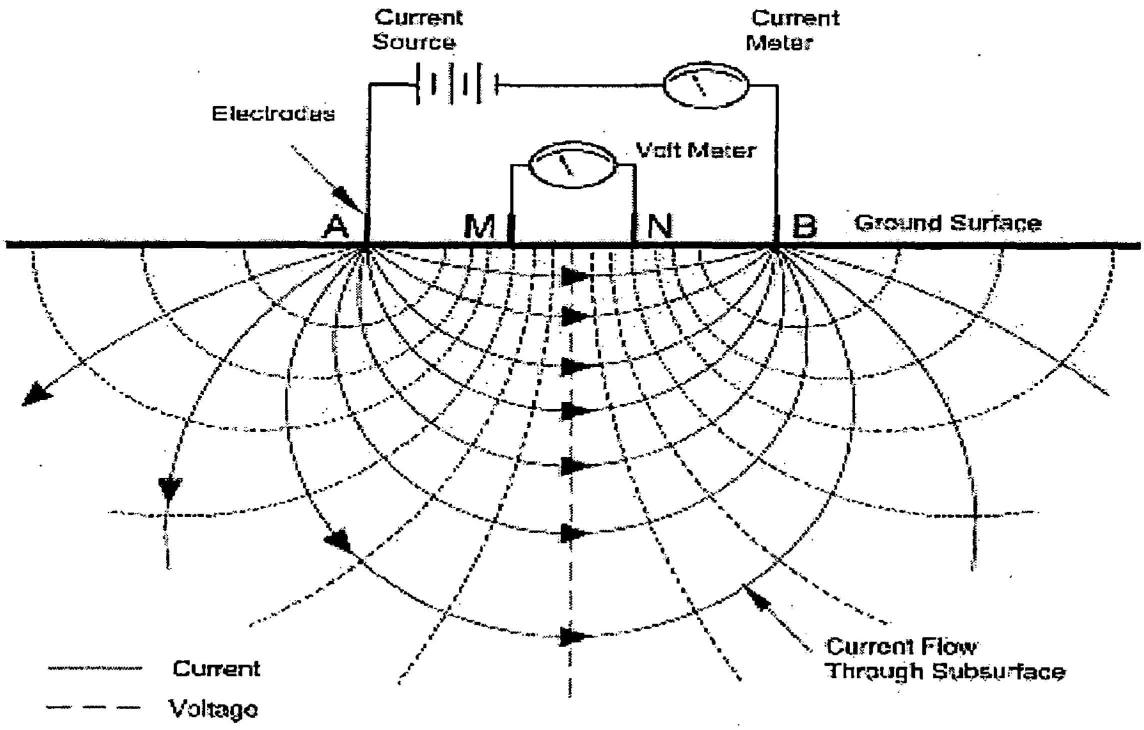


Fig. 1.1: A schematic diagram showing the basic principle of D.C. resistivity

Instrument readings (current and voltage) are generally reduced to "apparent resistivity" values. The apparent resistivity is the resistivity of the homogeneous half-space which would produce the observed instrument response for a given electrode spacing. Apparent resistivity is a weighted average of earth resistivities over the depth of investigation. For soundings a log-log plot of apparent resistivity versus electrode separation is obtained. This is sometimes referred to as the "sounding curve."

The resistivity data is then used to create a hypothetical model of the earth and its resistivity structure (geoelectric sections). Resistivity models are generally not unique i.e. a large number of earth models can produce the same observed data or sounding curve. In general, resistivity methods determine the "conductance" of a given stratigraphic layer or unit. The conductance is the product of the resistivity and the thickness of a unit. Hence that layer could be thinner and more conductive or thicker and less conductive, and produce essentially the same results. Because of this constraint on the model, borehole data or assumed unit resistivities can greatly enhance the interpretation.

The end product from a DC resistivity survey is generally a "geoelectric" cross-section thicknesses and resistivities of all the geoelectric units or layers. If borehole data or a conceptual geologic model is available, then a geologic identity can be assigned to the geoelectric units. A two-dimensional geoelectric section may be made up of a series of one-dimensional soundings joined together to form a two-dimensional section, or it may be a continual two-dimensional cross section.

Resistivity methods however don't yield; complete information and will never, even under favourable conditions, completely replace test drilling. They can, though, in many cases substantially reduce the amount of test drilling required by allowing more intelligent selection of test hole sites. In most of investigations a combination of drilling and geophysical survey will provide the optimum solution.

Resistivity surveys are not practical in all ground water investigations, but this determination can be made only with an understanding of capabilities, limitations and cost of geophysical surveys.

1.4 FIELD PROCEDURE FOR RESISTIVITY SURVEY

The instrument used in this work is ABEM terrameter SAS 300B, SAS means signal averaging system; in which 1, 4, 16 and 64 readings are taken and averaged out very shortly. This instrument, in resistivity surveying mode, directly read resistance between potential electrodes.

From Ohm's law,

$$R = V / I \quad (1.1)$$

$$\rho = R.A / L \quad (1.2)$$

$$\rho = V/I \, (A/L)$$

The ratio A / L is called geometric factor or shape factor of configuration.

Schlumberger configuration is used in resistivity survey; in this array distance between outer current electrode pair (AB Fig.1.1) is much greater than distance between inner potential electrode pair (MN). AB ≥ 5 MN is considerable in field practice.

The experiments are conducted in expanding electrode system, in which readings are taken from short distance between AB while keeping MN fixed and in each step distance between AB is increased; after 4-5 increment of AB, distance between MN is increased (doubled).

Resistance readings are noted from the ABEM terrameter SAS 300B and these readings are multiplied by geometric factor of Schlumberger configuration, the resulting product is termed as apparent resistivity.

The geometric factor (G) for Schlumberger configuration is given as:

$$G = \pi \left[\frac{(L/2)^2 - (b/2)^2}{b} \right]$$

L=AB & b=MN

1.5 INTERPRETATION OF VES CURVE

A curve is plotted as apparent resistivity on y-axis versus half of electrode spacing on x-axis, on log-log paper, this is called sounding curve. Interpretations are made by curve matching with master diagram, auxiliary point method and by IX-1D computer software out of available so many analytical techniques & computer softwares. The analytical techniques available up to now are limited to two or three layer solutions and for more than three layers these are much more complex & complicated and time consuming .The curve matching technique is applicable up to four layer model because collection of readymade curves become bulky & trouble some. In this method sounding curve is plotted on transparent log-log paper and slid on various master curves of two, three and four layer as required for solution of problem from available collection, until a sufficient portion match with one of the master curves, keeping its axis parallel to respective axis of master curve. The interpretation of sounding curve is directly read from the matched master curve. This method has an inherent problem that sounding curve of field data should match with one of the master curves, if necessary interpolation may be done. The auxiliary point method is similar to curve matching method, except that in this method sounding curve is slid alternatively on master curves & on auxiliary curves of Q, H, D & A type, depending on the situation. The necessary condition for this method is that the underlying layer should have thickness greater than the sum of thicknesses of overlying layers, which is a rare condition in field. However this method is extensively used for initial guess of resistivities and thicknesses of layers. There are so many softwares available for interpretation of a sounding curve for any number of layers, some old software are working on MS-DOS version but in this work IX-1D software is used which is working on WINDOWS version. These softwares are based on linear filter techniques & inversion methods; in which a synthetic curve is developed and matched with field sounding curve, number of iterations are done till the fitting error become less than 5%. Thicknesses and resistivities of various layers directly read from the presented analytical layered model.

1.6 OBJECTIVES

1. Creation of data base from the existing state tube wells
2. Analysis of data of existing state tube wells
3. Resistivity survey at selected sites in the study area
4. Creation of vertical electrical sounding (VES) data sheets
5. Quantitative interpretation of VES using IX-1D software
6. Geological/qualitative interpretation based on strata charts of state tube wells
7. Analysis of results for delineation of aquifers

CHAPTER-2

LITERATURE REVIEW

2.1 THE HISTORY OF RESISTIVITY METHOD

The early chronology, the first attempt to utilize electrical methods dates back to Robert W. Fox (1830) when he observed that electrical currents, flowing in Cornish copper mines, were the result of chemical reactions within the vein deposits, i.e. self potentials. According to Kelly, "The first recorded discovery of a sulphide body by electrical methods is to be credited to him, as the result of the investigations which he carried out in 1835, in the Penzance Mine of Cornwall."

As early as 1882, Carl Barus conducted experiments at the Comstock Lode Nevada, which convinced that the method could be used to prospect for hidden sulphide ores. The credit goes to Barus for introducing the nonpolarizing electrode. Conrad Schlumberger put the method on commercial basis in 1912. The first plan map of self potential over metallic deposits was prepared by Schlumberger in 1913 and was published in 1918; it depicted the pyrite mines at Sain-Bel, France. Roger C. Wells, of the U.S. Geological Survey, contributed the first chemical understanding of the passive self-potential phenomena in 1914. Fred H. Brown, in the era 1883 to 1891, and Alfred Williams and Leo Daft in 1897, first attempted to determine differences in earth resistivity associated with ore deposits and were granted patents on their methods. In 1893, James Fisher had measured the resistivity of copper bearing lodes in Michigan (Broderrick and Hohl, 1928). Schlumberger in 1912 gave the first practical approach, to utilise active electrical methods; wherein the earth is energized via a controlled source and the resulting artificial potentials are measured by potential meter.

The concept of apparent resistivity was introduced in about 1915 by both Wenner (1912) of the U.S. Bureau of Standards and by Schlumberger (1920). The held techniques for apparent resistivity were then developed by O. H. Gish and W. J. Rooney of the Carnegie Institution of Washington and by Marcel Schlumberger, E. G. Leonardon. E. P. Poldini, and H. G. Doll of the Schlumberger group. Wenner used the equal-spaced electrode array which today bears his name, while the Schlumberger group standardized an electrode configuration in which potential electrodes are sufficiently close together than, the current electrodes i.e. the electric field, is measured midway between the current electrodes (the Schlumberger array). The earliest attempt to understand telluric currents is generally credited to Charles Mateucci (1867) of the Greenwich Observatory. It was not until 1934 that Conrad Schlumberger made commercial use of the method. According to Sumner (1976) "Conrad Schlumberger was the first to describe a polarization provoquée i.e., induced polarization, in 1920 although he dropped the concept in favour of the self potential method." Harry W. Conklin, an American mining engineer, took out basic patents on the electromagnetic (EM) method in 1917. The first successful application of the Sundberg EM method, the forerunner of the horizontal loop method, occurred in 1925 (Sundberg et al. 1925). The Bieler-Watson (1931) method of measuring the ellipse of magnetic field polarization in the vicinity of a large horizontal transmitting coil appeared next. These were the foundations of the development of the theory and application for electrical methods of geophysical exploration. In the next decade or so, numerous books and treatises appeared which rapidly expanded the foundation. The most notable among these were Ambronn (1928), Eve and Keys (1929), and Broughton Edge and Laby (l931).

The theoretical basis for the electrical resistivity method became more firmly grounded with the forward solutions developed for horizontally layered earths by Stefanesco et al., (1930) and others. This work culminated in the publication of an album of curves for the Schlumberger array (Compagnie Generale de Geophysique, 1955) and for the Wenner array by Mooney and Wetzel (1956). Until recently, matching of observed and theoretical curves using such albums was the standard method of interpreting resistivity data over horizontally layered earths. Roy and Apparao (1971) and Madden (1971) demonstrated respectively, the depth of exploration for various electrode arrays and the resolving power of resistivity sounding for thin conductive and thin resistive beds.

Langer (l933) and Slichter C (1933) were the first to develop formulation of the inverse problem in resistivity sounding of horizontally layered structures. Koefoed (1968) and Ghosh (l97l) did much to make inversion practical. Zohdy (1975) developed a method of direct interpretation with which he obtained good results. However, none of the above investigations used the method of the generalized inverse introduced by Backus and Gilbert (1967). Inman et al., (1973) introduced the use of the latter method to resistivity sounding, demonstrating that it was the most powerful technique for estimating parameters of a layered earth and for describing the non uniqueness of the inverse solutions. Vozoff and Jupp (1975), Petrick et al., (1977), and others used simultaneous inversion of resistivity and other data sets.

Tagg (1930) computed apparent resistivity curves for Wenner array resistivity profiles across a vertical fault. Logn (1954) developed expressions for the apparent resistivity over thin vertical sheets. Lundberg and Zuschlag (l93l) computed potential-drop ratio curves over a vertical fault and a vertical dike. Many other workers pursued these initial leads. The dipping-bed problem in electrical geophysical applications was first solved by Skal'skaya (1948), and her work was extended by many others. VON Mises (1935) gave the exact solution for the potential due to a point current electrode over a horizontal buried cylinder. Van Nostrand and Cook (1966) presented an excellent summary of 1-D, 2-D and 3-D models available for interpretation of resistivity data to that time value. In last two-three decades, development of practically realizable numerical methods (e.g..the finite difference, finite-element, transmission-line, and integral equation methods) has permitted the computation of sounding profiling results for any electrode configuration over 2-D inhomogeneities of arbitrary shape. Madden (1972) introduced the transmission line method, Jepsen (1969) the finite difference method, and Coggon (1971), the finite-element method, while Snyder (1976) introduced the integral equation method. Edwards (1974) provided the basis for the magmetometric method of mapping resistivity. This technique is intended for deeper exploration than conventional resistivity methods because it relics upon measurement of magnetic field rather than electric field. The inversion of 2-D resistivity data is in its infancy, Pelton et al., (1978) developed an approach to inversion of 2-D dipole-dipole resistivity and IP data, using the transmission surface method, which relied upon storage in a computer of a data bank of forward solutions. Tripp et al., (1979), following a suggestion by Madden (1972), utilized Telegen's theorem and the transmission surface analogy to produce a true ridge regression generalized inverse solution for the dipole-dipole array over a 2-D earth structure.

Petrowsky (1928) first studied the potential distribution at the surface of the earth due to a buried electrically polarized sphere. Stefanesco (I950) first presented the very interesting and powerful alpha centre approach to 3-D modelling of resistivity data. Cook and Van Nostrand (1954) calculated a wide variety of resistivity curves over and near filled sinks, appropriate to the Lee and Wenner arrays. Seigel (1959) presented the response of a polarizable sphere in a half-space. The first 3-D numerical solution was presented by Hohmann (1975) in a geophysics paper which received a best paper award. Pridmore (1978) used the finite-element method to calculate apparent resistivities over a complex 3-D earth. Dey and Morrison (1979) used the finite-difference method to calculate apparent resistivity distributions for the dipole-dipole array over 3-D inhomogeneities.

The Schlumberger and Wenner arrays are frequently referred to as DC resistivity methods. At various early times DC and AC sources such as batteries and the commutated megger have been used. In decade 1980; Reliance has been placed on low-frequency (10^{-2} to 10^{2} Hz) generators, these generators have provided synchronized signals at the receiver either by (1) wave form recognition, (2) hard-wire link, or (3) synchronized clock link. Also in the last two decade, digital receivers in the field have facilitated various frequency or time-domain procedures for data processing such as stacking, noise rejection, and band-pass filtering (e.g., Sumner, 1976). In current technology; via in-field microprocessors and a time reference between transmitter and receiver permits processing, plotting, and interpretation of data in the field.

2.2 CORRELATION OF VERTICAL ELECTRICAL SOUNDING AND BOREHOLE-LOG DATA FOR DELINEATION OF SALTWATER AND FRESHWATER AQUIFERS

In a case history from the Mahanadi basin (India), Hodlur et al., (Jan-Feb 2006) demonstrated the use of resistivity data from electric-log soundings and from borehole logs to discriminate between saltwater and freshwater aquifers. They used interpreted data from eight surface-based vertical electrical soundings (VES) and electric well logs from three boreholes in the study area. They established a quantitative relation among longitudinal unit conductance S (obtained from VES), water resistivity ρ_w, and layer thickness h. They stated that ambiguities in resistivity data interpretation limit its ability to distinguish between freshwater and saltwater aquifers. Electric well-log data interpretation is much more accurate but requires boreholes, which are not cost effective when exploring for groundwater. Integrating well-log-based estimates of ρ_w into resistivity interpretation of surface-based soundings improves its ability to discriminate freshwater aquifers while maintaining cost-effective exploration.

Invasion and encroachment of saltwater into freshwater aquifers of coastal regions is a well-known phenomenon. In such areas, exploration for and identification of freshwater aquifers are primary concerns. Today, resistivity surveys with quantitative data interpretation are the most widely used geophysical techniques for exploring coastal aquifers in search of potable groundwater. Resistivity data interpretation is in principle capable of providing satisfactory resolution because saltwater resistivity is appreciably lower than that of freshwater.

2.3 BASIS FOR A FLEXIBLE LOW-COST AUTOMATED RESISTIVITY DATA ACQUISITION AND ANALYSIS SYSTEM

Meju Max A. and Montague M. (1995) developed an efficient and versatile automatic resistivity data acquisition and analysis (ARDAA) system with any 4-electrode output resistivity meter. The acquisition hardware comprises a low-cost Digital Switching Unit (DSU) or an "electronic switch box" which can be interfaced to a portable field microcomputer and a resistivity meter for automatic ground resistivity measurements. Data analysis can be affected in real-time using a simple effective direct inversion scheme that converts each apparent resistivity-electrode spacing data pair into corresponding effective resistivity depth information at a rate that is faster than that of acquisition leading to unhindered productivity. The DSU is software programmable thus allowing for easy reconfiguration for the electrode array-type deemed appropriate for a given field survey or for extension to other geophysical techniques where automatic multiple switching is required. Detailed discussions of the system design, practical considerations, time and cost-savings, and an adoption to the ABEM SAS300 terrameter are provided. A practical evaluation of the infield data-analysis scheme is given and suggestions are offered for extending the basic system for remote-site monitoring applications.

2.4 SCHLUMBERGER SOUNDINGS NEAR MEDICINE LAKE, CALIFORNIA

Zohdy Adel A. R. and Bisddrof Robert J. (1990) used direct current resistivity soundings to explore the geothermal potential of the Medicine Lake area in northern California proved to be challenging because of high contact resistances and winding roads. Deep Schlumberger soundings were made by expanding current electrode spacing along the winding roads. Measured apparent resistivities were corrected using the geometric factor for the exact array geometry instead of linear array geometry. For horizontally stratified, laterally homogeneous media, the apparent resistivities measured with a nonlinear Schlumberger array are equal to those measured with a linear Schlumberger array provided that (a) distances from the current electrodes to the center of the array are equal, and (b) the proper geometric factor is used to calculate the apparent resistivity. Corrected sounding data were interpreted using an automatic interpretation method. Forty-two maps of interpreted resistivity were calculated for depths extending from 20 to 1000 m. Computer animation of 42 maps revealed that (a) certain subtle anomalies migrate laterally with depth and can be traced to their origin; (b) an extensive volume of low-resistivity material underlies the survey area, and (c) the three areas (east of Bullseye Lake.

southwest of Glass Mountain, and northwest of Medicine Lake) may be favourable geothermal targets.

2.5 THE JOINT USE OF COINCIDENT LOOP TRANSIENT ELECTROMAGNETIC AND SCHLUMBERGER SOUNDING TO RESOLVE LAYERED STRUCTURES

One-dimensional earth models consisting of uniform horizontal layers are useful both as actual representations of earth structures and as host models for more complex structures. However, there are often inherent difficulties in establishing layer thicknesses and resistivities from one type of measurement alone. For example, the DC resistivity method is sensitive to both conductive and resistive layers, but as these layers become thin, non uniqueness becomes a severe problem. Electromagnetic (EM) methods are good for establishing the parameters of conductive layers, but they are quite insensitive to resistive layers. Raiche et al., (1985) used coincident loop transient electromagnetic (TEM) and Schlumberger methods, together with a joint inverse computer program, can vastly improve interpretation of layered-earth parameters. The final model is less dependent upon starting guesses, error bounds are much improved, and non uniqueness is much less of a problem. These advantages are illustrated by interpretation of real field data as well as by a theoretical study of four different types of earth models.

2.6 GEOPHYSICAL EXPLORATION FOR GROUNDWATER IN A SEDIMENTARY; A CASE STUDY: FROM NANKA OVER NANKA FORMATION IN ANAMBRA BASIN, SOUTHEASTERN NIGERIA

The interpretation of five resistivity curves by Emenike E. A. (2001) over Nanka town within geologic terrain often referred to as Nanka formation in Anambra Basin, south-eastern Nigeria indicates that the area has a great groundwater potential. A correlation of the curves with the lithologic log from a nearby borehole suggests that the major lithologic units penetrated by the sounding curves are laterite, clay sandstone and clay. The sandstone unit which is the aquiferous zone has a resistivity range of between 500 ohm.m and 960 ohm.m and thickness in excess of 200m. The depth to the water table is at least 100m.

2.7 TEMPERATURE DEPENDENCE OF THE ELECTRICAL RESISTIVITY OF WATER-SATURATED ROCKS

The electrical resistivities of several dacitic tuffs, sandstone, andesite, granite, and crystalline limestone samples, saturated with a 0.001 M aqueous solution of KCl, were measured by Llera et al.,(1990) in the range from room temperature to 250°C. The experiments were made using a cell technique with platinum electrodes. The data of particular interest are collected at room temperature to more than 200°C under high pressure. Basically the samples used in the present study show a quasi-exponential decrease of resistivity with temperature up to 200°C. The same temperature dependence is found for the resistivity of the saturating solution, thus confirming that conduction in water saturated rocks is essentially electrolytic. At temperatures above 200°C, some specimens of highly porous dacitic tuff still closely follow the saturating solution in the pattern of resistivity variation with temperature, exhibiting a minimum around 220°C; however, the behaviour of low-porosity crystalline rocks (notably granite) where a relatively abrupt decrease of resistivity is observed above 5O°C, departs from that of the saturating solution. Hysteresis phenomena are more or less observed in most rock samples; i.e., the resistivity after one complete thermal cycle is systematically lower than its initial value. This experimental evidence points out that mechanisms different from water characteristics, such as growth of micro cracks or chemical reactions, contribute to electrical conduction at high temperature. They pointed out that the electrical signature of the thermally induced growth of micro cracks (thermal cracking) in welded tuff and granite and suggest the possibility of using electrical measurements to monitor an extension of reservoir fractures in hot dry rock. Their interpretation of the observed dependence of resistivity on temperature is that mechanisms other than water characteristics, such as growth of micro cracks or chemical reactions, contribute to electrical conduction at high temperature.

2.8 ELECTRODE CONFIGURATION INFLUENCE ON RESISTIVITY MEASUREMENTS ABOUT A SPHERICAL ANOMALY

Lytle R. J. and Hanson J. M. (1983) stated that when electrical resistivity measurements are performed, the choice of the electrode configuration can significantly influence the utility of the results. If one wishes to search for particular types of anomalies, an assessment should be made before performing an experiment to determine which electrode configuration maximizes the likelihood of detecting such anomalies if they are present. This is designated as experimental design. The trade-offs involved with the various electrode configurations are well-known for surveys performed either from the ground surface or from within a single borehole (Evjen, 1938; Van Nostrand, 1953; Unz, 1963; Keller and Frischknecht, 1966; Rohlich, 1967; Parasnis, 1968; Roy and Apparao, 1971; Roy and Dhar, 1971; Roy, 1972; Moran et al, 1972; Snyder and Merkel, 1973). This paper discusses certain of the trade-offs involved with various electrode configurations used for cross-borehole probing. For convenience, the study herein is limited to cross-borehole probing where the electrodes are located at substantial distances from physically large electrical discontinuities (such as the ground-air interface). This effort adds to the knowledge presented previously (Daniels, 1977; Lytle, 1982) for cross-borehole probing.

2.9 MODELING RESISTIVITY ANOMALIES FROM LOCALIZED VOIDS UNDER IRREGULAR TERRAIN

In applying earth resistivity methods to the problem of locating and delineating subsurface structures, surface elevation variations along the surveyed terrain introduce distortions in the soundings. The analysis presented by Spiegel et al., (1980) is aimed at characterizing such terrain variations in the detection of relatively small subsurface targets such as caves, sinks, and tunnels in otherwise homogeneous earth materials. The analytical approach involves, first, the development of a suitable earth resistivity model for localized three-dimensional subsurface anomalies in a homogeneous flat half-space. Next, in order to apply the half-space resistivity model to irregular terrain, a Schwarz-Christoffel transformation is utilized to map the terrain surface variations into an equivalent flat half space. The technique is illustrated by calculating the resistivity response of three tunnels located below a hill with 40 m valleys on either side.

2.10 THE INVERSE PROBLEM OF THE DIRECT CURRENT CONDUCTIVITY PROFILE OF A LAYERED EARTH

Coen Shimon and Yu Michael Wang-Ho, (1981) presented a direct (noniterative) inversion algorithm for the determination of the conductivity profile of a layered earth from the measurements of the apparent resistivity with the Schlumberger array. The necessary conditions for the existence of a one-dimensional (1-D) continuous conductivity profile are determined, and the uniqueness of the solution is proved for complete and precise data.

2.11 A COMBINED APPROACH OF SCHLUMBERGER AND AXIAL POLE–DIPOLE CONFIGURATIONS FOR GROUNDWATER EXPLORATION IN HARD-ROCK AREAS

Chandra et al., (2006) stated that in hard rocks, groundwater accumulation occurs only because of secondary porosity developed due to weathering, fracturing, faulting, etc., which is highly variable and varies sharply within very short distances, contributing to near-surface inhomogeneities. This can affect the current-flow pattern in their surroundings and consequently distort the resistivity curve, and hence falsify the interpretation in terms of layer resistivity and its thickness. Thus it becomes a difficult task for locating a good well site in hard rocks. A combined approach of Schlumberger and axial pole – dipole configurations has been initiated, which will be helpful in locating the successful sites for drilling of wells in hard-rock areas.

2.12 TWO-DIMENSIONAL RESISTIVITY INVERSION

Tripp et al., (1984) based on their study suggested that resistivity data on a profile often must be interpreted in terms of a complex two-dimensional (2-D) model. However, trial-and-error modelling for such a case can be very difficult and frustrating. To make interpretation easier and more objective, they have developed a nonlinear inversion technique that estimates the resistivities of cells in a 2-D model of predetermined geometry, based on dipole-dipole resistivity data. Their numerical solution for the forward problem is based on the transmission-surface analogy. The partial derivatives of apparent resistivity with respect to model resistivities are equal to a simple function of the currents excited in the transmission surface by transmitters placed at receiver and transmitter sites. Thus, for the dipole-dipole array the inversion requires only one forward problem per iteration. They use the Box-Kanemasu method to stabilize the parameter at each step. They have tested inversion technique on synthetic and field data. In both cases, convergence is rapid and the method is practical if the number of parameters is not too large. The main limitations of the method are that the geometry of the model must be specified in advance, and that it is difficult to determine whether model misfit is due to 3-D effects or to under parameterization in the 2-D model. The technique should be used interactively, with models constrained by geologic information.

2.13 A COMBINATION OF ELECTRICAL RESISTIVITY, SEISMIC REFRACTION, AND GRAVITY MEASUREMENTS FOR GROUNDWATER EXPLORATION IN SUDAN

In the Savannah belt of central Sudan, near the town of Kosti, a regional geophysical survey has been carried out by Ronald A.V. O. (1981) forming part of a groundwater project. Because of the presence of detectable and significant contrasts in physical properties of the subsoil, integrated use could be made of electrical resistivity, seismic refraction, and gravity methods. In the interpretation of multilayer electrical sounding curves, additional subsurface information such as lithological well descriptions and geophysical well logs is normally a necessity for solving the problems of equivalence. Along a profile in the eastern part of the area studied, where additional subsurface information was scarce, 16 vertical electrical soundings have been made. A preliminary simple mathematical interpretation suggested possibilities for the presence of fresh groundwater in the eastern part of the profile. In order to solve the equivalence problem, seismic refraction work was carried out at some selected places; that yielded additional information on depths to bedrock. These seismic data made possible a unique solution of the electrical sounding curves, from which it could be concluded that all groundwater in the area is saline. Subsequent test drilling confirmed these findings.

A regional relative Bouguer anomaly map provided a picture of the general geologic structures and made possible rough estimates of depths to bedrock. In areas where the basement rocks are relatively close to the surface, as is the case with the profile presented, the gravity anomalies cannot be correlated with bedrock relief, because the effect is strongly influenced by lateral density variations within the bedrock itself. This is an example of a case where only an integrated application of several geophysical exploration methods can provide the desired hydrogeologic information in an acceptable balance between reliability and cost.

CHAPTER –3

THEORY OF ELECTRICAL RESISTIVITY

3.1 GEOPHYSICAL EXPLORATION

Geophysical exploration is the scientific measurement of physical properties of earth's crust for investigation of mineral deposits or geological structure. With the discovery of oil by geophysical method in 1926, economic pressure for locating petroleum and mineral deposits stimulated the development and improvement of many geophysical methods and equipments. In recent years, however, refinement of geophysical techniques as well as an increasing recognition of the advantages of these methods for ground water exploration has changed the situation. These methods are frequent- inexact or difficult to interpret and they are most useful when supplemented by subsurface investigation.

Geophysical methods detect differences or anomalies of physical properties with in earth crust. Density, magnetism, elasticity and electrical resistivity are properties which most commonly measured. Experience and research have enabled differences in those properties to be interpreted in terms of geological structure; rock type, porosity, water content and water quality.

3.2 ELECTRICAL RESISTIVITY METHOD

An electrical method in which current is applied by conduction to the ground by pair of electrodes penetrating into ground and resulting distribution of potential in the ground is mapped by using another pair of potential electrodes connected to a sensitive voltmeter. From the magnitude of current applied and from the knowledge of the current electrode separation, it is possible to calculate potential distribution and path of current flow. The degree to which potential at surface is affected depends on the size, shape, location and electrical resistivity of the subsurface masses. It is therefore possible to obtain information about the subsurface distribution of the bodies from potential measurements made at the surface.

The usual practice is to pass the current into ground by means of two electrodes and to measure the potential drop in-between current electrodes, a second pair of electrodes placed in line between current electrodes.

From the magnitudes of current applied and potential measured in between current electrodes, a quantity known as apparent resistivity can be calculated. If the ground is homogenous then this is the true ground resistivity but in general on field it is not so; in general ground is inhomogeneous, stratified, irregular in nature and anistropic, so it is weighted average of resistivities of formations through which current is passed. It is from an analysis that variation of this quantity with change in electrode spacing and position and deductions about subsurface can be made.

3.3 RESISTIVITY OF ROCK AND MINERALS

The electrical conduction in most of rocks is essentially electrolytic. This is because most minerals grains (except metallic ores and clay minerals) are insulators, electrical conduction being through interestial water in pores and fissures. Hence the resistivity of a rock formation generally depends upon resistivity of contained electrolyte and inversely related to the porosity and degree of saturation.

In general hard rocks are bad conductors of electricity, but conduction may take place through along cracks and fissures. In porous sediment formations, the degree of saturation and nature of the pore electrolytes govern the resistivity. In such rocks the resistivity ρ when fully saturated with water of resistivity (ρ_w) is proportional to ρ_w so that the ratio $\mathbf{F} = \rho/\rho_w$ (known as formation factor) tends to be constant for particular formation.

Therefore resistivity is extremely variable parameter not only from formation to formation but even within a particular formation. There is no general correlation between lithology and resistivity. Clay, marls, sand and gravel, limestone and crystalline rocks are in increasing order of resistivity.

Table 3.1: Electrical Resistivities of Rocks & Sediments

Rock &sediments	Electrical resistivity (Ωm)
Limestone &marble	$>10^{12}$
Quartz	$>10^{10}$
Rock salt	10^{6}-10^{7}
Granite	5000 -10^{6}
Sandstones	35 – 4000
Moraine	8 – 4000
Lime stones	120 – 400
Clays	1 - 120

The values given in Table 3.1 are the range of resistivity usually encountered for some common type of rocks, they have variable resistivity range.

Practically all rocks and minerals are semiconductor, their conductivity (1/resistivity) increases with the increases in temperatures and follow the equation.

$$\sigma = \sigma \, e^{-E/KT}$$

Where T is absolute temperature, K is Boltzman's constant and E is activation energy.

The resistivity of porous, water bearing rocks (free of clay minerals) follows Archie's law $\rho = \rho_0 f^{-m} S^{-n}$

Where

ρ_0 = resistivity of water filling in pores.

f = porosity, volume fraction of pores.

S = fraction of pore space filled by water.

n, m = certain parameters.

The value of n is normally close to 2 if 30% of pore space is filled with water but can be much greater for lesser water content.

The value of m depends upon degree of cementation as this is often well correlated with geological age of rock. It range from 1.3 (loose tertiary sediment to 1.95 (well cemented Palaeozoic one), but can be outside this range for individual case.

The determination of resistivity of rock formations is simple and need only current density in the rock sample and potential difference across a rectangular or cylindrical sample with plane end faces.

3.4 THEORY OF CURRENT FLOW

The simplest approach to the theoretical study of current flow is based on assuming completely homogenous, isotropic earth layer of uniform resistivity.

Let us consider a homogeneous layer of length L and resistance R through which a current I is flowing (see Fig. 3.1). The potential difference across the ends, given by Ohm's law

$$\Delta V = RI$$

Or

$$\frac{\Delta V}{I} = R \qquad (3.1)$$

Where

I = Current in conducting body.

ΔV = Potential difference between two surfaces of constant potential.

R = A constant called the resistance between surfaces.

We must also introduce at this point the definition of resistivity.

If a conductor carries a current with parallel lines of flow over a cross sectional area A, then its resistivity ρ is define by

$$\rho = \frac{RA}{L} \tag{3.2}$$

Where R is the resistance measured between two equipotential surfaces separated by a distance L (see Fig. 3.1).

From Eqs. (3.1) & (3.2)

$$I = \frac{\Delta V}{R} = \frac{\Delta V \; A}{\rho L}$$

& current density j is given by $j = \frac{I}{A} = \frac{\Delta V}{\rho L}$ (3.3)

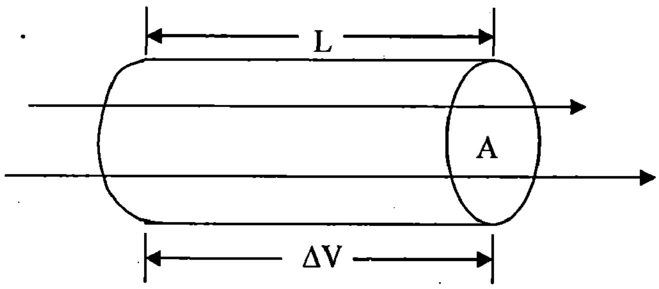


Fig. 3.1: Conceptual diagram to define resistivity

If the lines of flow are not parallel, so that the current density varies over the conductor, the same argument can be applied to an infinitesimal element of the conductor bounded by equipotential surfaces which may be curved. The ratio ΔV/L becomes in the limit the maximum potential gradient dV/dL and the expression of Ohm's law is:

$$j = -\frac{1}{\rho}\frac{dV}{dL} \tag{3.4}$$

The negative sign is introduced to express the fact that potential increases in the opposite direction of current flow.

The component of current density in a direction r is

$$j_r = -\frac{1}{\rho}\frac{\partial V}{\partial r} \qquad (3.5)$$

In which the potential gradient in direction r is used instead of the maximum gradient. It is an important fact that in a homogeneous medium an increase in current density, seen as a crowding or convergence of current lines, means an increase in the magnitude of the potential gradient.

3.4.1 Potential Due to a Point Source in a Homogeneous Medium

In this context, it is assumed that there is point source of strength S, treated as positive 'source' and a negative or sink source for away from it, say at infinity from the positive 'source'.

The potential due to point source is given by

$$V = S/r$$

S is the strength of source and r is the distance from it. The value of S depends upon the resistivity, the current and the situation of the source.

Firstly imagine the medium to be infinite in extent. Consider current which flow outward through a sphere of radius r surrounding the source. The current flowing through one square centimetre of the surface of this is

$$j = -\frac{1}{\rho}\frac{\partial V}{\partial r} = \frac{1}{\rho}\frac{S}{r^2} \qquad (3.6)$$

Since the current density is the same over the whole spherical surface the total current is

$$I = 4\pi \cdot r^2 \frac{S}{\rho r^2} \qquad (3.7)$$

$$I = 4\pi \frac{S}{\rho} \qquad (3.8)$$

$$S = \frac{I\rho}{4\pi}$$

However, if the medium is only semi-infinite and is bounded by a plane surface separating it from the air, which can be taken to be of infinite resistivity, and the source is located at the interface, a different result is obtained. This is of course the condition that is met in practice in resistivity surveying.

But under the same condition the current flow outward through a hemisphere only then.

$$S = \frac{I\rho}{2\pi} \qquad (3.9)$$

If the potential gradient be measured at some point has distant r from the source at the surface then from the knowledge this & of the current strength, the resistivity can be found

$$V = \frac{S}{r} = \frac{I\rho}{2\pi \cdot r}$$

$$\frac{\partial V}{\partial r} = -\frac{I\rho}{2\pi r.r} = -\frac{I\rho}{2\pi r^2}$$

$$\rho = -\frac{2\pi r^2}{I}\frac{\partial V}{\partial r} \qquad (3.10)$$

3.4.2 Potential Due to Pair of Electrode (source & sink) Situated at Finite Distance

Figure 3.2 shows setup for measurement of potential difference between pair of potential electrode between source and sink in a line

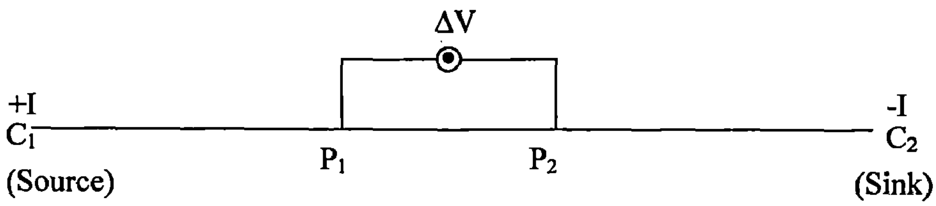


Fig. 3.2: Setup for measurement of potential difference between source & sink

P. D. between point P_1 & P_2 due to source

$$\Delta V = \frac{I\rho}{2\pi}\left(\frac{1}{C_1P_1} - \frac{1}{C_1P_2}\right) \tag{3.11}$$

Similarly P. D. between P_1 & P_2 due to sink

$$\Delta V = \frac{-I\rho}{2\pi}\left(\frac{1}{C_2P_1} - \frac{1}{C_2P_2}\right) \tag{3.12}$$

The total P.D. between P_1 & P_2 is therefore sum of Eqs. (3.11) & (3.12)

$$\Delta V = \frac{I\rho}{2\pi}\left(\frac{1}{C_1P_1} - \frac{1}{C_1P_2} - \frac{1}{C_2P_1} + \frac{1}{C_2P_2}\right)$$

$$\rho = 2\pi \frac{\Delta V}{I} \frac{I}{G} \tag{3.13}$$

Where

ρ = True resistivity

G = Geometric factor or shape factor of an electrode configuration

The value of ρ in this way for a homogeneous conducting medium is independent of positions of electrode and is not affected when the positions of the current and potential electrodes are inter changed.

It is also valid for heterogeneous earth consisting of any number of separate regions, each of which is homogeneous medium whose conductivity is independent of current density.

3.5 APPARENT RESISTIVITY AND TRUE RESISTIVITY

The true resistivity of the underground can be computed by Eq. (3.13) provided that under ground is completely homogeneous. For heterogeneous underground the resistivity computed by Eq. (3.13) varies with the position of electrodes. For example, if current electrodes are moved while potential electrodes are kept fixed. Also, if a given electrode configuration moved as a whole, a different value of ρ is obtained for each position of the array, provided lateral variations in resistivity exist within the ground. The resistivity obtained by Eq. (3.13) for a heterogeneous underground is, therefore designated as the apparent resistivity ρ_a.

The apparent resistivity is a formal; rather an artificial concept and it should not be considered to be average of resistivities encountered in the heterogeneous under ground formation. The concept of apparent resistivity is very useful in surface investigations e.g. resistivity surveying. For proper interpretation of this quantity (ρ_a) one must always bear in-mind the configuration with which it has been determined.

3.6 TWO MEDIA OF DIFFERING RESISTIVITY SEPARATED BY A PLANE INTERFACE

At the boundary between two media of different resistivities the potential remains continuous while current lines are refracted according to the law of tangents as they pass through the boundary.

Consider a boundary between two media of resistivities $\rho_1 \& \rho_2$ as shown in Fig. 3.3, x direction is taken as parallel to boundary and y-direction being normal to it.

A current density j is flowing in upper media has component as jx_1 and jy_1 and in lower media component are jx_2 & jy_2.

Therefore the tangential components of the potential gradient in two media must be the same,

$$\frac{\partial V_1}{\partial x} = \frac{\partial V_2}{\partial x}$$

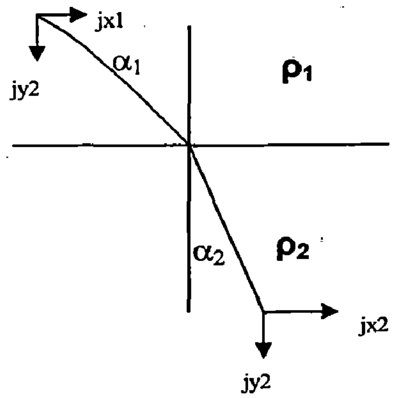


Fig. 3.3: The refraction of a line of current flow at a boundary

Now $$jx_1\rho_1 = -\frac{\partial V_1}{\partial x}$$

And $$jx_2\rho_2 = -\frac{\partial V_1}{\partial x}$$

Therefore $$jx_1\rho_1 = jx_2\rho_2 \tag{3.14}$$

Also the normal component of the current approaching to the boundary from both sides must be equal.

$$jy_1 = jy_2 \tag{3.15}$$

Dividing Eq. (3.14) by Eq. (3.15)

$$\frac{jx_1\rho_1}{jy_1} = \frac{jx_2}{jy_2}\rho_2$$

Also $\dfrac{jx_1}{Jy_1} = \tan\alpha_1$ & $\dfrac{jx_2}{Jy_2} = \tan\alpha_2$

$$\rho_1 \tan\alpha_1 = \rho_2 \tan\alpha_2$$

$$\frac{\rho_1}{\rho_2} = \frac{\tan\alpha_2}{\tan\alpha_1} \tag{3.16}$$

Where $\rho_2 > \rho_1$, the current lines will therefore be refracted towards the normal. The divergence or convergence of current lines will depend upon whether the source is situated in lower or higher resistivity medium (see Fig. 3.4).

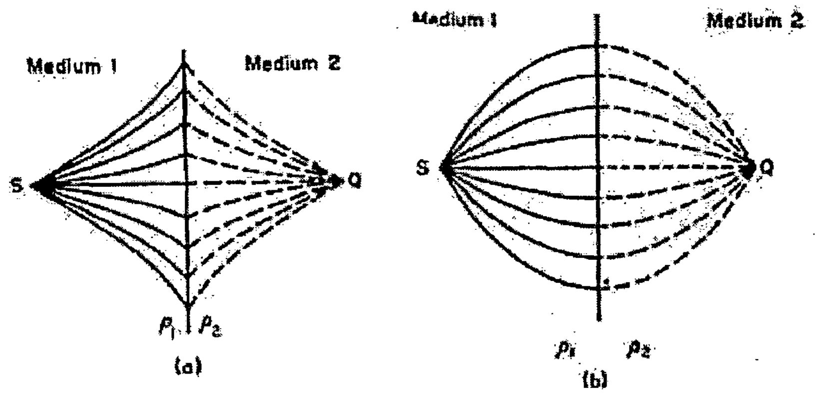


Fig. 3.4: The effect of boundary on the distribution of lines of current flow (a) where $\rho_2 > \rho_1$ (b) where $\rho_1 > \rho_2$

3.7 OPTICAL THEORY OF CURRENT DISTRIBUTION

By optical analogy the potential at any point P would be that from S plus the amount reflected by medium 2 or layer ρ_2. As if the reflected amount were coming from the image S^1. If the dimming of the apparent source at S^1 be indicated by a factor k (similar to the reflection coefficient in optics)

The potential at P, see Fig. 3.5

$$V_1(P) = \frac{I\,\rho_1}{2\pi}\left(\frac{1}{r_1} + \frac{k}{r_2}\right)$$

Imagine that P is in second media then potential

$$V_2(P) = \frac{I\rho_2}{2\pi}\left(\frac{1}{r_1} - \frac{k}{r_1}\right)$$

If $r_1 = r_2$ then $V_1(P) = V_2(P)$

$$\frac{I\rho_1}{2\pi}\left(\frac{1+k}{r_1}\right)=\frac{I\rho_2}{2\pi}\frac{(1-k)}{r_1}$$

$$\rho_1(1+k)=\rho_2(1-k)$$

$$\frac{\rho_1}{\rho_2}=\frac{1-k}{1+k} \qquad (3.17a)$$

Or $$k=\frac{\rho_2-\rho_1}{\rho_2+\rho_1} \qquad (3.17\ b)$$

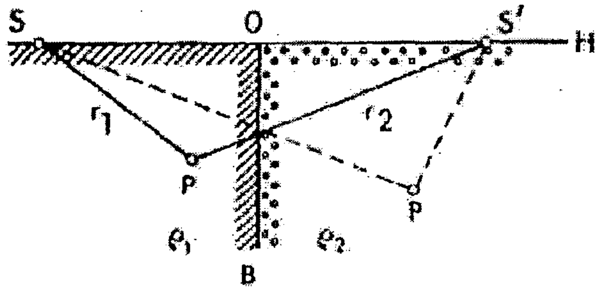


Fig. 3.5: The potential distribution in two media

The value of dimming factor always lies between ± 1 if second layer is pure insulator $(\rho_2=0)$ k=+1 if second layer is prefect conductor $(\rho_2=0)k=$-1 if $\rho_1=\rho_2=0$, no boundary exist and k =0.

3.8 THE FOUR ELECTRODE SYSTEM OF MEASUREMENT

In the previous sections, it has been discussed that the measurements of potential near a single positive source where the corresponding negative source considered at infinite distance. In these circumstances the outward flow of current is radial except, if it is not distorted by inhomogenties in resistivity. However it is generally more useful if current flow can be concentrated within depth from the surface to which it is investigated. It can be done by limiting current electrode separations. Fig. 3.6 shows, for homogeneous ground, the variation of current density in a plane which is normal to and mid way between two electrodes; this is being plotted as a function of the ratio of depth to electrode separation. From this it is apparent that the distance below the surface above which any chosen proportion of the current flows has relationship. This is not strictly true in layered ground, the distribution of the current depending also on the resistivities of various layers. Nevertheless it is still true that increasing the spacing of current electrode increases the proportion of current flowing below a particular depth (see Fig. 3.7).

The current density at a particular depth varies with electrode separation, the maximum occurring when the separation of current electrode is equal to 1.4 h.

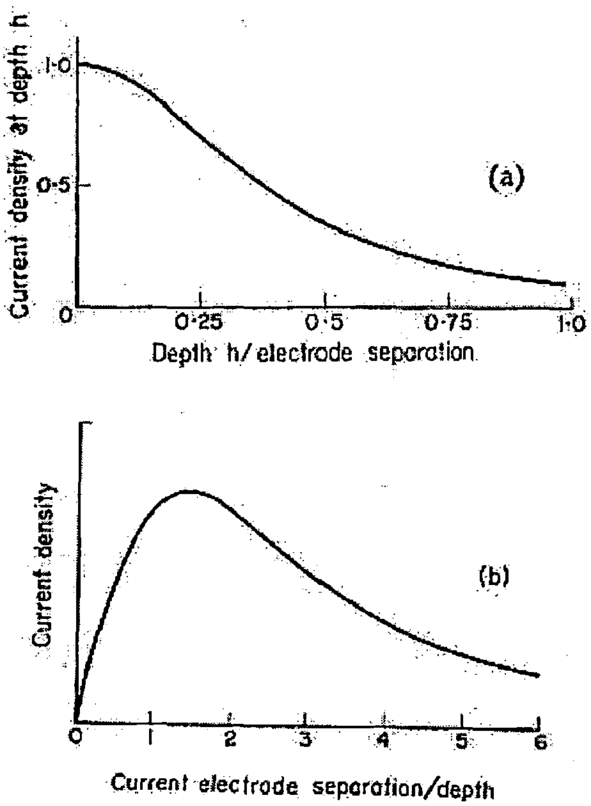


Fig. 3.6: (a) The variation of current density (expressed as a fraction of its value at the surface) with depth in a flow mid way between the current electrodes (b) current density at unit depth as a function of current electrode spacing

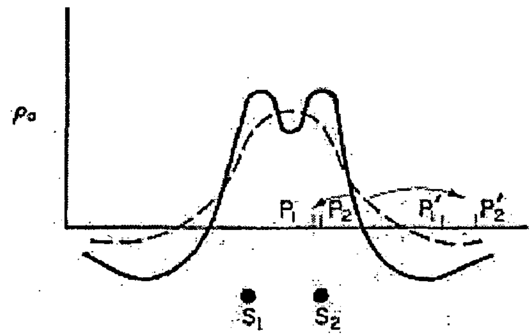


Fig. 3.7: The effect of increasing electrode separation on the resistivity anomaly due to two small bodies S_1 and S_2

—— Anomaly obtained with a small separation P_1P_2

------- Anomaly obtained with a small separation $P_1'P_2'$

As the electrode separation is increased (see Fig. 3.7) an average gradient over a longer distance is measured; the sharpness of the measured peaks of the two disturbances will decrease and finally the two will merge into one broad anomaly.

3.9 DIFFERENT TYPE OF ARRAY ARRANGEMENT

3.9.1 Wenner configuration: In this arrangement four electrodes are placed in line at equal distance apart, the inner pair being the potential electrodes and outer pair are current electrodes. During the measurement, all the four electrodes are moved. This method is most suited for contour maps in which curves of equal resistivities are plotted on graph for a specified area.

$$\rho_a = 2\pi \; a \frac{V}{I} \tag{3.18}$$

$$\rho a = 2\pi . a \, R$$

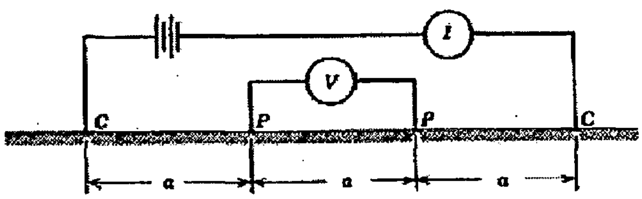


Fig. 3.8: Wenner electrode configuration

3.9.2 Schlumberger configuration: This is also a symmetrical layout but the separation of the potential electrodes is smaller compared to current electrode. L >> b but for field application L≥ 5b is considerable. This array is most suited where high resolution is needed i.e.—Vertical electrical sounding, where stratified layers to be identified.

$$\rho a = \pi \left[\frac{(L/2)^2 - (b/2)^2}{b} \right] \frac{V}{I} \qquad (3.19)$$

Where $2\pi a$ and $\left[\frac{(L/2)^2 - (b/2)^2}{b} \right]$ are termed as geometric factor of configuration.

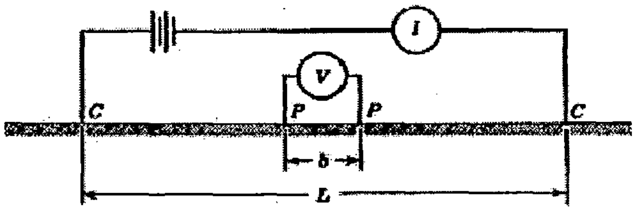


Fig. 3.9: Schlumberger electrode configuration

3.10 VERTICAL ELECTRICAL SOUNDING (VES)

The aim of resistivity survey is to delineate resistivity boundaries and also often to measure formation resistivities. When ground consist of a number of more or less horizontal layers, knowledge of vertical variation in the resistivity is required. The objective of VES is to deduce the variation of resistivity with depth below a given point on the ground surface, and to correlate it with the available geological information in order to infer the depths and resistivities of the layers (formation) present.

The procedure is based on the fact that current penetrates continuously deeper with the increasing separation of current electrodes in VES, Schlumberger configuration is used. When the electrode separation C_1C_2 is small, compared with the thickness of upper layer, the apparent resistivity as determined by measuring ΔV between potential electrodes P_1 P_2, would be virtually the same as the resistivity of upper layer ρ_1. Keeping P_1P_2 constant, distance between C_1C_2 is increased in step by step and taking measurement of apparent resistivity for each step. A stage is arrived when potential measurement between P_1P_2 become insufficient, the distance between P_1P_2 is increased but keeping the ratio $L \geq 5b$ in the same progression, several readings are taken for apparent resistivity and the data obtained are presented in the form of curve on log-log paper, this is called sounding curve and on the basis of sounding curve interpretations are made.

Figure 3.10 shows typical two and three layer sounding curves for the variation in apparent resistivity as a function of the current electrode separation for Schlumberger electrode configuration.

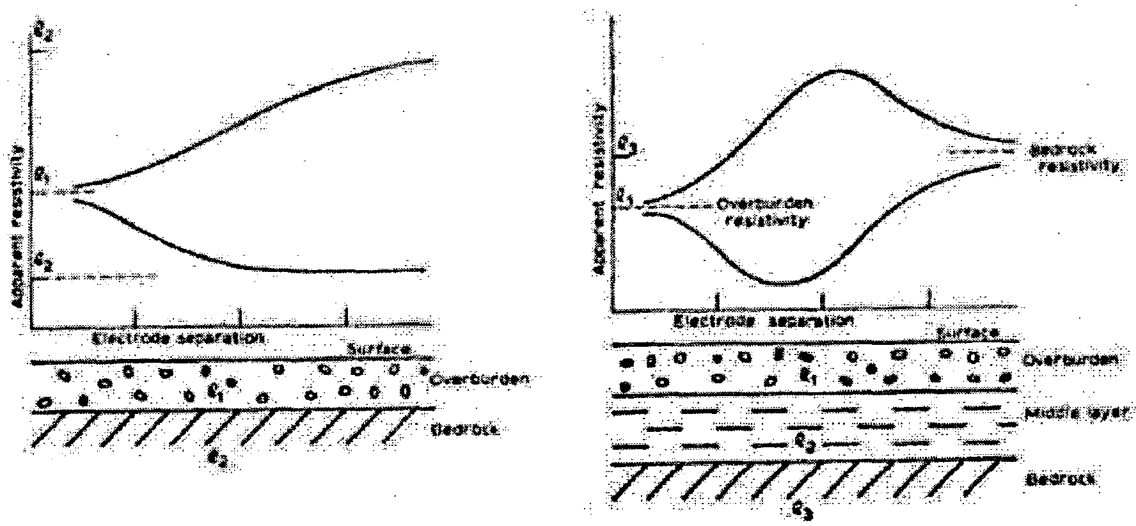


Fig. 3.10: Showing two & three layer electrical sounding curve

3.11 TYPES OF VES CURVE

With the addition of a third layer (h_2 ρ_2) sandwiched between top layer (h_1, ρ_1) and substratum (ρ_3) the problem becomes much more complex. The apparent resistivity curve can then take four basic shapes (Fig. 3.11) known as Q (or DH, descending Hummel), A (ascending), K (or DA, displaced anistropic) and H (Hummel type with minimum) depending upon the relative magnitudes of ρ_1, ρ_2 & ρ_3. In every case, however, ρ_a approaches ρ_1 for small values of L and ρ_3 for large ones. At intermediate values of L it is influenced by the resistivity of middle layer.

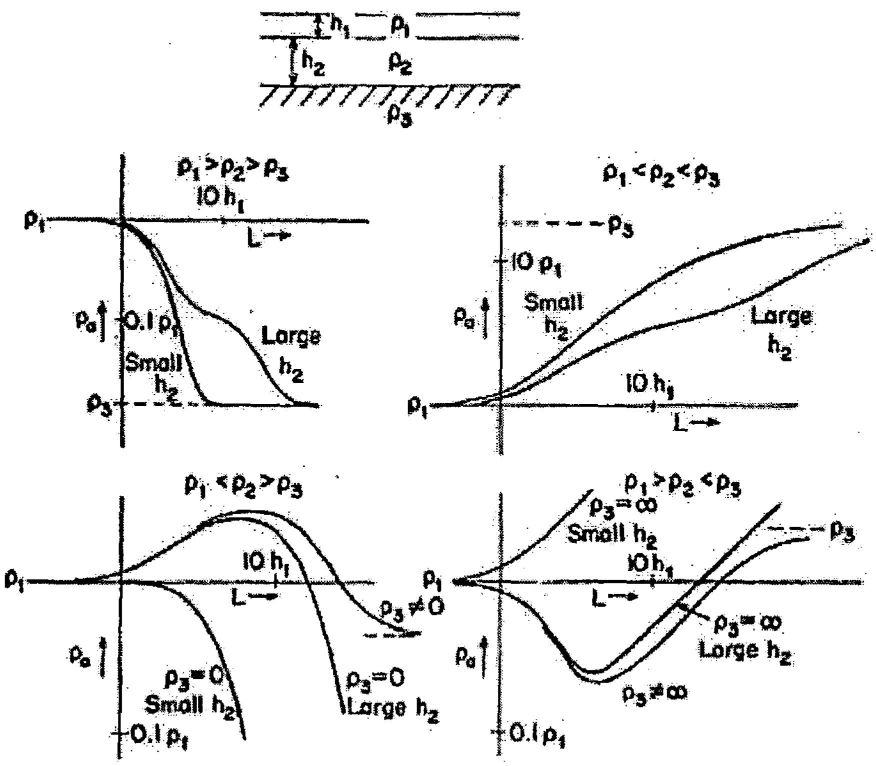


Fig. 3.11: Q (or DH), A, K (or DA) and H-type curves in VES

CHAPTER –4

INTERPRETATION METHODS

4.1 INTERPRETATION OF VES CURVE

When apparent resistivity ρ_a is plotted against electrode spacing (a for Wenner, and L/2 for Schlumberger) for various spacing at one location, a smooth curve can be drawn through the points. The interpretation of such curve in terms of subsurface condition is a complex and frequent difficult problem. The solution can be obtained in two parts (1) Interpretation in terms of various layers of actual (as distinguished from apparent) resistivities and their depths (2) interpretation of the actual resistivities in terms of subsurface geologic and ground water conditions. First part can be accomplished with theoretically computed resistivity sounding curve of two, three and four-layer cases for various ratios of resistivities. Master curves and evaluation of curve matching techniques have been published for the Wenner configuration and Schlumberger configuration.

Second Part depends on availability of nearby bore hole data. Comparing actual resistivity variations with depth to data from a nearby logged test hole, enables a correlation to be established with subsurface geologic and ground water condition.

The quantitative interpretation (first part) of resistivity data is one of the most intricate problems and one should constantly guard against simple rules of thumb in this respect. In spite of the elaborate mathematical study of the problem made by several authors (Tagg 1964, Koefoed 1968, Ghosh 1971, Inman et al., 1973, Zohdy, 1975, Parker 1984), it is very difficult to obtain reliable results applying a theoretical analysis to the resistivity data obtained in the field. This is because the theory developed can only be applied to simple plane-layered models, whereas in practice the variation in resistivity are usually much more complex both in lateral and vertical direction.

However, some geological situations can be approximated quite closely by simple layered structure for which interpretation techniques based on the use of standard theoretical curves.

A set of 2400 three and four layer curves for use with data obtained using a Wenner type of electrode configuration has been published by Mooney and Wetzel (1956). The compagnie generale de geophysique (1955) has been also published a smaller collection of 480 three layer curves for use with Schlumberger type electrode arrangement.

When carrying out depth interpretation, it is good practice to start by trying the curve matching method, for in this way a good deal of information about ground can be quickly and simply obtained. Even though an exact interpretation may not prove possible; one can often get an idea of the number of layers present and of the relative thicknesses and resistivity ratios, always provided that ground is approximately horizontally layered.

Conditions vary so widely that it is not possible to give any general figure for the accuracy of depth interpretation. Three or four layer curves are used more to get a general idea of the layering rather than to evaluate thicknesses. This is because so often the vertical resistivity variation is more complex and covers a wide range than can be covered by types of curves and there is also no way of allowing for lateral resistivity changes.

4.2 CURVE MATCHING BY MASTER CURVES

This method involves a comparison of the measured curve with a set of theoretically calculated master curves. It can be used provided that

(1) The data can be plausibly referred to the number of layers for which the master curves are calculated.

(2) The curve has been calculated for the electrode configuration of problem.

Master curves are calculated assuming $\rho_1 = 1\Omega m$ and $h_1 = 1m$ and plotted on double logarithmic paper (Fig. 4.1).

The observed ρ_a is plotted against L on the transparent double logarithmic paper with the same modulus as the master curves paper. Keeping respective axes parallel, the transparent paper is slid on various mater curves in succession until a satisfactory match is obtained with some curve. The value of L (or AB/2) coinciding with point 1.0 on x-axis of matching curve gives h_1 and the measured value of ρ_a coinciding with the point 1.0 on y-axis gives ρ_1. The values of h_2, ρ_2, h_3, ρ_3, etc are obtained from the appropriate parameters belonging to the matching master curve.

The curve matching technique by means of standard curve is practicable only when number of layers is small, say up to four. Even for four layers the number of reasonable parameter combinations is so large and the collection of curves so bulky that interpretation by matching becomes generally impracticable and for a larger numbers of layers it is virtually impossible.

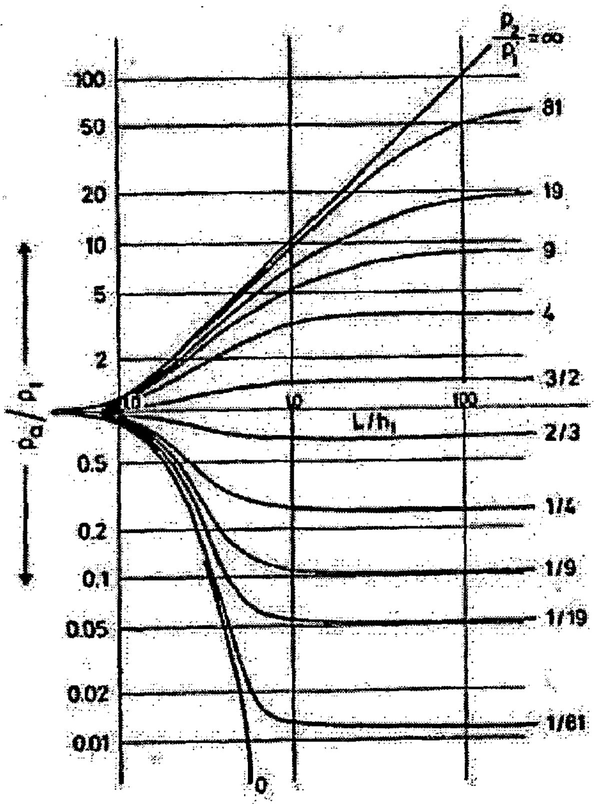


Fig. 4.1: Master curve and example of curve matching of two layers sounding curve

4.3 THE AUXILLARY POINT METHOD

This method is developed by Hummel. The method is explained with a set of example for which consider a three layer case with $h_2 >> h_1$. Clearly as long as the current electrode separation does not exceed a certain value, the apparent resistivity curve will not differ appreciably from a two-layer case with the same ρ_2 / ρ_1 as that in the three layer case under consideration. At large electrode separations the third layer that is the infinite substratum (ρ_3) will influence the measurements.

Hummel showed that for sufficiently large separations of current electrode the apparent resistivity curve obtained is virtually same as for two layer case with the same substratum with an overlying layer of thickness $H = h_1 + h_2$ and ρ_m is given by

$$\frac{H}{\rho_m} = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} \tag{4.1}$$

ρ_m is derived by applying Kirchoff's law for resistances in parallel.

Rearranging Eq. (4.1)

$$\frac{\rho_m}{\rho_1} = \frac{\rho_2/\rho_1}{\rho_2/\rho_1 - 1 + \frac{H}{m}} \times \frac{H}{m} \tag{4.2}$$

By curve matching with master curves, ρ_m can be calculated but to avoid calculations for ρ_m, the right hand side of Eq. (4.2) is plotted on an auxiliary master diagram (see Fig. 4.3) as a function of the dimensionless parameter H/h_1. A family of curves for various ρ_1/ρ_2 values is obtained and ρ_m can be read off as ordinate of the appropriate curve.

The method can be used in principle to a sounding curve for any number of layers by the alternate use of the two layer master curves and family of auxiliary curves (Q, A, K & H types).

An explanatory example (see Fig. 4.2) with hypothetical data is as follows:

A transparent paper on which the sounding curve has been traced is slid on master curves, keeping the respective axes parallel to each other until a reasonably long portion of the first branch of the measured curves coincide with one of master curves. In example the coinciding master curve is one of which $\rho_2/\rho_1 = 3$ (dashed in Fig. 4.2). The origin (1, 1) of the master collection is marked on the tracing (circle A with cross in Fig. 4.2) the coordinates of A give ρ_1, h_1.

The tracing is now placed on auxiliary curves Fig. 4.3, on which the family of Eq. (4.2) has been drawn on double log paper with same modulus, with point A coinciding with the origin of the auxiliary curves; the respective axes are being parallel. The auxiliary curve for which $\rho_2/\rho_1 = 3$ is copied on the tracing for a sufficient length. This is the curve marked $\rho_m / \rho_1 = 3$.

The tracing is now slid on master curve Fig. 4.1 keeping axes parallel and with the origin always on the copied curve $\rho_m/\rho_1 = 3$, until a further reasonably long portion of the measured sounding curve (the descending branch) coincides with one of master curves in Fig. 4.1. This is dashed curve $\rho_3/\rho_m^{(1)} = 0.11$. The origin of master curve again marked on the tracing (point B). The coordinates of B give $h_1 + h_2$ and $\rho_m^{(1)}$.

The tracing is now once more placed on the auxiliary curves and curve for 0.11 copied. On retransferring the tracing on master curve and repeating the procedure to obtain a coinciding master curve $\left(\rho_4/\rho_m^{(2)} = 9\right)$, we locate the point C, the coordinates of which give $\rho_m^{(2)}$ and $h_1+h_2+h_3$ where

$$\frac{h_1 + h_2 + h_3}{\rho_m^{(2)}} = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \frac{h_3}{\rho_3}$$

Thus resistivities and thicknesses of various layers obtained and complete result is shown on Fig.4.2.

The most serious limitation of the auxiliary point method is that it requires the thickness of each successive layer to be much greater than the combined thickness of all the overlaying layers. The method is never extensively used and can give satisfactory results in experienced hands. The risk of misleading result is however; very great since the basic condition is a severe geological restriction. Fast computer methods are available; the main use of the auxiliary point method is the initial guess of solution for subsequent optimization.

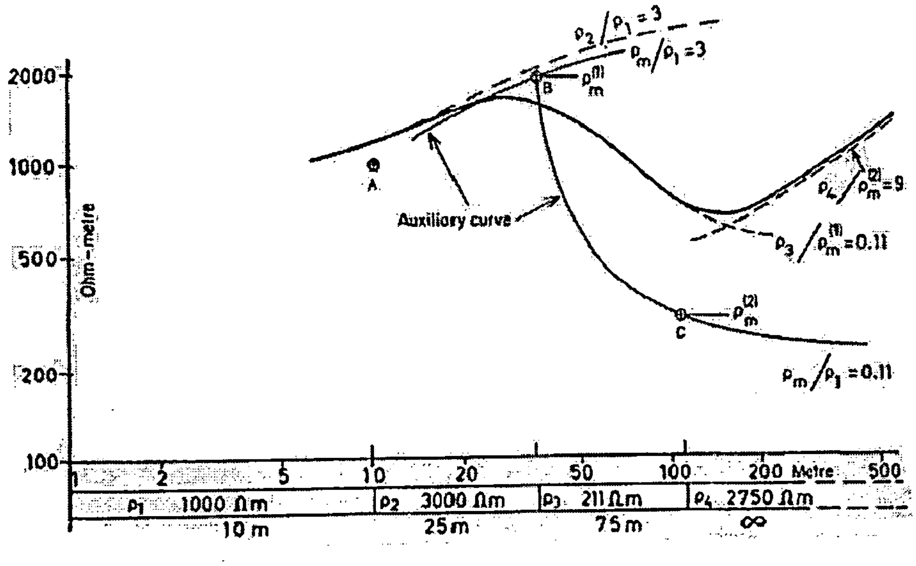


Fig. 4.2: A hypothetical example of auxiliary point method of VES interpretation

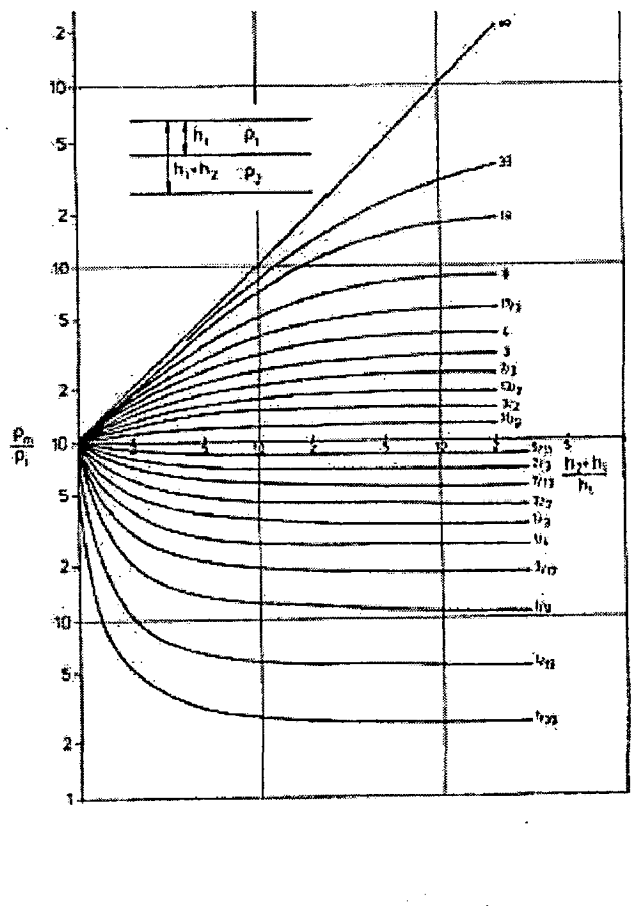


Fig. 4.3: Auxiliary curve based on Eq. 4.2 for VES interpretation

4.4 IX- ID VES INTERPRETATION SOFTWARE METHOD

IX-1D is a 1-D direct current resistivity, induced polarization (IP), magneto telluric (MT) and electromagnetic (EM) interpretation software with following features-

1. Support most DC resistivity array, including Wenner, Schlumberger, dipole-dipole, pole-dipole and pole-pole arrays.
2. Creation of data by spreadsheet entry.
3. Import data from or models from flat ASC II files.
4. Import of borehole resistivity data from flat ASC II files.
5. Numeric editing of data and models using spreadsheets.
6. Forward modelling and comparison of synthetic curve for the data.
7. Inverse the modelling to improve the fit to the layered model for given data.
8. Automatic estimation of layered model for the given data.
9. Automatic estimation of a smooth layered model.

The standard display show the data on the left and model on the right. Vertical axis is apparent resistivity and horizontal axis is half of electrode spacing for Schlumberger array.

Forward modelling is carried out using linear filters in a manner similar to that described by Davis et. al., (1980), except that it uses a 283 point adaptive linear filter from Anderson (1979).

4.5 AMBIGUITY IN RESISTIVITY INTERPRETATION

In actual application of the various interpretation methods to a particular field problem limitation are set by the maximum distance from the current source to which the electric field is given and by irregularities in the field to surface inhomogeneities. Further more all measurements have a finite accuracy. On account of all these causes a correct and 100% accurate matching result with bore well data is not obtained. Different places, different layered ground may not have unique sounding representation. Two different layered models may have a common sounding curve, thus interpretation of a sounding curve may be misleading, faulty, incorrect etc.

In addition, the "Principle of equivalence" and the "Principle of suppression" introduce other types of ambiguity in the interoperation. For example a relatively thin conductive layer sandwiched between two layers of higher resistivities will tend to concentrate current flow in it. The total current carried by it will be unaltered if we increase it's resistivity 'ρ' but at the same time increase it's thickness 'h' so the ratio h/ρ is constant see Fig. 4.4.

On the other hand, a resistant bed is introduced between two more conductive layers is characterized by it's product of thickness and resistivity (hρ). Thus all middle layers for which the product hρ is constant are electrically equivalent. In either case a unique determination of h and ρ would be difficult if not impossible.

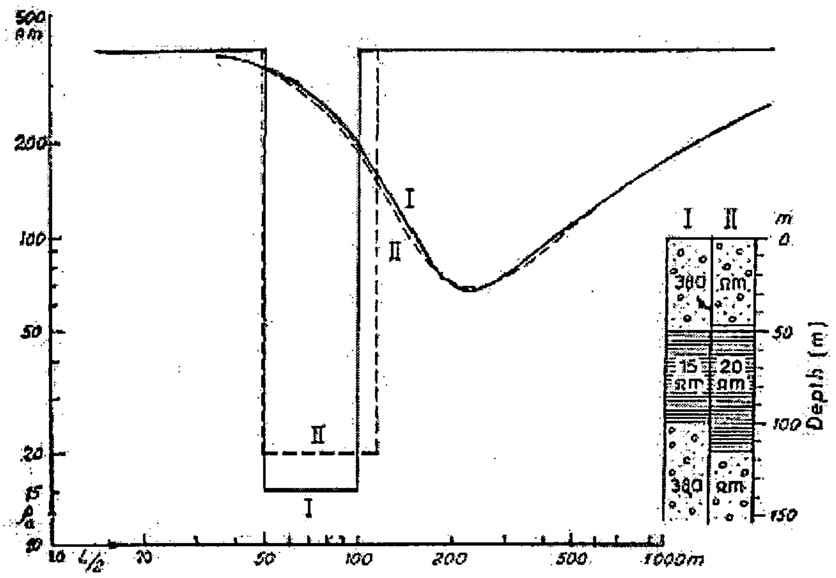


Fig. 4.4: Showing the principle of equivalence

CHAPTER –5

INSTRUMENT FEATURES

5.1 INSTRUMENT USED IN RESISTIVITY SURVEY

In early days electrical resistivity surveying was done with instruments which generate alternating current, this is because of-

(1) Electrochemical e.m.f. produced between the metal electrodes and the ground, would be a source of error in reading.

(2) Direct current (DC) measurements are also effected by natural earth current which produces a slowly varying potential difference across the electrodes.

Electro chemical effect can be avoided by using non-polarizing electrodes, an electrode of this type consist of a porous pot containing a metal electrode immersed in an electrolyte of one of it's own salt for example a copper electrode immerged in porous pot of copper sulphate. But this type of electrode system is inconvenient and troublesome and time consuming; solution of these electrodes is non-polarizable stainless steel electrodes.

It is desirable that low frequency current should be used, this is because ground inductance and capacitances and more complex frequencies effects measurements above a few tens of cycles per second.

Alternating current based survey is not suitable for deeper penetration of current into ground. DC survey is the most suitable for vertical electrical sounding where depth of penetration is more important.

However, if investigation down to much more depth is required, more accurate results are likely to be obtained by using an instrument with a greater power output.

Greater the depth of investigation larger must be separation between current electrodes and the smaller becomes the ground resistance between them.

In this work of resistivity surveying, the equipment ABEM Terrameter **SAS 300B** have been used, because of it's portability and ability to investigate deeper depths. Some features of ABEM terrameter SAS 300B and working procedure are illustrated in the subsequent sections.

5.2 SAS- STANDS FOR SIGNAL AVERAGING SYSTEM

A method whereby consecutive readings are taken automatically and the results are averaged out continuously. Continuously updated running average is presented automatically on the display. This continues until the operator is satisfied with the stability of the result. SAS results are more reliable than those obtained using single shot systems. More over, SAS results are easier to check than results obtained using signal stacking.

5.3 RESISTIVITY OPERATING MODE

It comprises a battery powered, deep penetration resistivity meter with an output sufficient for a current electrode separation of 2000 meters under good surveying conditions. Discrimination circuitry and programming separates DC voltages; self potentials and noise from the incoming signal.

V/I is calculated automatically and displayed in digital form in kilo ohms, ohms or milliohms.

The overall range thus extends from 0.05 milliohms to 1999 kilo ohms. The range can be extended down to 0.002 milliohms by means of the SAS 2000 Booster.

5.4 COMPONENTS OF TERRAMETER ABEM SAS 300B

The terrameter SAS 300B contains three main units, all housed in a single casing, the transmitter, the receiver and the microprocessor. The electrically isolated transmitter sends out well-defined and regulated signal currents. The receiver discriminates noise and measure voltages correlated with transmitted signal current. The microprocessor monitors and controls operations and calculates results.

In geophysical surveys, the SAS 300B permits natural or induced signals to be measured at extremely low levels, with excellent penetration and low power consumption.

5.4.1 Transmitter

The transmitted current output is commutated in a time pattern suitable for resistivity surveying.

Standard factory current output programming (in combination with the receiving principle) provides skin impedance effects equivalent to approximately 0.4 Hz for 3.6 seconds of current flow. The operator can however, select two other time scale equivalent to 0.2 and 0.1 Hz. These should only be used under extreme depth and resistivity conditions since the corresponding time cycles (7.2 and 14.4 seconds of current flow) increase power consumption. For normal use, the standard factory programming is equivalent to DC surveying. The current amplitude is set by the operator to suit the actual survey conditions. It can be set 0.2, 0.5, 1, 2.5, 10, 20 mA at 160V maximum current electrode potential. The range can be extended to 500 mA or to 400V by using the optional terrameter SAS 2000 booster.

5.4.2 Receiver

The transmitted signal (plus SP and ground noise) is measured by the receiver at discrete time intervals when the eddy currents, the IP and the cable transients have decayed to low levels.

Penetration and accuracy limits are imposed mainly by noise caused by telluric currents, power transmission lines and electro chemical variations at the potential electrodes.

A unique integrator combined with an ingenious measurement strategy permits the terrameter SAS 300B receiver to extract the signal from man made and natural noise, even when using low, safe signal voltage levels. This measurement strategy includes signal stacking, logical and analogue filtering, rejection of induced polarization (IP) effects and rejection of the transient phase of signal current.

5.4.3 Microprocessor

The microprocessor controls and monitors all measurements to ensure optimal accuracy and sensitivity and to make certain that the instrument is used correctly when the operator presses the MEASURE button; the microprocessor runs a thorough check of circuits and switch positions. It also checks the battery condition and usability of selected parameters. The complete check up procedure takes only one second and, if necessary, warning and information comprising beeper signals and simple error codes tell the operator to change parameters or to check circuits. When satisfied, the microprocessor automatically starts the measurement cycle, and after all readings have been taken it puts the instrument into standby mode with the final result displayed.

5.5 RESISTANCE MEASUREMENT

In the resistance measuring mode the terrameter SAS 300 B measures signal voltage created by the transmitter signal current while rejecting both DC (Self potential) voltage and noise, V/I is automatically calculated and displayed digitally in kilo ohms, ohms or milliohms.

The relevant receiver resistance range is automatically selected. The result is displayed to 3 or 4 decimal places. When transmitter is operating at 20 mA, the terrameter SAS 300B has a significant resolution of 0.05 milliohms for a single reading. When the terrameter SAS 2000 booster is used to obtain a current of 500 mA, the resolution for a single reading is 0.002 milliohms.

To take full advantage of outstanding capabilities of the terrameter SAS 300B, meticulous care must be taken for the arrangement of cables and electrodes used in field. Current leakage and creep can substantially reduce the attainable accuracy and sensitivity and thus depth penetration.

Figure 5.1 shows the SAS penetration depth and approximate distance between current electrodes used for Schlumberger sounding (At different transmitted currents and potential electrodes separations). Homogeneous ground and normal telluric noise are assumed. A few measuring cycles are sufficient for checking the noise level. The distances between the current electrodes (A&B) can be doubled by running 64 averaging cycles.

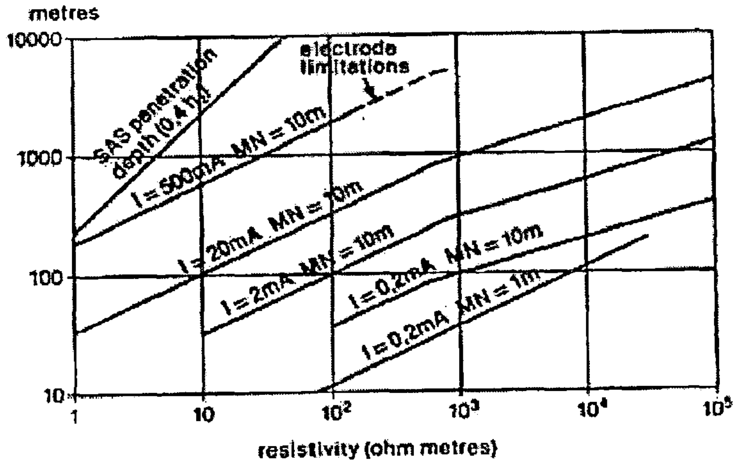


Fig. 5.1: Penetration depth curves

5.6 INSTRUMENT CONTROLS

The Terrameter SAS 300 B has the following five controls:

1. SAS (Signal averaging system) selector (Also called the cycle selector). This 4-position selector is used to choose single reading mode or 4, 16 and 64 signal averaging mode.
2. Function selector – this function permits either choose resistivity measurement or voltage measurement (SP method), another location of selector to tune it for battery checking position, the battery voltage is measured.

   If the battery is properly charged the display will read out 12.5 to 15v. If reading is less than 11.5v, the battery will soon need recharging.
3. ON/OFF switch.

   Switches power on / off.
4. Current selector – with this, select the position of current for the built-in transmitter (0.2 mA to 20 mA) in seven steps. For extra high power settings ranging upward from 50 mA are available with the optional terrameter SAS 2000 Booster.

5. Measure push button – when operator presses the measure push button, the microprocessor runs through it's automatic diagnostic program and if every thing is satisfactory, starts the Terrameter SAS 300 B measurement procedure automatically, when measurement is complete, the SAS 300B is returned to standby made with the last result on digital display.

5.7 INSTRUMENT TERMINALS

The current electrode terminals are at right side on the control panel, the potential electrode terminals are at left side. Note that both the terminals circuits are protected by semi conductors, lightening, high voltage, cattle fences or other high voltage sources may, however, damage the instrument. Lightening miles away may induce hundreds of voltages in long cable layouts and this entails risk for both personnel and equipment.

One should never take measurements during thunderstorm.

If a thunderstorm should come up while measurements are being taken, disconnect the cables from the terminals without touching any ware conductor, since an induced voltage may occur.

To reduce risk for leakage currents between adjacent electrodes smear a very thin film of silicone grease on the panel face around and between the terminals.

5.8 DESICCATOR CARTRIDGE

The desiccator cartridge that screws into the lower right hand corner of the control panel helps to prevent moisture from attacking the circuitry inside the instrument and is mainly intended for protection during shipping and storage. This desiccator cartridge is provided with a round indicator on it's face. When desiccator is active, this indicator is blue. As the desiccator absorbs the moisture, the round indicator slowly changes colour becomes lighter.

5.9 DISPLAY AND BEEPER

A liquid crystal display (LCD) presents data, warning and instructions for the operator. A beeper signal is also provided which alarms the operator to interpret the displayed information. Protect the LCD against strong sunlight, for longer life of LOD display.

5.10 EQUIPMENT SETUP AND OPERATING PROCEDURE ON FIELD

(a) Equipment Setup

The equipment setup almost requires following item:

(1) ABEM terrameter SAS 300 B

(2) Two wire bench of cable reel of length 1000 m

(3) One wire bench for potential electrodes

(4) Four stainless steel electrode.

(5) Four wire lead from terrameter to wire bench.

(6) One center pointing cricket wicket type stick.

(7) Two measuring tape 100-100m.

(8) Two hammer to driven electrode into ground.

(9) One 500 m long plastic thin rope for straight line.

(10) One small table to rest terrameter and one chair for operator.

(11) Water cane, some dry areas may require wetting around electrode.

(12) A notebook and a pocket size calculator.

(b) Operating Procedure

The field setup of the equipment is shown in Fig. 5.2, which is a Schlumberger array sounding setup, there should be ample separation (>5 m) between potential and current cables due to the fact that crosstalk can occur. This is particularly important when there is a long distance between A & B.

1. Position the SAS 300 B half way between the potential electrodes (M&N). Connect terminals P_1 & P_2 to terminals M & N respectively.
2. Connect the current electrodes (A & B) to terminals C_1 & C_2 respectively. Run these adjacent parallel to the SAS 300 B and arrange them symmetrically with respect to the potential electrodes.
3. All the four electrodes are driven into ground and connected to their respective cables.
4. Turn function selector to check battery voltage if $V \geq 12.5$ OK, switch off power then turn function selector to ohm position. Turn the cycle selector to second position and current selector to 20 mA position. Switch on power and press 'Measure' button and see display.
5. If error code 1 appears and beeper sounds repeatedly, reduce current step by step until beeper stop sounding. Then wait for a reading to appear on the display.
6. Observe four readings that appear successively on the display. If these are nearly equal, the noise level is low and you can reduce the setting of the 'cycle sector' to 1. However if third and fourth readings differ significantly from others, turn the cycle selector to position 16 or even 64, thus obtaining 16 or 64 cycles of measurements. Alternatively one can increase the current by the improving the current electrode grounding or using the SAS 2000 Booster.
7. Negative resistance readings can occur for two reasons
   - The current or the potential electrodes have been connected with reversed polarities.

- The noise level may be much higher than the signal level (long distances between A & B and low current). If this is causing signal negative readings, signal averaging must be used.

8. If other error codes appear on the display follow the section 3.1.7 of manual of SAS 300 B.

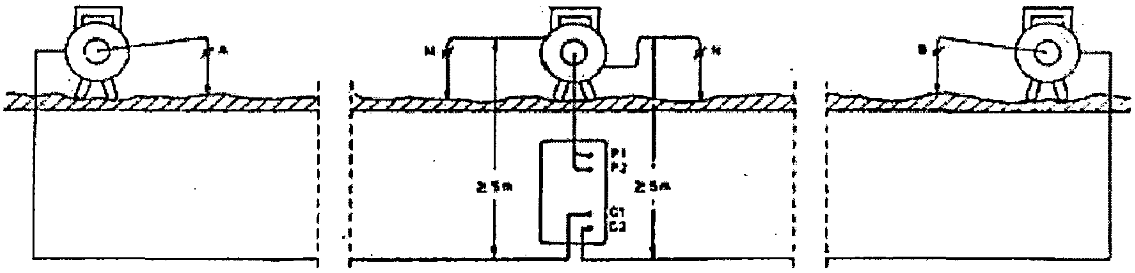


Fig. 5.2: Field setup of terrameter SAS 300B

5.11 ACCURACY AND PRECISION

Accuracy is defined as "the maximum error in the measurement of a physical quantity in terms of the output of an instrument when referred to the individual instruments". It is usually given as a percentage of full scale.

Precision is defined as "the number of distinguishable alternatives from which a representation was selected" this is sometimes indicated by the number of significant digits a representation contains.

The overall system accuracy of the SAS 300 B is ± 2% of the reading plus 2 digital increments (V or R).

CHAPTER-6

HYDROLOGY AND TUBE WELL DATA OF THE STUDY AREA

6.1 LOCATION

The study area is spreaded in the two development blocks Roorkee and Narsan of Tehsile Roorkee, District-Haridwar, Uttaranchal. The study area has moderate subtropical monsoonic climate. The temperature ranges from 3^0C in winter to 42^0C in summer. The average annual rainfall is about 1016 mm. The major portion of rainfall occurs during the months of July, August and September. Minor rainfall also occurs during winters. The area has fertile soils developed over the alluvial plain region of Gangetic basin.

6.2 HYDROGEOLOGICAL FEATURES OF THE AREA

The alluvial plain is composed of sand, clay and kankar, which are semi-consolidated and fluviatile in nature. Like Terai and Bhabhar zone, the sediments of alluvial plain also largely derived from the Himalayan and are deposited by the streams flowing southward, southwest ward or southeast ward. In this area sediments are derived by Solani river and the Ganga river, while going through data collected from tube well division Roorkee of irrigation department of Uttaranchal government; some sites have gravel, pebbles, sand stone, hard sand stone and very hard stone, that replicates that source of sediments is the Himalaya.

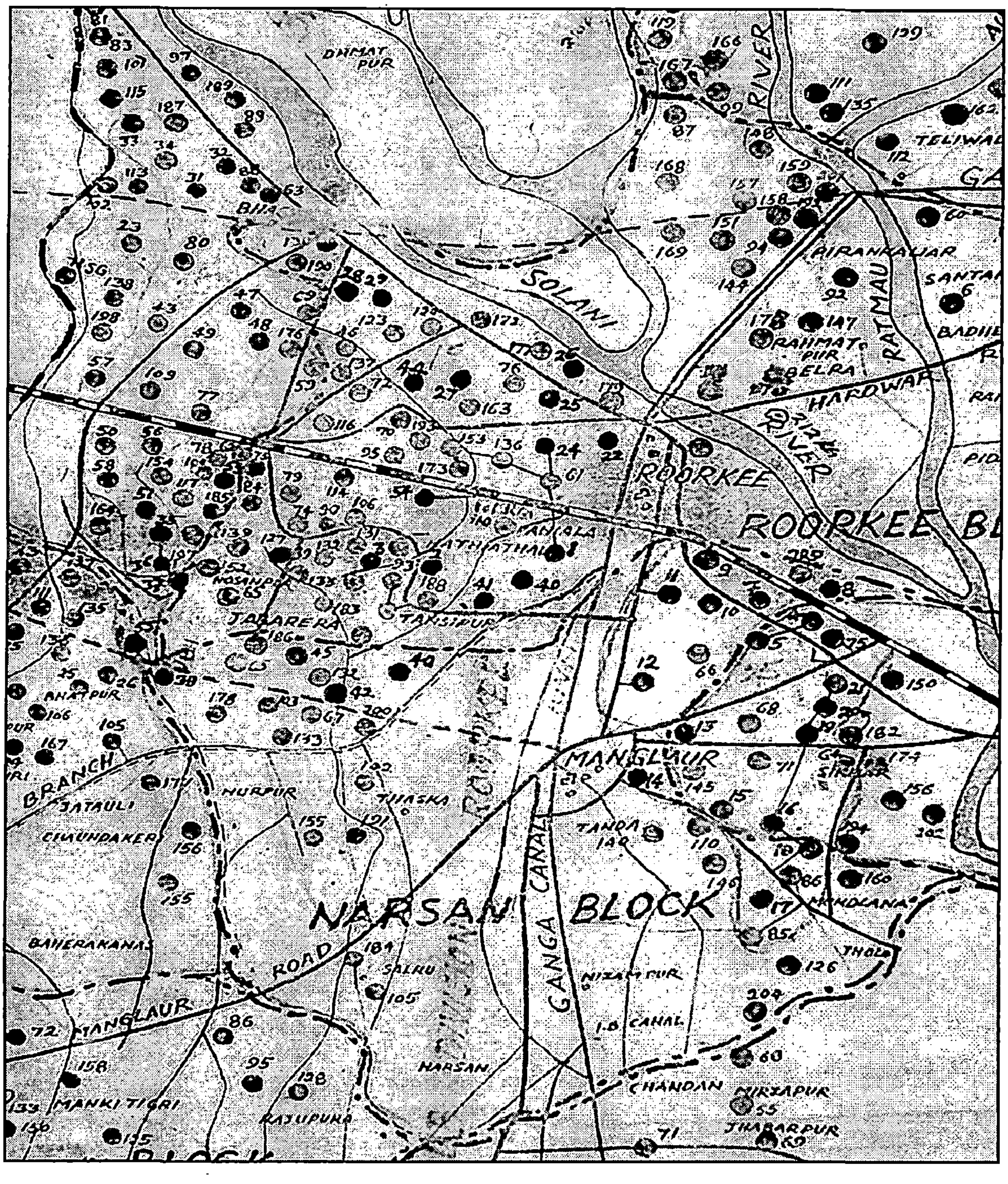
The various lithological units in the alluvial plain in western U.P. and Uttaranchal region reveal an erratic distribution. Most of these occur in lenticular form showing interfingering. Existing bore hole logs indicates a lithological continuity along the N–S section while E–W sections are discontinuous sand and gravel beds represent channel deposits while the silt and clay form flood plains.

The ground water conditions in all alluvial plains are considerably influenced by the varying lithology of the subsurface formations. As for the general nature of fluviatile deposits of Indogangetic plains it has been observed that the strata exhibit great variation in both laterally and vertically. The main sources of water, strata wise are medium sand, coarse sand, gravel, pebble and sand stone with medium or coarse sand, these aquifers are recharged by rainfall, channels, canals, streams and rivers. The most common structures in the study area are deep and shallow wells.

From the tube well data of the area, there are two types of aquifers in the area. The upper one is the shallow unconfined aquifer which generally extends up to 25 meter. The deeper aquifers are confined to semi-confined in nature and located in the range of 30 to 140 meter.

6.3 STRATA CHART OF STATE TUBE WELLS

From Tube well division Roorkee, irrigation department, Uttaranchal, strata charts of 41 tube wells are collected, the locations of which are given in Fig. 6.1, these tube wells lie in Roorkee block and Narsan block, nearby to Roorkee city. Strata charts of tube wells are given in Appendix 1.



• State tube wells

——— Metal road

Fig.6.1: Map of study area

CHAPTER-7

RESISTIVITY SURVEY AND INTERPRETATION

7.1 VES DATA SHEETS

Vertical electrical soundings are conducted at nearby places to state government tube wells at 41 sites in the study area. These surveys are conducted using Schlumberger configuration. The procedure and equipment setup have already been explained in previous chapters. VES data sheets are given in this chapter.

7.2 SOUNDING CURVES AND MODEL GRAPHIC

The resistivity data collected from VES survey are interpreted by using IX-1D software; the method for interpretation is already explained in chapter-4. The sounding curves and models in graphic form, obtained from IX-1D software are displayed in this chapter.

7.3 MODELS OBTAINED FROM INTERPRETATION

Graphic form of the models obtained from interpretation of VES data using IX-1D software are already displayed. This software also display model in analytical data form; so these models are displayed as quantitative interpretation of VES in this chapter.

VES DATA SHEET

Table 7.1: Sounding No. 1 **Location** **Paniala Chandapur**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	5.673	11.75	66.66
2	3	1	2.418	27.47	66.41
3	4	1	1.342	49.45	66.38
4	5	1	0.852	77.71	66.24
5	5	2	1.787	37.68	67.34
6	6	2	1.224	54.95	67.28
7	8	2	0.649	98.91	64.17
8	10	2	0.394	155.43	61.17
9	10	4	0.809	75.36	60.98
10	12	4	0.513	109.9	56.42
11	15	4	0.291	173.48	50.54
12	20	4	0.136	310.86	42.16
13	20	8	0.277	150.72	41.72
14	25	8	0.151	239.03	36.21
15	30	8	0.099	346.97	34.2
16	40	8	0.057	621.72	35.18
17	50	8	0.040	974.97	38.72
18	50	20	0.105	367.8	38.65
19	60	20	0.077	549.5	42.58
20	80	20	0.049	989.1	48.65
21	100	20	0.034	1554.3	52.49
22	100	40	0.063	753.6	47.73
23	120	40	0.047	1099	51.42
24	160	40	0.027	1978.2	53.38
25	200	40	0.017	3108.6	53.02
26	200	80	0.036	1507.2	54.56
27	250	80	0.023	2390.32	54.04
28	300	80	0.021	2469.7	51.51
29	350	80	0.010	4745.32	49.58
30	400	80	0.008	6217.2	47.29

VES DATA SHEET

Table 7.2: Sounding No. 2 **Location** **Latherdeva Shekh**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity Ωm)
1	2	1	2.164	11.75	25.43
2	3	1	0.925	27.47	25.41
3	4	1	0.520	49.45	25.69
4	5	1	0.340	77.71	26.44
5	5	2	0.724	37.68	27.28
6	6	2	0.516	54.95	28.33
7	8	2	0.303	98.91	29.94
8	10	2	0.204	155.43	31.69
9	10	4	0.421	75.36	31.73
10	12	4	0.308	109.9	33.86
11	15	4	0.213	173.48	36.94
12	20	4	0.136	310.86	42.16
13	20	8	0.276	150.72	41.54
14	25	8	0.189	239.03	45.08
15	30	8	0.139	346.97	48.2
16	40	8	0.086	621.72	53.54
17	50	8	0.060	974.97	58.88
18	50	20	0.159	367.8	58.36
19	60	20	0.115	549.5	62.92
20	80	20	0.068	989.1	67.27
21	100	20	0.047	1554.3	72.56
22	100	40	0.092	753.6	69.24
23	120	40	0.066	1099	72.6
24	160	40	0.037	1978.2	73.73
25	200	40	0.024	3108.6	73.99
26	200	80	0.049	1507.2	74.12
27	250	80	0.030	2390.32	71.23
28	300	80	0.027	2469.7	65.94
29	350	80	0.013	4745.32	62.34
30	400	80	0.009	6217.2	57.54

VES DATA SHEET

Table 7.3: Sounding No. 3 **Location** **Harjoulli Jhojna**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	2.722	11.75	31.98
2	3	1	1.209	27.47	33.22
3	4	1	0.666	49.45	32.92
4	5	1	0.419	77.71	32.53
5	5	2	0.875	37.68	32.96
6	6	2	0.605	54.95	33.25
7	8	2	0.342	98.91	33.86
8	10	2	0.219	155.43	34.04
9	10	4	0.459	75.36	34.56
10	12	4	0.317	109.9	34.86
11	15	4	0.211	173.48	36.54
12	20	4	0.122	310.86	37.98
13	20	8	0.252	150.72	38.02
14	25	8	0.170	239.03	40.68
15	30	8	0.134	346.97	46.4
16	40	8	0.083	621.72	51.51
17	50	8	0.058	974.97	56.66
18	50	20	0.156	367.8	57.32
19	60	20	0.118	549.5	64.76
20	80	20	0.067	989.1	66.76
21	100	20	0.044	1554.3	67.94
22	100	40	0.091	753.6	68.32
23	120	40	0.066	1099	72.6
24	160	40	0.039	1978.2	76.91
25	200	40	0.024	3108.6	76.16
26	200	80	0.050	1507.2	75.32
27	250	80	0.031	2390.32	74.42
28	300	80	0.029	2469.7	71.94
29	350	80	0.015	4745.32	69.88
30	400	80	0.011	6217.2	66.01

VES DATA SHEET

Table 7.4: Sounding No. 4 **Location** **Landaura**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	3.018	11.75	35.46
2	3	1	1.271	27.47	34.92
3	4	1	0.704	49.45	34.81
4	5	1	0.444	77.71	34.52
5	5	2	0.928	37.68	34.96
6	6	2	0.639	54.95	35.14
7	8	2	0.361	98.91	35.67
8	10	2	0.240	155.43	37.26
9	10	4	0.499	75.36	37.61
10	12	4	0.369	109.9	40.59
11	15	4	0.248	173.48	42.97
12	20	4	0.149	310.86	46.4
13	20	8	0.309	150.72	46.58
14	25	8	0.211	239.03	50.54
15	30	8	0.150	346.97	52.02
16	40	8	0.087	621.72	54.22
17	50	8	0.058	974.97	56.68
18	50	20	0.153	367.8	56.2
19	60	20	0.108	549.5	59.43
20	80	20	0.065	989.1	64.76
21	100	20	0.044	1554.3	67.94
22	100	40	0.087	753.6	65.48
23	120	40	0.062	1099	67.92
24	160	40	0.035	1978.2	69.88
25	200	40	0.022	3108.6	68.57
26	200	80	0.041	1507.2	62.32
27	250	80	0.024	2390.32	57.21
28	300	80	0.021	2469.7	53.02
29	350	80	0.011	4745.32	50.07
30	400	80	0.008	6217.2	46.83

VES DATA SHEET

Table 7.5: Sounding No. 5 **Location** **Landaura**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	10.395	11.75	122.14
2	3	1	4.260	27.47	117.03
3	4	1	2.293	49.45	113.38
4	5	1	1.413	77.71	109.81
5	5	2	2.906	37.68	109.49
6	6	2	1.893	54.95	104.04
7	8	2	0.984	98.91	97.37
8	10	2	0.603	155.43	93.75
9	10	4	1.238	75.36	93.32
10	12	4	0.820	109.9	90.12
11	15	4	0.494	173.48	85.74
12	20	4	0.257	310.86	80.02
13	20	8	0.524	150.72	78.93
14	25	8	0.316	239.03	75.5
15	30	8	0.200	346.97	69.53
16	40	8	0.105	621.72	65.54
17	50	8	0.062	974.97	60.92
18	50	20	0.167	367.8	61.55
19	60	20	0.116	549.5	63.74
20	80	20	0.067	989.1	66.61
21	100	20	0.045	1554.3	69.81
22	100	40	0.095	753.6	71.77
23	120	40	0.068	1099	74.8
24	160	40	0.040	1978.2	79.17
25	200	40	0.027	3108.6	84.18
26	200	80	0.056	1507.2	84.29
27	250	80	0.037	2390.32	87.5
28	300	80	0.037	2469.7	90.93
29	350	80	0.020	4745.32	92.94
30	400	80	0.015	6217.2	95.21

VES DATA SHEET

Table 7.6: Sounding No. 6 **Location** **Daulatpur**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	9.150	11.75	107.51
2	3	1	3.870	27.47	106.3
3	4	1	2.090	49.45	103.34
4	5	1	1.255	77.71	97.51
5	5	2	2.580	37.68	97.22
6	6	2	1.622	54.95	89.12
7	8	2	0.763	98.91	75.42
8	10	2	0.405	155.43	62.92
9	10	4	0.830	75.36	62.52
10	12	4	0.441	109.9	48.42
11	15	4	0.211	173.48	36.62
12	20	4	0.084	310.86	26.12
13	20	8	0.173	150.72	26.08
14	25	8	0.101	239.03	24.26
15	30	8	0.075	346.97	26.18
16	40	8	0.053	621.72	32.72
17	50	8	0.041	974.97	40.22
18	50	20	0.110	367.8	40.5
19	60	20	0.085	549.5	46.76
20	80	20	0.059	989.1	58.32
21	100	20	0.044	1554.3	67.94
22	100	40	0.090	753.6	68.12
23	120	40	0.073	1099	79.82
24	160	40	0.046	1978.2	90.28
25	200	40	0.031	3108.6	96.86
26	200	80	0.064	1507.2	97.2
27	250	80	0.044	2390.32	104.3
28	300	80	0.042	2469.7	104.3
29	350	80	0.021	4745.32	101.39
30	400	80	0.016	6217.2	98.69

VES DATA SHEET

Table 7.7: Sounding No. 7 **Location** **Nanglai Marti**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	1.552	11.75	18.24
2	3	1	0.672	27.47	18.46
3	4	1	0.384	49.45	18.98
4	5	1	0.243	77.71	18.88
5	5	2	0.496	37.68	18.68
6	6	2	0.361	54.95	19.84
7	8	2	0.204	98.91	20.18
8	10	2	0.134	155.43	20.84
9	10	4	0.285	75.36	21.46
10	12	4	0.201	109.9	22.12
11	15	4	0.145	173.48	25.24
12	20	4	0.088	310.86	27.47
13	20	8	0.189	150.72	28.42
14	25	8	0.127	239.03	30.42
15	30	8	0.095	346.97	32.84
16	40	8	0.063	621.72	38.96
17	50	8	0.041	974.97	40.36
18	50	20	0.131	367.8	48.01
19	60	20	0.103	549.5	56.46
20	80	20	0.064	989.1	63.14
21	100	20	0.044	1554.3	68.2
22	100	40	0.092	753.6	69.29
23	120	40	0.069	1099	75.74
24	160	40	0.041	1978.2	81.11
25	200	40	0.026	3108.6	79.41
26	200	80	0.052	1507.2	78.55
27	250	80	0.031	2390.32	73.36
28	300	80	0.028	2469.7	68.41
29	350	80	0.013	4745.32	62.8
30	400	80	0.009	6217.2	54.88
31	450	80	0.006	7885.32	49.61
32	500	160	0.009	4783.1	44.56

VES DATA SHEET

Table 7.8: Sounding No. 8 **Location** **Jaurasi**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	3.226	11.75	37.9
2	3	1	1.399	27.47	38.42
3	4	1	0.784	49.45	38.75
4	5	1	0.503	77.71	39.08
5	5	2	1.040	37.68	39.18
6	6	2	0.722	54.95	39.7
7	8	2	0.407	98.91	40.26
8	10	2	0.262	155.43	40.78
9	10	4	0.550	75.36	41.45
10	12	4	0.406	109.9	44.65
11	15	4	0.277	173.48	47.97
12	20	4	0.173	310.86	53.83
13	20	8	0.360	150.72	54.23
14	25	8	0.248	239.03	59.25
15	30	8	0.201	346.97	69.57
16	40	8	0.132	621.72	82.06
17	50	8	0.093	974.97	90.65
18	50	20	0.248	367.8	91.24
19	60	20	0.172	549.5	94.67
20	80	20	0.086	989.1	85.42
21	100	20	0.057	1554.3	89.21
22	100	40	0.128	753.6	96.65
23	120	40	0.095	1099	104.3
24	160	40	0.055	1978.2	109.42
25	200	40	0.033	3108.6	102.33
26	200	80	0.070	1507.2	105.32
27	250	80	0.046	2390.32	109.41
28	300	80	0.045	2469.7	111.49
29	350	80	0.023	4745.32	110.48
30	400	80	0.017	6217.2	108.52

VES DATA SHEET

Table 7.9: Sounding No. 9 **Location** **Dandhera**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	9.859	11.75	115.84
2	3	1	4.298	27.47	118.07
3	4	1	2.411	49.45	119.23
4	5	1	1.578	77.71	122.65
5	5	2	3.328	37.68	125.41
6	6	2	2.365	54.95	129.94
7	8	2	1.365	98.91	134.98
8	10	2	0.876	155.43	136.23
9	10	4	1.816	75.36	136.87
10	12	4	1.239	109.9	136.2
11	15	4	0.770	173.48	133.66
12	20	4	0.406	310.86	126.24
13	20	8	0.835	150.72	125.84
14	25	8	0.471	239.03	112.62
15	30	8	0.295	346.97	102.33
16	40	8	0.147	621.72	91.28
17	50	8	0.090	974.97	87.87
18	50	20	0.239	367.8	87.96
19	60	20	0.160	549.5	88.1
20	80	20	0.096	989.1	94.82
21	100	20	0.062	1554.3	96.65
22	100	40	0.124	753.6	93.32
23	120	40	0.082	1099	90.5
24	160	40	0.044	1978.2	86.36
25	200	40	0.025	3108.6	79.12
26	200	80	0.053	1507.2	79.46
27	250	80	0.031	2390.32	73.11
28	300	80	0.027	2469.7	67.28
29	350	80	0.013	4745.32	62.35
30	400	80	0.009	6217.2	58.88

VES DATA SHEET

S Table 7.10: ounding No. 10 **Location** **Dandhera**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	11.934	11.75	140.22
2	3	1	5.100	27.47	140.1
3	4	1	2.782	49.45	137.57
4	5	1	1.753	77.71	136.23
5	5	2	3.612	37.68	136.1
6	6	2	2.410	54.95	132.44
7	8	2	1.264	98.91	125.01
8	10	2	0.745	155.43	115.84
9	10	4	1.529	75.36	115.22
10	12	4	0.949	109.9	104.29
11	15	4	0.521	173.48	90.34
12	20	4	0.229	310.86	71.23
13	20	8	0.472	150.72	71.08
14	25	8	0.246	239.03	58.88
15	30	8	0.162	346.97	56.13
16	40	8	0.089	621.72	55.07
17	50	8	0.063	974.97	61.17
18	50	20	0.167	367.8	61.38
19	60	20	0.126	549.5	69.25
20	80	20	0.086	989.1	84.59
21	100	20	0.063	1554.3	97.51
22	100	40	0.130	753.6	97.73
23	120	40	0.101	1099	111.52
24	160	40	0.064	1978.2	127.24
25	200	40	0.045	3108.6	138.85
26	200	80	0.092	1507.2	139.32
27	250	80	0.059	2390.32	142.1
28	300	80	0.058	2469.7	142.91
29	350	80	0.029	4745.32	136.57
30	400	80	0.021	6217.2	132.43

VES DATA SHEET

Table 7.11: Sounding No. 11 **Location** **Dandhera**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	12.929	11.75	151.92
2	3	1	5.229	27.47	143.64
3	4	1	2.717	49.45	134.34
4	5	1	1.639	77.71	127.36
5	5	2	3.395	37.68	127.93
6	6	2	2.074	54.95	113.96
7	8	2	1.090	98.91	107.82
8	10	2	0.622	155.43	96.61
9	10	4	1.263	75.36	95.18
10	12	4	0.794	109.9	87.21
11	15	4	0.424	173.48	73.47
12	20	4	0.208	310.86	64.66
13	20	8	0.425	150.72	64
14	25	8	0.240	239.03	57.28
15	30	8	0.137	346.97	47.57
16	40	8	0.066	621.72	41.12
17	50	8	0.038	974.97	37.4
18	50	20	0.100	367.8	36.93
19	60	20	0.062	549.5	34.14
20	80	20	0.033	989.1	32.72
21	100	20	0.022	1554.3	33.83
22	100	40	0.045	753.6	34.11
23	120	40	0.036	1099	39.97
24	160	40	0.025	1978.2	48.61
25	200	40	0.018	3108.6	57.32
26	200	80	0.039	1507.2	58.71
27	250	80	0.027	2390.32	65.33
28	300	80	0.030	2469.7	74.41
29	350	80	0.017	4745.32	80.21
30	400	80	0.014	6217.2	87.47

VES DATA SHEET

Table 7.12: Sounding No. 12 Location Bijoulli

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	14.303	11.75	168.06
2	3	1	5.944	27.47	163.28
3	4	1	3.251	49.45	160.78
4	5	1	2.004	77.71	155.74
5	5	2	3.940	37.68	148.45
6	6	2	2.625	54.95	144.23
7	8	2	1.431	98.91	141.52
8	10	2	0.902	155.43	140.22
9	10	4	1.957	75.36	147.45
10	12	4	1.338	109.9	147.01
11	15	4	0.831	173.48	144.23
12	20	4	0.460	310.86	142.91
13	20	8	0.946	150.72	142.53
14	25	8	0.594	239.03	141.91
15	30	8	0.405	346.97	140.52
16	40	8	0.223	621.72	138.85
17	50	8	0.140	974.97	136.23
18	50	20	0.327	367.8	120.34
19	60	20	0.217	549.5	119.23
20	80	20	0.115	989.1	113.66
21	100	20	0.068	1554.3	106.3
22	100	40	0.143	753.6	108.07
23	120	40	0.097	1099	106.22
24	160	40	0.052	1978.2	102.34
25	200	40	0.032	3108.6	98.51
26	200	80	0.060	1507.2	90.45
27	250	80	0.036	2390.32	86.22
28	300	80	0.033	2469.7	82.19
29	350	80	0.016	4745.32	77.63
30	400	80	0.012	6217.2	72.6

VES DATA SHEET

Table 7.13: Sounding No. 13 **Location** **Kambora**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	4.105	11.75	48.23
2	3	1	1.788	27.47	49.12
3	4	1	1.008	49.45	49.86
4	5	1	0.642	77.71	49.92
5	5	2	1.330	37.68	50.13
6	6	2	0.920	54.95	50.56
7	8	2	0.521	98.91	51.57
8	10	2	0.338	155.43	52.49
9	10	4	0.702	75.36	52.87
10	12	4	0.487	109.9	53.48
11	15	4	0.311	173.48	53.87
12	20	4	0.175	310.86	54.36
13	20	8	0.358	150.72	53.93
14	25	8	0.220	239.03	52.5
15	30	8	0.144	346.97	50.1
16	40	8	0.076	621.72	47.29
17	50	8	0.048	974.97	46.83
18	50	20	0.128	367.8	47.22
19	60	20	0.089	549.5	49.13
20	80	20	0.055	989.1	54.1
21	100	20	0.039	1554.3	60.03
22	100	40	0.080	753.6	60.39
23	120	40	0.059	1099	64.76
24	160	40	0.037	1978.2	73.32
25	200	40	0.024	3108.6	75.42
26	200	80	0.050	1507.2	75.86
27	250	80	0.032	2390.32	76.16
28	300	80	0.030	2469.7	74.72
29	350	80	0.015	4745.32	73.14
30	400	80	0.011	6217.2	70.58

VES DATA SHEET

Table 7.14: Sounding No. 14 **Location** **Manglore**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	15.605	11.75	183.36
2	3	1	6.118	27.47	168.06
3	4	1	3.149	49.45	155.74
4	5	1	1.856	77.71	144.23
5	5	2	3.786	37.68	142.67
6	6	2	2.275	54.95	125
7	8	2	0.977	98.91	96.65
8	10	2	0.519	155.43	80.64
9	10	4	0.984	75.36	74.15
10	12	4	0.589	109.9	64.76
11	15	4	0.333	173.48	57.78
12	20	4	0.186	310.86	57.83
13	20	8	0.358	150.72	54.03
14	25	8	0.252	239.03	60.17
15	30	8	0.191	346.97	66.18
16	40	8	0.135	621.72	83.77
17	50	8	0.102	974.97	99.48
18	50	20	0.273	367.8	100.53
19	60	20	0.215	549.5	118.21
20	80	20	0.146	989.1	144.23
21	100	20	0.104	1554.3	161.78
22	100	40	0.232	753.6	174.58
23	120	40	0.174	1099	191.16
24	160	40	0.106	1978.2	209.25
25	200	40	0.067	3108.6	209.21
26	200	80	0.125	1507.2	188.39
27	250	80	0.075	2390.32	179.58
28	300	80	0.069	2469.7	169.62
29	350	80	0.032	4745.32	154.22
30	400	80	0.023	6217.2	141.52

VES DATA SHEET

Table 7.15: Sounding No. 15 **Location** **Nathur Khera**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	13.900	11.75	163.32
2	3	1	6.023	27.47	165.45
3	4	1	3.420	49.45	169.12
4	5	1	2.258	77.71	175.46
5	5	2	4.626	37.68	174.32
6	6	2	3.241	54.95	178.12
7	8	2	1.834	98.91	181.41
8	10	2	1.194	155.43	185.56
9	10	4	2.489	75.36	187.56
10	12	4	1.714	109.9	188.42
11	15	4	1.100	173.48	190.86
12	20	4	0.612	310.86	190.35
13	20	8	1.257	150.72	189.41
14	25	8	0.733	239.03	175.12
15	30	8	0.502	346.97	174.12
16	40	8	0.278	621.72	172.59
17	50	8	0.176	974.97	171.42
18	50	20	0.466	367.8	171.41
19	60	20	0.328	549.5	180.11
20	80	20	0.188	989.1	185.62
21	100	20	0.124	1554.3	192.32
22	100	40	0.255	753.6	192.44
23	120	40	0.182	1099	200.11
24	160	40	0.114	1978.2	225.62
25	200	40	0.081	3108.6	250.85
26	200	80	0.169	1507.2	255.46
27	250	80	0.117	2390.32	280.33
28	300	80	0.130	2469.7	320.11
29	350	80	0.074	4745.32	350.86
30	400	80	0.000	6217.2	

VES DATA SHEET

Table 7.16: Sounding No. 16 **Location** **Akbarpur**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	12.967	11.75	152.36
2	3	1	5.469	27.47	150.24
3	4	1	3.006	49.45	148.65
4	5	1	1.898	77.71	147.46
5	5	2	3.911	37.68	147.36
6	6	2	2.670	54.95	146.72
7	8	2	1.435	98.91	141.89
8	10	2	0.852	155.43	132.44
9	10	4	1.743	75.36	131.33
10	12	4	1.116	109.9	122.65
11	15	4	0.662	173.48	114.78
12	20	4	0.332	310.86	103.34
13	20	8	0.683	150.72	102.92
14	25	8	0.408	239.03	97.61
15	30	8	0.282	346.97	97.68
16	40	8	0.168	621.72	104.32
17	50	8	0.115	974.97	112.23
18	50	20	0.309	367.8	113.66
19	60	20	0.219	549.5	120.34
20	80	20	0.131	989.1	129.94
21	100	20	0.085	1554.3	132.43
22	100	40	0.177	753.6	133.11
23	120	40	0.121	1099	132.43
24	160	40	0.058	1978.2	113.84
25	200	40	0.033	3108.6	102.46
26	200	80	0.067	1507.2	101.39
27	250	80	0.035	2390.32	82.82
28	300	80	0.028	2469.7	68.57
29	350	80	0.013	4745.32	59.43
30	400	80	0.008	6217.2	51.51

VES DATA SHEET

Table 7.17: Sounding No. 17 **Location** **Mundalana**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	11.271	11.75	132.43
2	3	1	4.774	27.47	131.13
3	4	1	2.553	49.45	126.24
4	5	1	1.564	77.71	121.53
5	5	2	3.204	37.68	120.74
6	6	2	2.068	54.95	113.66
7	8	2	1.014	98.91	100.3
8	10	2	0.560	155.43	87.02
9	10	4	1.169	75.36	88.11
10	12	4	0.734	109.9	80.64
11	15	4	0.380	173.48	65.93
12	20	4	0.182	310.86	56.67
13	20	8	0.381	150.72	57.38
14	25	8	0.218	239.03	52.02
15	30	8	0.150	346.97	52.06
16	40	8	0.088	621.72	54.57
17	50	8	0.061	974.97	59.43
18	50	20	0.184	367.8	67.68
19	60	20	0.135	549.5	73.98
20	80	20	0.081	989.1	79.9
21	100	20	0.056	1554.3	87.02
22	100	40	0.117	753.6	88.1
23	120	40	0.084	1099	92.12
24	160	40	0.047	1978.2	92.68
25	200	40	0.028	3108.6	87.87
26	200	80	0.057	1507.2	86.55
27	250	80	0.034	2390.32	81.22
28	300	80	0.031	2469.7	75.42
29	350	80	0.014	4745.32	68.17
30	400	80	0.010	6217.2	64.17
31	450	80	0.008	7885.32	59.38
32	500	160	0.012	4783.1	56.78

VES DATA SHEET

Table 7.18: Sounding No. 18 **Location** **Ghoshipur**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	11.371	11.75	133.61
2	3	1	4.774	27.47	131.13
3	4	1	2.628	49.45	129.94
4	5	1	1.625	77.71	126.24
5	5	2	3.349	37.68	126.18
6	6	2	2.275	54.95	125
7	8	2	1.194	98.91	118.07
8	10	2	0.711	155.43	110.49
9	10	4	1.475	75.36	111.18
10	12	4	0.949	109.9	104.34
11	15	4	0.552	173.48	95.76
12	20	4	0.280	310.86	87.02
13	20	8	0.578	150.72	87.16
14	25	8	0.344	239.03	82.18
15	30	8	0.239	346.97	82.99
16	40	8	0.136	621.72	84.59
17	50	8	0.092	974.97	89.56
18	50	20	0.242	367.8	89.19
19	60	20	0.168	549.5	92.19
20	80	20	0.101	989.1	99.5
21	100	20	0.064	1554.3	99.68
22	100	40	0.133	753.6	100.33
23	120	40	0.093	1099	102.33
24	160	40	0.051	1978.2	100.4
25	200	40	0.030	3108.6	93.96
26	200	80	0.056	1507.2	84.59
27	250	80	0.032	2390.32	76.16
28	300	80	0.028	2469.7	69.38
29	350	80	0.014	4745.32	64.17
30	400	80	0.010	6217.2	59.43

VES DATA SHEET

Table 7.19: Sounding No. 19 **Location** **Ghatharauna**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	12.890	11.75	151.46
2	3	1	5.469	27.47	150.24
3	4	1	3.008	49.45	148.74
4	5	1	1.903	77.71	147.92
5	5	2	3.919	37.68	147.66
6	6	2	2.651	54.95	145.65
7	8	2	1.424	98.91	140.86
8	10	2	0.886	155.43	137.75
9	10	4	1.830	75.36	137.92
10	12	4	1.226	109.9	134.79
11	15	4	0.756	173.48	131.14
12	20	4	0.403	310.86	125.36
13	20	8	0.827	150.72	124.64
14	25	8	0.521	239.03	124.5
15	30	8	0.359	346.97	124.72
16	40	8	0.213	621.72	132.44
17	50	8	0.147	974.97	142.92
18	50	20	0.389	367.8	143.12
19	60	20	0.281	549.5	154.18
20	80	20	0.165	989.1	163.28
21	100	20	0.105	1554.3	163.28
22	100	40	0.215	753.6	161.95
23	120	40	0.147	1099	161.78
24	160	40	0.078	1978.2	153.48
25	200	40	0.046	3108.6	141.52
26	200	80	0.093	1507.2	140.67
27	250	80	0.054	2390.32	128.41
28	300	80	0.049	2469.7	120.34
29	350	80	0.024	4745.32	115.68
30	400	80	0.018	6217.2	109.41

VES DATA SHEET

Table 7.20: Sounding No. 20 Location Landaura

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	12.398	11.75	145.68
2	3	1	5.202	27.47	142.91
3	4	1	2.866	49.45	141.73
4	5	1	1.818	77.71	141.31
5	5	2	3.738	37.68	140.86
6	6	2	2.504	54.95	137.57
7	8	2	1.336	98.91	132.14
8	10	2	0.788	155.43	122.53
9	10	4	1.612	75.36	121.48
10	12	4	1.034	109.9	113.66
11	15	4	0.579	173.48	100.4
12	20	4	0.291	310.86	90.56
13	20	8	0.586	150.72	88.32
14	25	8	0.325	239.03	77.63
15	30	8	0.217	346.97	75.42
16	40	8	0.125	621.72	77.63
17	50	8	0.084	974.97	82.18
18	50	20	0.226	367.8	83.21
19	60	20	0.158	549.5	87.02
20	80	20	0.092	989.1	91.29
21	100	20	0.059	1554.3	91.48
22	100	40	0.121	753.6	91.4
23	120	40	0.081	1099	88.76
24	160	40	0.042	1978.2	83.4
25	200	40	0.025	3108.6	77.63
26	200	80	0.052	1507.2	78.47
27	250	80	0.030	2390.32	71.94
28	300	80	0.028	2469.7	68.66
29	350	80	0.013	4745.32	63.22

VES DATA SHEET

Table 7.21: Sounding No. 21 **Location** **Landaura**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	4.287	11.75	50.37
2	3	1	1.878	27.47	51.59
3	4	1	1.055	49.45	52.15
4	5	1	0.676	77.71	52.56
5	5	2	1.402	37.68	52.84
6	6	2	0.971	54.95	53.34
7	8	2	0.549	98.91	54.35
8	10	2	0.356	155.43	55.39
9	10	4	0.738	75.36	55.64
10	12	4	0.529	109.9	58.15
11	15	4	0.352	173.48	61.11
12	20	4	0.204	310.86	63.33
13	20	8	0.421	150.72	63.46
14	25	8	0.270	239.03	64.54
15	30	8	0.182	346.97	63.29
16	40	8	0.105	621.72	65.25
17	50	8	0.066	974.97	64.48
18	50	20	0.175	367.8	64.19
19	60	20	0.126	549.5	69.25
20	80	20	0.071	989.1	70.18
21	100	20	0.045	1554.3	70.29
22	100	40	0.093	753.6	70.41
23	120	40	0.065	1099	71.67
24	160	40	0.037	1978.2	72.37
25	200	40	0.022	3108.6	68.44
26	200	80	0.045	1507.2	68.15
27	250	80	0.027	2390.32	65.17
28	300	80	0.025	2469.7	62.35
29	350	80	0.013	4745.32	60.36
30	400	80	0.009	6217.2	58.16

VES DATA SHEET

Table 7.22: Sounding No. 22 **Location** **Salempur**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	11.271	11.75	132.43
2	3	1	4.509	27.47	123.86
3	4	1	2.234	49.45	110.49
4	5	1	1.244	77.71	96.65
5	5	2	2.551	37.68	96.12
6	6	2	1.496	54.95	82.18
7	8	2	0.618	98.91	61.17
8	10	2	0.299	155.43	46.42
9	10	4	0.609	75.36	45.86
10	12	4	0.360	109.9	39.56
11	15	4	0.191	173.48	33.12
12	20	4	0.101	310.86	31.38
13	20	8	0.205	150.72	30.89
14	25	8	0.131	239.03	31.34
15	30	8	0.098	346.97	33.86
16	40	8	0.059	621.72	36.54
17	50	8	0.043	974.97	42.16
18	50	20	0.115	367.8	42.32
19	60	20	0.084	549.5	45.96
20	80	20	0.051	989.1	50.36
21	100	20	0.034	1554.3	53.54
22	100	40	0.070	753.6	53.08
23	120	40	0.050	1099	54.92
24	160	40	0.028	1978.2	56.13
25	200	40	0.019	3108.6	58.14
26	200	80	0.039	1507.2	58.86
27	250	80	0.024	2390.32	58.31
28	300	80	0.023	2469.7	57.21
29	350	80	0.012	4745.32	56.68
30	400	80	0.009	6217.2	55.62

VES DATA SHEET

Table 7.23: Sounding No. 23 Location Salempur Rajputana

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	4.456	11.75	52.36
2	3	1	1.949	27.47	53.54
3	4	1	1.104	49.45	54.57
4	5	1	0.722	77.71	56.12
5	5	2	1.492	37.68	56.2
6	6	2	1.061	54.95	58.32
7	8	2	0.612	98.91	60.58
8	10	2	0.417	155.43	64.76
9	10	4	0.829	75.36	62.48
10	12	4	0.567	109.9	62.32
11	15	4	0.407	173.48	70.52
12	20	4	0.238	310.86	73.94
13	20	8	0.492	150.72	74.22
14	25	8	0.311	239.03	74.42
15	30	8	0.217	346.97	75.3
16	40	8	0.121	621.72	75.42
17	50	8	0.078	974.97	76.52
18	50	20	0.205	367.8	75.22
19	60	20	0.137	549.5	75.12
20	80	20	0.076	989.1	75.48
21	100	20	0.047	1554.3	72.38
22	100	40	0.096	753.6	72.31
23	120	40	0.064	1099	70.48
24	160	40	0.035	1978.2	69.31
25	200	40	0.022	3108.6	67.28
26	200	80	0.045	1507.2	67.15
27	250	80	0.026	2390.32	61.44
28	300	80	0.023	2469.7	56.68
29	350	80	0.011	4745.32	53.06
30	400	80	0.008	6217.2	49.12

VES DATA SHEET

Table 7.24: Sounding No. 24 **Location** **Matlabpur**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	4.453	11.75	52.32
2	3	1	1.873	27.47	51.44
3	4	1	0.978	49.45	48.35
4	5	1	0.594	77.71	46.15
5	5	2	1.265	37.68	47.67
6	6	2	0.852	54.95	46.83
7	8	2	0.422	98.91	41.78
8	10	2	0.233	155.43	36.21
9	10	4	0.482	75.36	36.3
10	12	4	0.294	109.9	32.3
11	15	4	0.155	173.48	26.96
12	20	4	0.072	310.86	22.48
13	20	8	0.140	150.72	21.1
14	25	8	0.083	239.03	19.86
15	30	8	0.058	346.97	20.08
16	40	8	0.035	621.72	21.85
17	50	8	0.023	974.97	22.26
18	50	20	0.061	367.8	22.33
19	60	20	0.047	549.5	25.56
20	80	20	0.028	989.1	27.73
21	100	20	0.020	1554.3	31.38
22	100	40	0.039	753.6	29.46
23	120	40	0.029	1099	31.68
24	160	40	0.018	1978.2	35.18
25	200	40	0.012	3108.6	37.62
26	200	80	0.026	1507.2	38.71
27	250	80	0.017	2390.32	40.17
28	300	80	0.017	2469.7	41.56
29	350	80	0.008	4745.32	40.07
30	400	80	0.006	6217.2	39.48

VES DATA SHEET

Table 7.25: Sounding No. 25 **Location** **Saliyar**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	11.160	11.75	131.13
2	3	1	4.768	27.47	130.98
3	4	1	2.602	49.45	128.68
4	5	1	1.594	77.71	123.86
5	5	2	3.270	37.68	123.22
6	6	2	2.170	54.95	119.23
7	8	2	1.096	98.91	108.42
8	10	2	0.616	155.43	95.76
9	10	4	1.235	75.36	93.04
10	12	4	0.738	109.9	81.12
11	15	4	0.407	173.48	70.58
12	20	4	0.154	310.86	47.73
13	20	8	0.313	150.72	47.11
14	25	8	0.163	239.03	38.92
15	30	8	0.097	346.97	33.52
16	40	8	0.049	621.72	30.48
17	50	8	0.032	974.97	30.78
18	50	20	0.083	367.8	30.38
19	60	20	0.056	549.5	31.02
20	80	20	0.034	989.1	33.55
21	100	20	0.023	1554.3	35.52
22	100	40	0.048	753.6	36.21
23	120	40	0.034	1099	37.24
24	160	40	0.021	1978.2	40.98
25	200	40	0.013	3108.6	41.54
26	200	80	0.027	1507.2	40.82
27	250	80	0.016	2390.32	38.46
28	300	80	0.015	2469.7	37.27
29	350	80	0.007	4745.32	34.86
30	400	80	0.005	6217.2	31.98

VES DATA SHEET

Table 7.26: Sounding No. 26 **Location** **Madhavpur**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	4.557	11.75	53.54
2	3	1	1.949	27.47	53.54
3	4	1	1.083	49.45	53.54
4	5	1	0.695	77.71	54.03
5	5	2	1.407	37.68	53.02
6	6	2	0.965	54.95	53.02
7	8	2	0.536	98.91	53.02
8	10	2	0.341	155.43	53.02
9	10	4	0.692	75.36	52.18
10	12	4	0.464	109.9	51.04
11	15	4	0.294	173.48	51.04
12	20	4	0.154	310.86	47.73
13	20	8	0.314	150.72	47.28
14	25	8	0.193	239.03	46.22
15	30	8	0.125	346.97	43.4
16	40	8	0.061	621.72	37.98
17	50	8	0.033	974.97	32.6
18	50	20	0.088	367.8	32.24
19	60	20	0.052	549.5	28.79
20	80	20	0.025	989.1	24.73
21	100	20	0.014	1554.3	22.48
22	100	40	0.031	753.6	23.14
23	120	40	0.021	1099	22.64
24	160	40	0.011	1978.2	22.69
25	200	40	0.007	3108.6	22.92
26	200	80	0.015	1507.2	21.88
27	250	80	0.010	2390.32	22.86
28	300	80	0.009	2469.7	22.94
29	350	80	0.005	4745.32	22.96
30	400	80	0.004	6217.2	23.02

VES DATA SHEET

Table 7.27: Sounding No. 27 **Location** **Nanhera Anantpur**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	4.301	11.75	50.54
2	3	1	1.858	27.47	51.03
3	4	1	1.052	49.45	52.02
4	5	1	0.657	77.71	51.06
5	5	2	1.407	37.68	53.01
6	6	2	0.980	54.95	53.85
7	8	2	0.545	98.91	53.9
8	10	2	0.351	155.43	54.56
9	10	4	0.724	75.36	54.58
10	12	4	0.501	109.9	55.01
11	15	4	0.324	173.48	56.13
12	20	4	0.189	310.86	58.88
13	20	8	0.383	150.72	57.77
14	25	8	0.256	239.03	61.17
15	30	8	0.188	346.97	65.4
16	40	8	0.116	621.72	71.93
17	50	8	0.080	974.97	78.39
18	50	20	0.213	367.8	78.45
19	60	20	0.152	549.5	83.77
20	80	20	0.087	989.1	86.22
21	100	20	0.055	1554.3	85.38
22	100	40	0.105	753.6	79.35
23	120	40	0.067	1099	73.98
24	160	40	0.037	1978.2	73.32
25	200	40	0.022	3108.6	67.23
26	200	80	0.045	1507.2	68.57
27	250	80	0.025	2390.32	60.57
28	300	80	0.023	2469.7	56.13
29	350	80	0.011	4745.32	52.49
30	400	80	0.008	6217.2	49.58

VES DATA SHEET

Table 7.28: Sounding No. 28 **Location Karoundhi**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	6.800	11.75	79.9
2	3	1	2.643	27.47	72.6
3	4	1	1.237	49.45	61.17
4	5	1	0.662	77.71	51.42
5	5	2	1.352	37.68	50.95
6	6	2	0.782	54.95	42.97
7	8	2	0.327	98.91	32.3
8	10	2	0.172	155.43	26.68
9	10	4	0.338	75.36	25.44
10	12	4	0.214	109.9	23.55
11	15	4	0.122	173.48	21.23
12	20	4	0.068	310.86	21.18
13	20	8	0.140	150.72	21.06
14	25	8	0.090	239.03	21.48
15	30	8	0.063	346.97	21.84
16	40	8	0.039	621.72	24.08
17	50	8	0.027	974.97	26.18
18	50	20	0.070	367.8	25.92
19	60	20	0.050	549.5	27.72
20	80	20	0.031	989.1	30.64
21	100	20	0.021	1554.3	32.6
22	100	40	0.045	753.6	33.8
23	120	40	0.031	1099	34.06
24	160	40	0.017	1978.2	33.86
25	200	40	0.010	3108.6	32.3
26	200	80	0.021	1507.2	31.1
27	250	80	0.012	2390.32	29.34
28	300	80	0.011	2469.7	26.44
29	350	80	0.005	4745.32	24.26
30	400	80	0.004	6217.2	22.92

VES DATA SHEET

Table 7.29: Sounding No. 29 Location Manak Adampur

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	6.824	11.75	80.18
2	3	1	2.936	27.47	80.64
3	4	1	1.626	49.45	80.43
4	5	1	1.028	77.71	79.89
5	5	2	2.102	37.68	79.2
6	6	2	1.400	54.95	76.92
7	8	2	0.748	98.91	74
8	10	2	0.458	155.43	71.23
9	10	4	0.934	75.36	70.36
10	12	4	0.612	109.9	67.28
11	15	4	0.386	173.48	66.96
12	20	4	0.226	310.86	70.26
13	20	8	0.472	150.72	71.1
14	25	8	0.319	239.03	76.16
15	30	8	0.239	346.97	82.78
16	40	8	0.154	621.72	95.76
17	50	8	0.113	974.97	110.49
18	50	20	0.297	367.8	109.32
19	60	20	0.212	549.5	116.24
20	80	20	0.128	989.1	126.22
21	100	20	0.084	1554.3	129.94
22	100	40	0.175	753.6	132.14
23	120	40	0.117	1099	128.68
24	160	40	0.059	1978.2	116.78
25	200	40	0.032	3108.6	98.56
26	200	80	0.064	1507.2	95.92
27	250	80	0.030	2390.32	72.6
28	300	80	0.025	2469.7	62.74
29	350	80	0.011	4745.32	52.26
30	400	80	0.007	6217.2	44.67

VES DATA SHEET

Table 7.30: Sounding No. 30 Location Manak Adampur

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	14.677	11.75	172.46
2	3	1	6.207	27.47	170.51
3	4	1	3.159	49.45	156.21
4	5	1	1.906	77.71	148.09
5	5	2	3.948	37.68	148.76
6	6	2	2.411	54.95	132.51
7	8	2	1.268	98.91	125.37
8	10	2	0.723	155.43	112.34
9	10	4	1.469	75.36	110.67
10	12	4	0.923	109.9	101.41
11	15	4	0.492	173.48	85.43
12	20	4	0.242	310.86	75.19
13	20	8	0.494	150.72	74.42
14	25	8	0.279	239.03	66.6
15	30	8	0.159	346.97	55.31
16	40	8	0.076	621.72	47.12
17	50	8	0.042	974.97	41.4
18	50	20	0.114	367.8	41.93
19	60	20	0.068	549.5	37.14
20	80	20	0.036	989.1	35.72
21	100	20	0.024	1554.3	37.83
22	100	40	0.051	753.6	38.11
23	120	40	0.040	1099	43.97
24	160	40	0.025	1978.2	48.61
25	200	40	0.018	3108.6	57.32
26	200	80	0.039	1507.2	58.71
27	250	80	0.027	2390.32	65.33
28	300	80	0.030	2469.7	74.41
29	350	80	0.017	4745.32	80.21
30	400	80	0.013	6217.2	83.47

VES DATA SHEET

Table 7.31: Sounding No. 31 **Location** **Hoshangpur**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	15.435	11.75	181.36
2	3	1	5.944	27.47	163.28
3	4	1	2.973	49.45	147
4	5	1	1.609	77.71	125.01
5	5	2	3.246	37.68	122.32
6	6	2	1.817	54.95	99.84
7	8	2	0.698	98.91	69.02
8	10	2	0.340	155.43	52.86
9	10	4	0.692	75.36	52.15
10	12	4	0.395	109.9	43.4
11	15	4	0.215	173.48	37.29
12	20	4	0.120	310.86	37.26
13	20	8	0.253	150.72	38.14
14	25	8	0.175	239.03	41.78
15	30	8	0.134	346.97	46.42
16	40	8	0.088	621.72	54.56
17	50	8	0.064	974.97	62.35
18	50	20	0.170	367.8	62.42
19	60	20	0.126	549.5	69.25
20	80	20	0.079	989.1	78.39
21	100	20	0.054	1554.3	83.89
22	100	40	0.112	753.6	84.57
23	120	40	0.079	1099	87.35
24	160	40	0.045	1978.2	88.69
25	200	40	0.029	3108.6	88.91
26	200	80	0.058	1507.2	87.36
27	250	80	0.035	2390.32	83.76
28	300	80	0.033	2469.7	82.1
29	350	80	0.017	4745.32	80.04
30	400	80	0.013	6217.2	79.16

VES DATA SHEET

Table 7.32: Sounding No. 32 **Location** **Jabarhera**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	9.146	11.75	107.46
2	3	1	2.693	27.47	73.99
3	4	1	0.994	49.45	49.13
4	5	1	0.453	77.71	35.18
5	5	2	0.882	37.68	33.22
6	6	2	0.476	54.95	26.18
7	8	2	0.201	98.91	19.86
8	10	2	0.122	155.43	18.93
9	10	4	0.250	75.36	18.82
10	12	4	0.175	109.9	19.24
11	15	4	0.122	173.48	21.16
12	20	4	0.079	310.86	24.48
13	20	8	0.162	150.72	24.46
14	25	8	0.119	239.03	28.56
15	30	8	0.093	346.97	32.3
16	40	8	0.062	621.72	38.72
17	50	8	0.045	974.97	43.8
18	50	20	0.119	367.8	43.89
19	60	20	0.089	549.5	48.64
20	80	20	0.056	989.1	55.08
21	100	20	0.038	1554.3	59.43
22	100	40	0.080	753.6	60.5
23	120	40	0.058	1099	63.82
24	160	40	0.034	1978.2	67.94
25	200	40	0.022	3108.6	67.92
26	200	80	0.044	1507.2	66.53
27	250	80	0.027	2390.32	65.41
28	300	80	0.025	2469.7	61.16
29	350	80	0.012	4745.32	57.21
30	400	80	0.009	6217.2	53.54

VES DATA SHEET

Table 7.33: Sounding No. 33 **Location** **Lodhipur**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	4.684	11.75	55.04
2	3	1	2.044	27.47	56.14
3	4	1	1.160	49.45	57.35
4	5	1	0.748	77.71	58.12
5	5	2	1.546	37.68	58.27
6	6	2	1.064	54.95	58.48
7	8	2	0.630	98.91	62.34
8	10	2	0.421	155.43	65.4
9	10	4	0.870	75.36	65.59
10	12	4	0.620	109.9	68.11
11	15	4	0.413	173.48	71.6
12	20	4	0.243	310.86	75.42
13	20	8	0.500	150.72	75.38
14	25	8	0.323	239.03	77.15
15	30	8	0.222	346.97	76.91
16	40	8	0.122	621.72	76.16
17	50	8	0.076	974.97	74.04
18	50	20	0.201	367.8	73.94
19	60	20	0.127	549.5	69.88
20	80	20	0.065	989.1	64.76
21	100	20	0.038	1554.3	59.43
22	100	40	0.072	753.6	54.57
23	120	40	0.049	1099	53.54
24	160	40	0.027	1978.2	52.49
25	200	40	0.018	3108.6	54.56
26	200	80	0.036	1507.2	54.72
27	250	80	0.023	2390.32	55.07
28	300	80	0.023	2469.7	57.21
29	350	80	0.012	4745.32	56.14
30	400	80	0.009	6217.2	55.82

VES DATA SHEET

Table 7.34: Sounding No. 34 **Location** **Padli Gujar**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	7.094	11.75	83.35
2	3	1	3.065	27.47	84.2
3	4	1	1.706	49.45	84.34
4	5	1	1.089	77.71	84.65
5	5	2	2.238	37.68	84.34
6	6	2	1.555	54.95	85.46
7	8	2	0.872	98.91	86.29
8	10	2	0.531	155.43	82.48
9	10	4	1.078	75.36	81.26
10	12	4	0.735	109.9	80.79
11	15	4	0.389	173.48	67.57
12	20	4	0.192	310.86	59.58
13	20	8	0.343	150.72	51.76
14	25	8	0.199	239.03	47.65
15	30	8	0.134	346.97	46.59
16	40	8	0.067	621.72	41.58
17	50	8	0.041	974.97	40.43
18	50	20	0.113	367.8	41.6
19	60	20	0.083	549.5	45.58
20	80	20	0.047	989.1	46.62
21	100	20	0.036	1554.3	56.05
22	100	40	0.075	753.6	56.15
23	120	40	0.066	1099	72.19
24	160	40	0.040	1978.2	78.39
25	200	40	0.027	3108.6	84.26
26	200	80	0.057	1507.2	86.14
27	250	80	0.041	2390.32	97.9
28	300	80	0.044	2469.7	107.72
29	350	80	0.024	4745.32	114.36
30	400	80	0.020	6217.2	121.63

VES DATA SHEET

Table 7.35: Sounding No. 35 **Location** **Tanshipur**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	4.586	11.75	53.89
2	3	1	1.981	27.47	54.43
3	4	1	1.103	49.45	54.52
4	5	1	0.704	77.71	54.73
5	5	2	1.447	37.68	54.52
6	6	2	1.005	54.95	55.25
7	8	2	0.564	98.91	55.79
8	10	2	0.343	155.43	53.32
9	10	4	0.697	75.36	52.54
10	12	4	0.469	109.9	51.52
11	15	4	0.282	173.48	48.97
12	20	4	0.167	310.86	51.96
13	20	8	0.347	150.72	52.25
14	25	8	0.201	239.03	48.1
15	30	8	0.136	346.97	47.04
16	40	8	0.068	621.72	41.98
17	50	8	0.042	974.97	40.81
18	50	20	0.114	367.8	41.99
19	60	20	0.084	549.5	46.01
20	80	20	0.048	989.1	47.06
21	100	20	0.036	1554.3	56.58
22	100	40	0.075	753.6	56.69
23	120	40	0.066	1099	72.88
24	160	40	0.040	1978.2	79.14
25	200	40	0.027	3108.6	85.07
26	200	80	0.058	1507.2	86.95
27	250	80	0.037	2390.32	88.62
28	300	80	0.037	2469.7	90.74
29	350	80	0.020	4745.32	95.03
30	400	80	0.016	6217.2	97.17

VES DATA SHEET

Table 7.36: Sounding No. 36 Location Salahpur

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	13.896	11.75	163.28
2	3	1	5.881	27.47	161.56
3	4	1	3.215	49.45	158.98
4	5	1	2.026	77.71	157.46
5	5	2	4.170	37.68	157.12
6	6	2	2.806	54.95	154.18
7	8	2	1.540	98.91	152.32
8	10	2	0.964	155.43	149.83
9	10	4	1.984	75.36	149.52
10	12	4	1.292	109.9	142.04
11	15	4	0.786	173.48	136.28
12	20	4	0.398	310.86	123.86
13	20	8	0.817	150.72	123.11
14	25	8	0.499	239.03	119.23
15	30	8	0.334	346.97	115.84
16	40	8	0.186	621.72	115.86
17	50	8	0.123	974.97	120.34
18	50	20	0.328	367.8	120.65
19	60	20	0.223	549.5	122.63
20	80	20	0.125	989.1	123.42
21	100	20	0.077	1554.3	118.98
22	100	40	0.149	753.6	112.46
23	120	40	0.097	1099	106.48
24	160	40	0.049	1978.2	96.82
25	200	40	0.028	3108.6	87.38
26	200	80	0.058	1507.2	87.29
27	250	80	0.032	2390.32	76.84
28	300	80	0.028	2469.7	68.57
29	350	80	0.013	4745.32	62.34
30	400	80	0.009	6217.2	57.21

VES DATA SHEET

Table 7.37: Sounding No. 37 Location Nanhera Ikbalpur

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	4.148	11.75	48.74
2	3	1	1.838	27.47	50.48
3	4	1	0.978	49.45	48.36
4	5	1	0.649	77.71	50.43
5	5	2	1.389	37.68	52.33
6	6	2	0.985	54.95	54.12
7	8	2	0.583	98.91	57.66
8	10	2	0.376	155.43	58.42
9	10	4	0.795	75.36	59.91
10	12	4	0.539	109.9	59.23
11	15	4	0.371	173.48	64.36
12	20	4	0.220	310.86	68.38
13	20	8	0.465	150.72	70.08
14	25	8	0.295	239.03	70.51
15	30	8	0.209	346.97	72.51
16	40	8	0.116	621.72	72.43
17	50	8	0.073	974.97	70.88
18	50	20	0.182	367.8	66.79
19	60	20	0.116	549.5	64.01
20	80	20	0.062	989.1	61.12
21	100	20	0.039	1554.3	61.39
22	100	40	0.077	753.6	57.8
23	120	40	0.049	1099	54.01
24	160	40	0.025	1978.2	48.77
25	200	40	0.015	3108.6	46.15
26	200	80	0.030	1507.2	45.21
27	250	80	0.017	2390.32	40.27
28	300	80	0.014	2469.7	34.45
29	350	80	0.006	4745.32	30.11
30	400	80	0.004	6217.2	27.7

VES DATA SHEET

Table 7.38: Sounding No. 38 **Location Delna**

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	4.468	11.75	52.5
2	3	1	1.858	27.47	51.04
3	4	1	0.994	49.45	49.13
4	5	1	0.609	77.71	47.29
5	5	2	1.249	37.68	47.05
6	6	2	0.829	54.95	45.53
7	8	2	0.426	98.91	42.16
8	10	2	0.255	155.43	39.56
9	10	4	0.526	75.36	39.64
10	12	4	0.346	109.9	37.98
11	15	4	0.214	173.48	37.12
12	20	4	0.126	310.86	39.07
13	20	8	0.256	150.72	38.52
14	25	8	0.175	239.03	41.78
15	30	8	0.129	346.97	44.67
16	40	8	0.078	621.72	48.2
17	50	8	0.054	974.97	52.86
18	50	20	0.144	367.8	52.98
19	60	20	0.099	549.5	54.56
20	80	20	0.056	989.1	55.08
21	100	20	0.035	1554.3	54.04
22	100	40	0.070	753.6	52.42
23	120	40	0.044	1099	48.85
24	160	40	0.023	1978.2	45.21
25	200	40	0.014	3108.6	43.4
26	200	80	0.029	1507.2	43.11
27	250	80	0.017	2390.32	40.59
28	300	80	0.015	2469.7	37.98
29	350	80	0.008	4745.32	36.54
30	400	80	0.006	6217.2	35.18

VES DATA SHEET

Table 7.39: Sounding No. 39 Location Harchandpur

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	3.885	11.75	45.65
2	3	1	1.905	27.47	52.32
3	4	1	1.284	49.45	63.47
4	5	1	0.903	77.71	70.21
5	5	2	1.881	37.68	70.89
6	6	2	1.435	54.95	78.84
7	8	2	0.894	98.91	88.47
8	10	2	0.615	155.43	95.62
9	10	4	1.272	75.36	95.88
10	12	4	0.932	109.9	102.47
11	15	4	0.626	173.48	108.58
12	20	4	0.377	310.86	117.23
13	20	8	0.785	150.72	118.24
14	25	8	0.543	239.03	129.84
15	30	8	0.390	346.97	135.48
16	40	8	0.231	621.72	143.84
17	50	8	0.156	974.97	152.36
18	50	20	0.417	367.8	153.42
19	60	20	0.281	549.5	154.28
20	80	20	0.150	989.1	148.25
21	100	20	0.088	1554.3	137.41
22	100	40	0.164	753.6	123.48
23	120	40	0.112	1099	122.56
24	160	40	0.057	1978.2	113.47
25	200	40	0.034	3108.6	105.21
26	200	80	0.069	1507.2	104.33
27	250	80	0.039	2390.32	94.25
28	300	80	0.034	2469.7	83.41
29	350	80	0.016	4745.32	75.66
30	400	80	0.011	6217.2	71.23
31	450	80	0.008	7885.32	64.48
32	500	160	0.013	4783.1	61.18

VES DATA SHEET

Table 7.40: Sounding No. 40 Location Balailpur Paniyala

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	4.871	11.75	57.24
2	3	1	2.145	27.47	58.92
3	4	1	1.204	49.45	59.55
4	5	1	0.777	77.71	60.41
5	5	2	1.615	37.68	60.86
6	6	2	1.130	54.95	62.12
7	8	2	0.644	98.91	63.65
8	10	2	0.417	155.43	64.76
9	10	4	0.860	75.36	64.82
10	12	4	0.593	109.9	65.18
11	15	4	0.385	173.48	66.77
12	20	4	0.219	310.86	68.18
13	20	8	0.449	150.72	67.71
14	25	8	0.271	239.03	64.76
15	30	8	0.186	346.97	64.53
16	40	8	0.105	621.72	65.1
17	50	8	0.066	974.97	64.3
18	50	20	0.175	367.8	64.22
19	60	20	0.120	549.5	66.02
20	80	20	0.068	989.1	67.27
21	100	20	0.045	1554.3	69.88
22	100	40	0.092	753.6	69.2
23	120	40	0.061	1099	66.66
24	160	40	0.033	1978.2	66.05
25	200	40	0.020	3108.6	62.34
26	200	80	0.041	1507.2	61.58
27	250	80	0.024	2390.32	57.77
28	300	80	0.022	2469.7	55.1
29	350	80	0.011	4745.32	51.42
30	400	80	0.008	6217.2	48.24

VES DATA SHEET

Table 7.41: Sounding No. 41 Location Kharkhar Boyal

Serial No.	AB/2 (m)	MN (m)	Resistance (Ω)	Shape factor (G)	Apparent Resistivity (Ωm)
1	2	1	4.297	11.75	50.49
2	3	1	1.795	27.47	49.31
3	4	1	0.988	49.45	48.84
4	5	1	0.648	77.71	50.32
5	5	2	1.327	37.68	50
6	6	2	0.958	54.95	52.65
7	8	2	0.551	98.91	54.47
8	10	2	0.357	155.43	55.43
9	10	4	0.737	75.36	55.52
10	12	4	0.526	109.9	57.77
11	15	4	0.346	173.48	60
12	20	4	0.199	310.86	61.74
13	20	8	0.410	150.72	61.82
14	25	8	0.274	239.03	65.4
15	30	8	0.194	346.97	67.28
16	40	8	0.112	621.72	69.88
17	50	8	0.072	974.97	70.1
18	50	20	0.191	367.8	70.1
19	60	20	0.127	549.5	69.82
20	80	20	0.070	989.1	69.64
21	100	20	0.046	1554.3	70.96
22	100	40	0.095	753.6	71.94
23	120	40	0.066	1099	72.6
24	160	40	0.039	1978.2	76.92
25	200	40	0.026	3108.6	80.64
26	200	80	0.054	1507.2	80.71
27	250	80	0.034	2390.32	81.56
28	300	80	0.033	2469.7	80.59
29	350	80	0.017	4745.32	78.38
30	400	80	0.012	6217.2	75.42

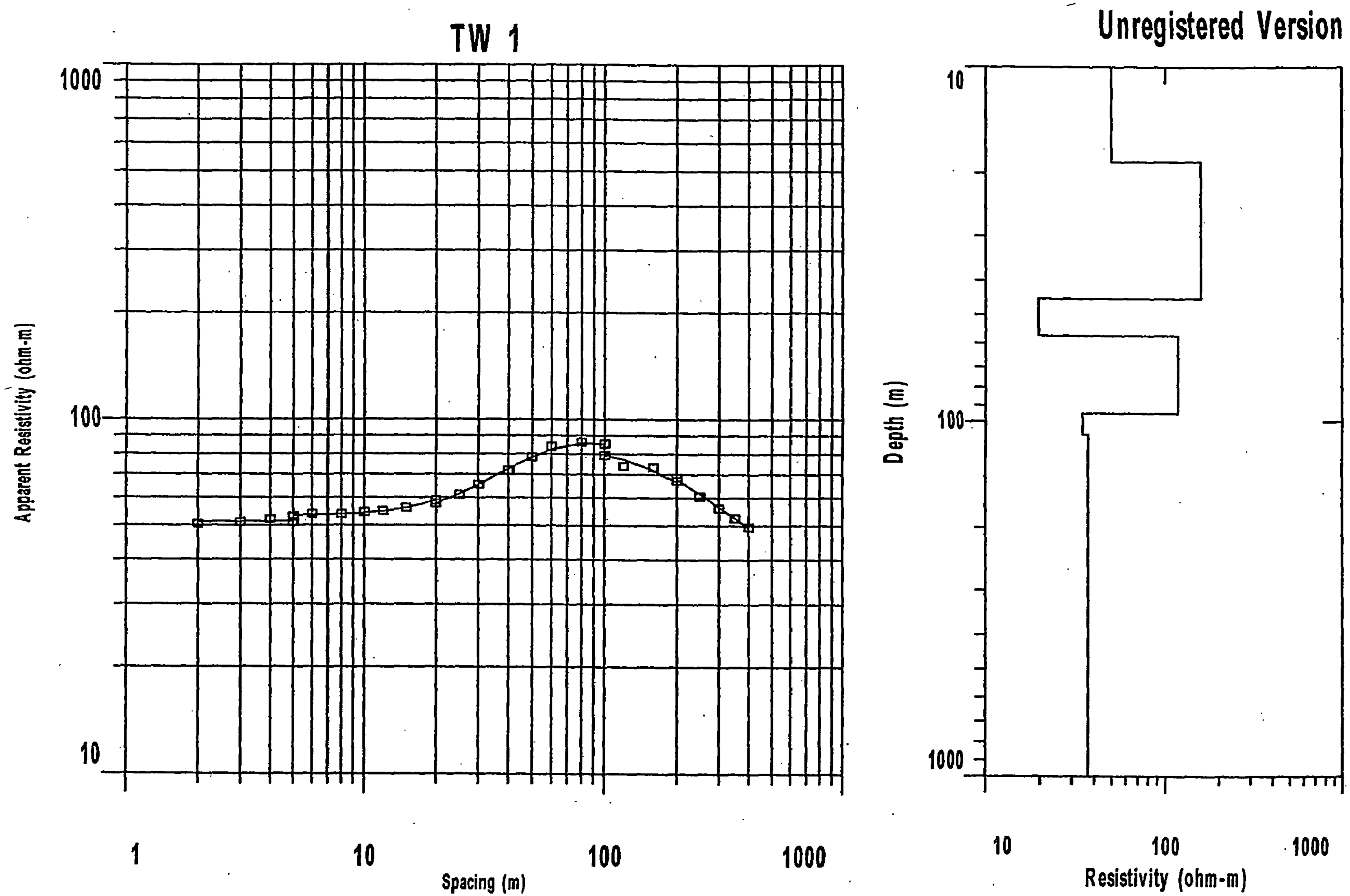


Fig. 7.1: Model output for VES-1

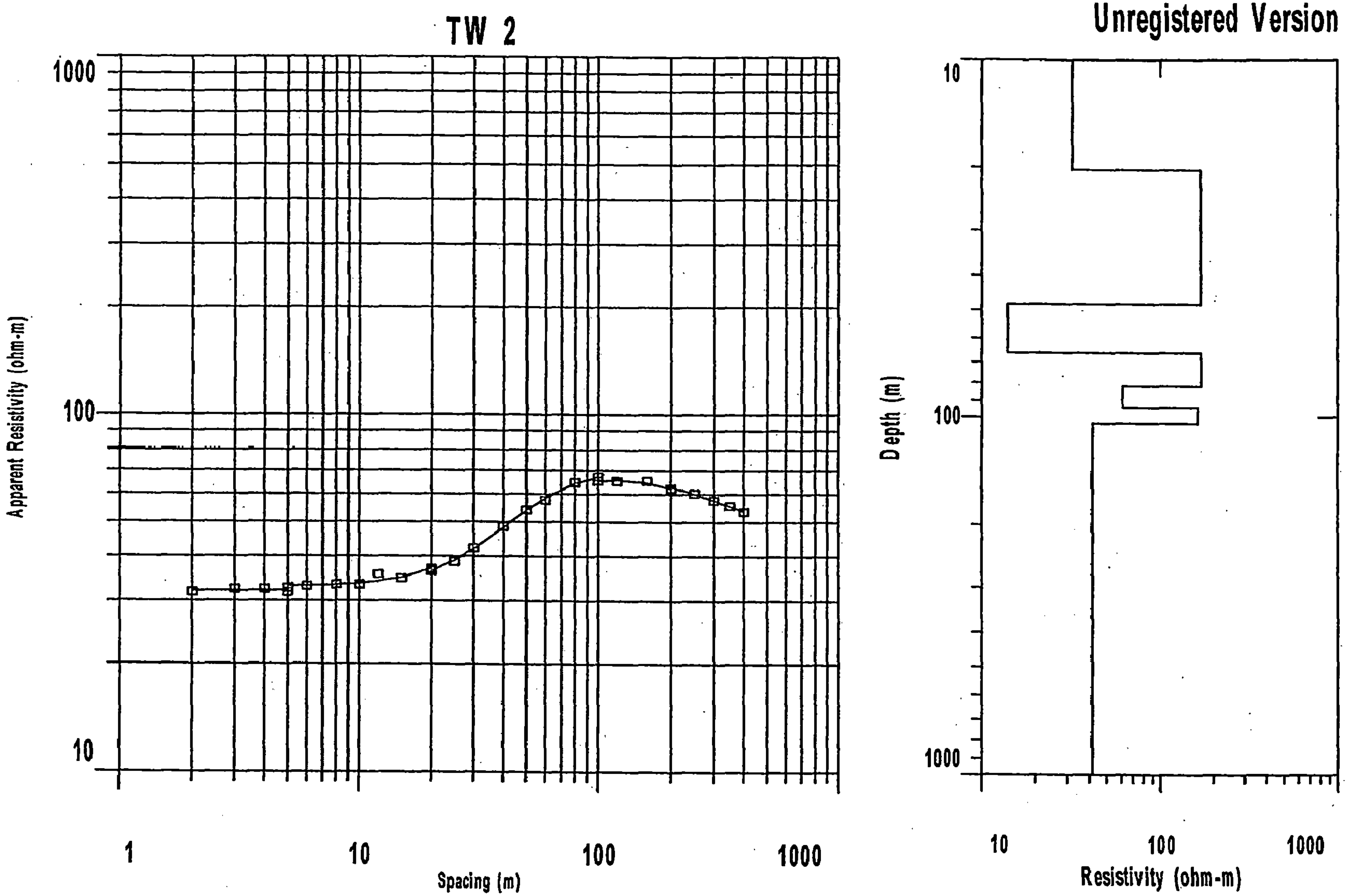


Fig. 7.2: Model output for VES-2

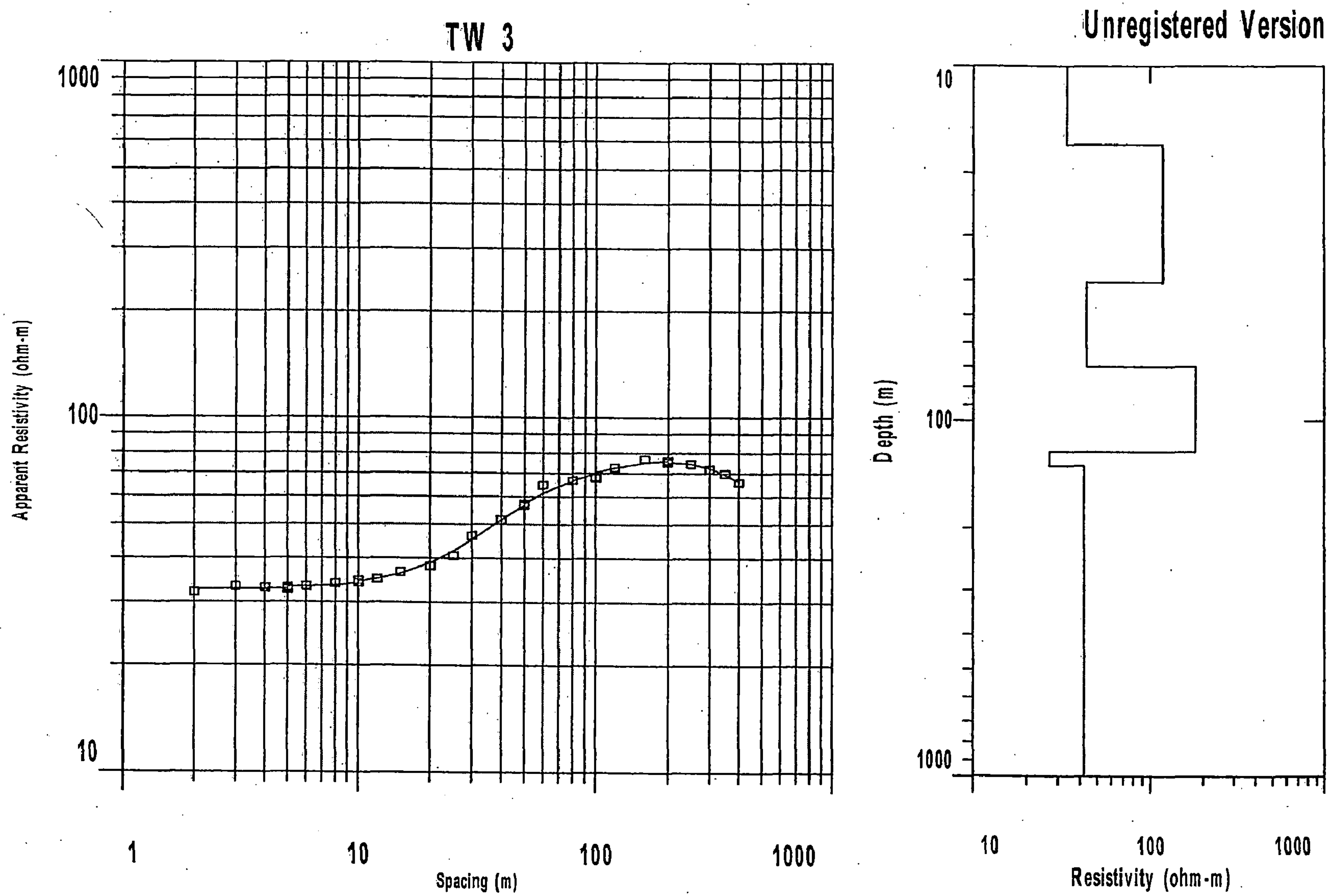
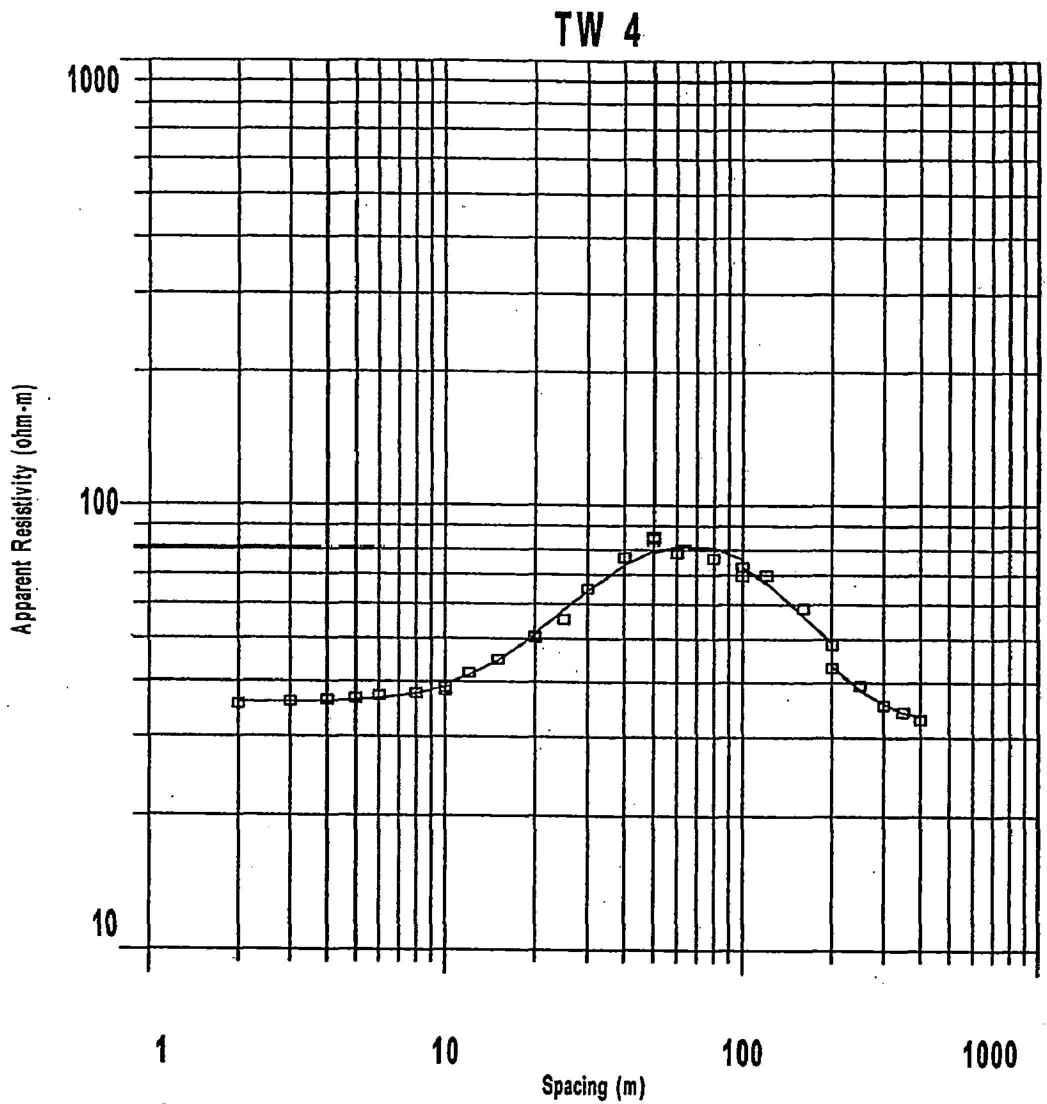


Fig. 7.3: Model output for VES-3



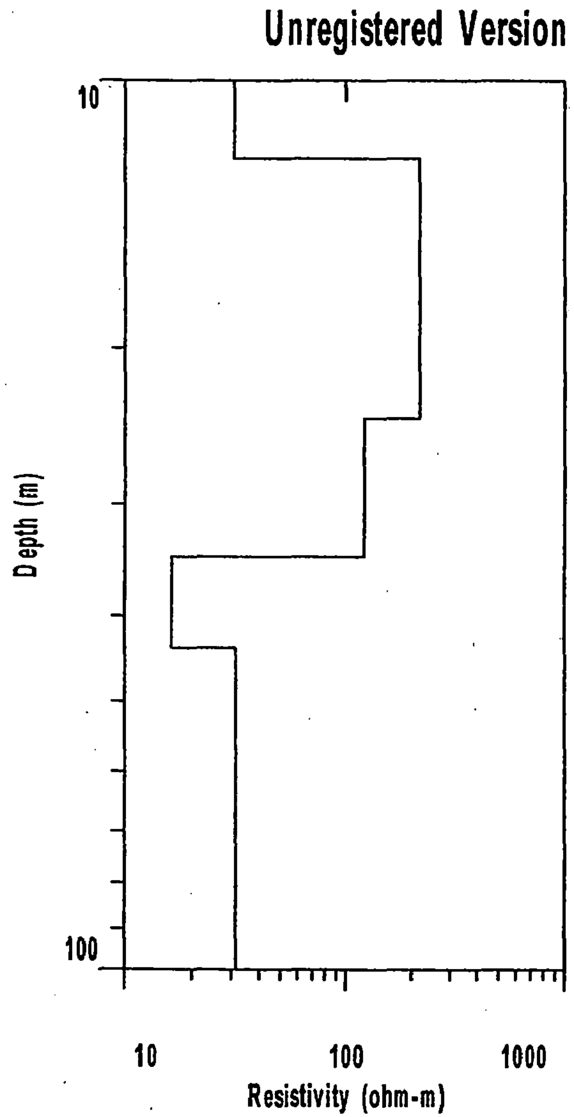


Fig. 7.4: Model output for VES-4

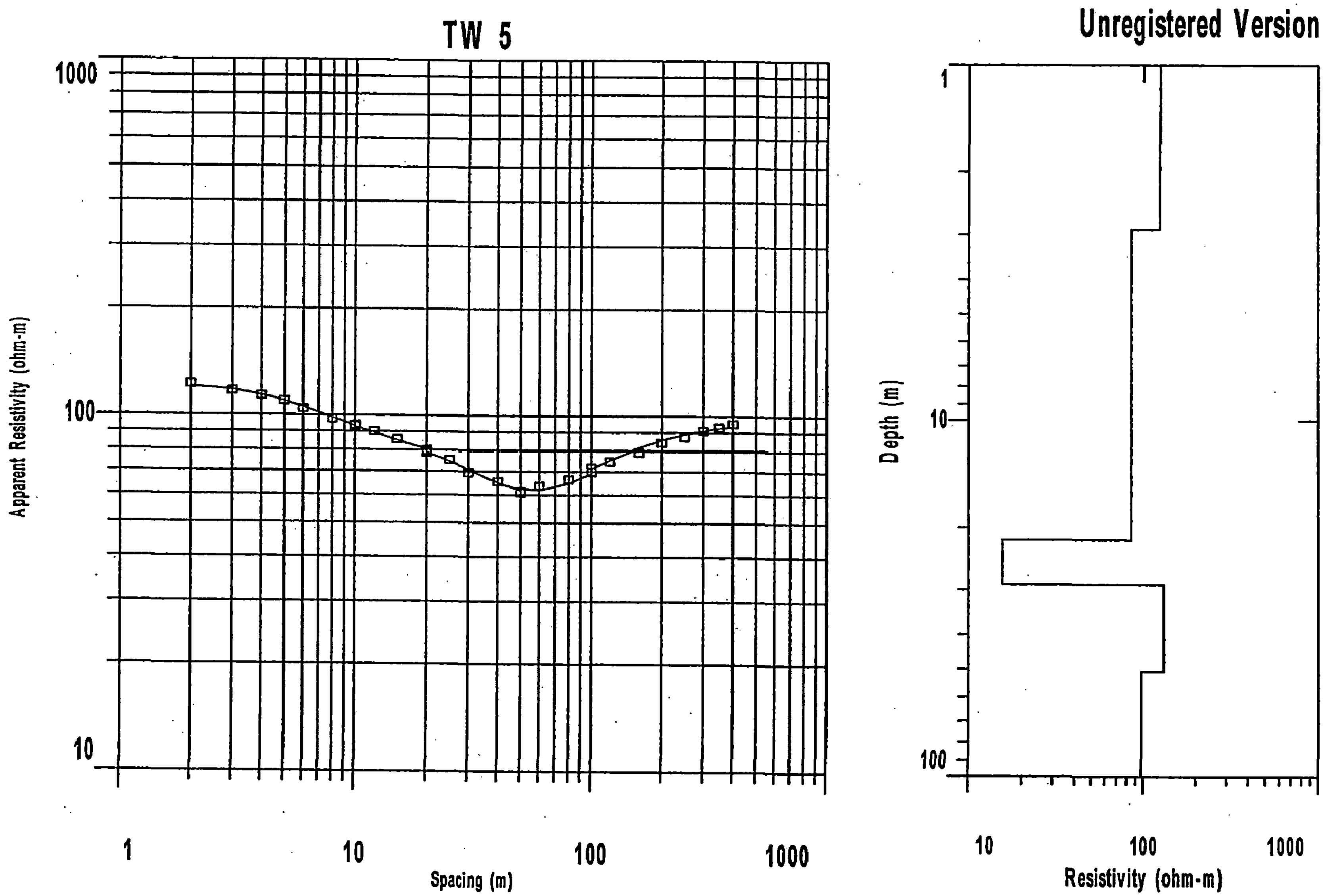


Fig. 7.5: Model output for VES-5

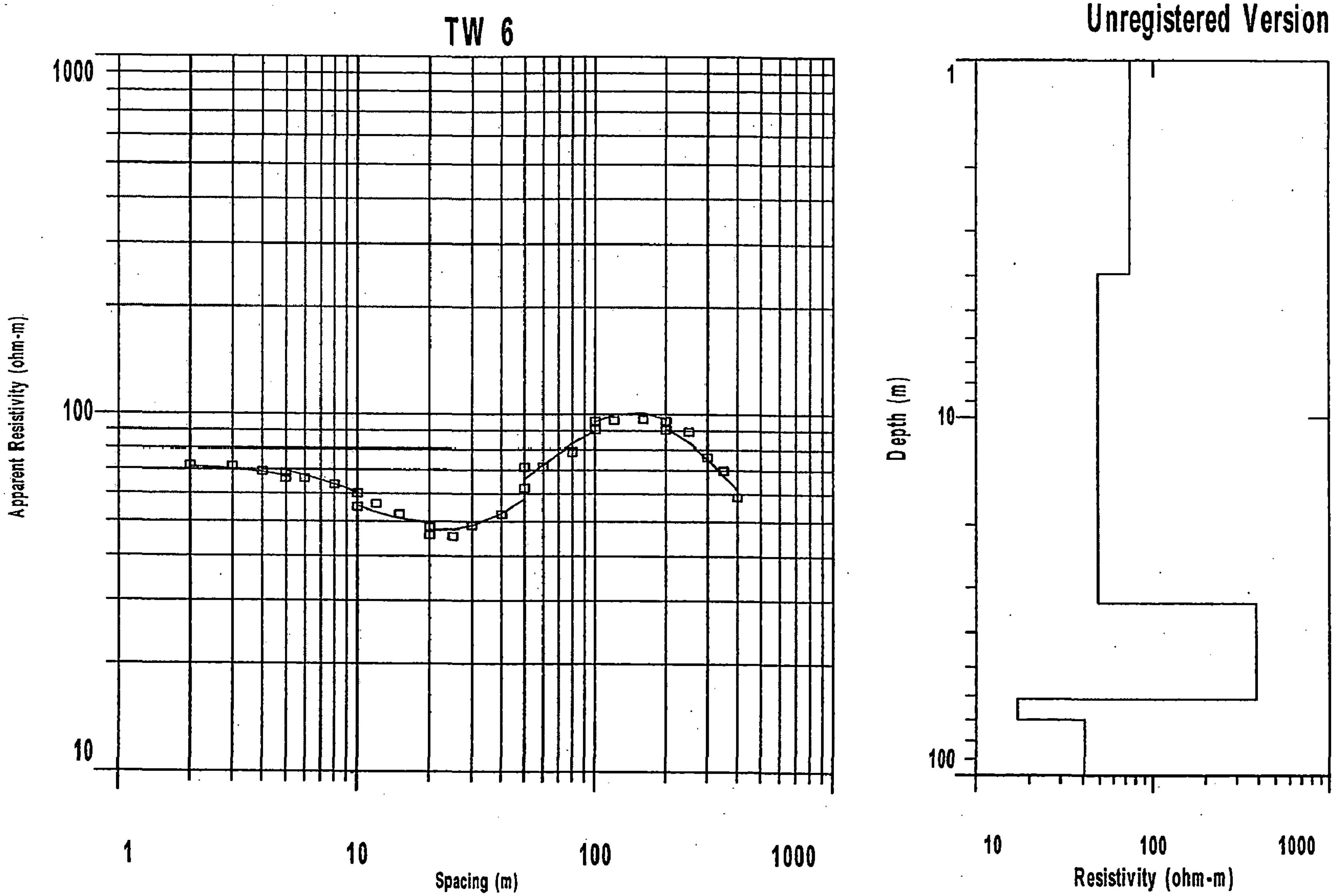


Fig. 7.6: Model output for VES-6

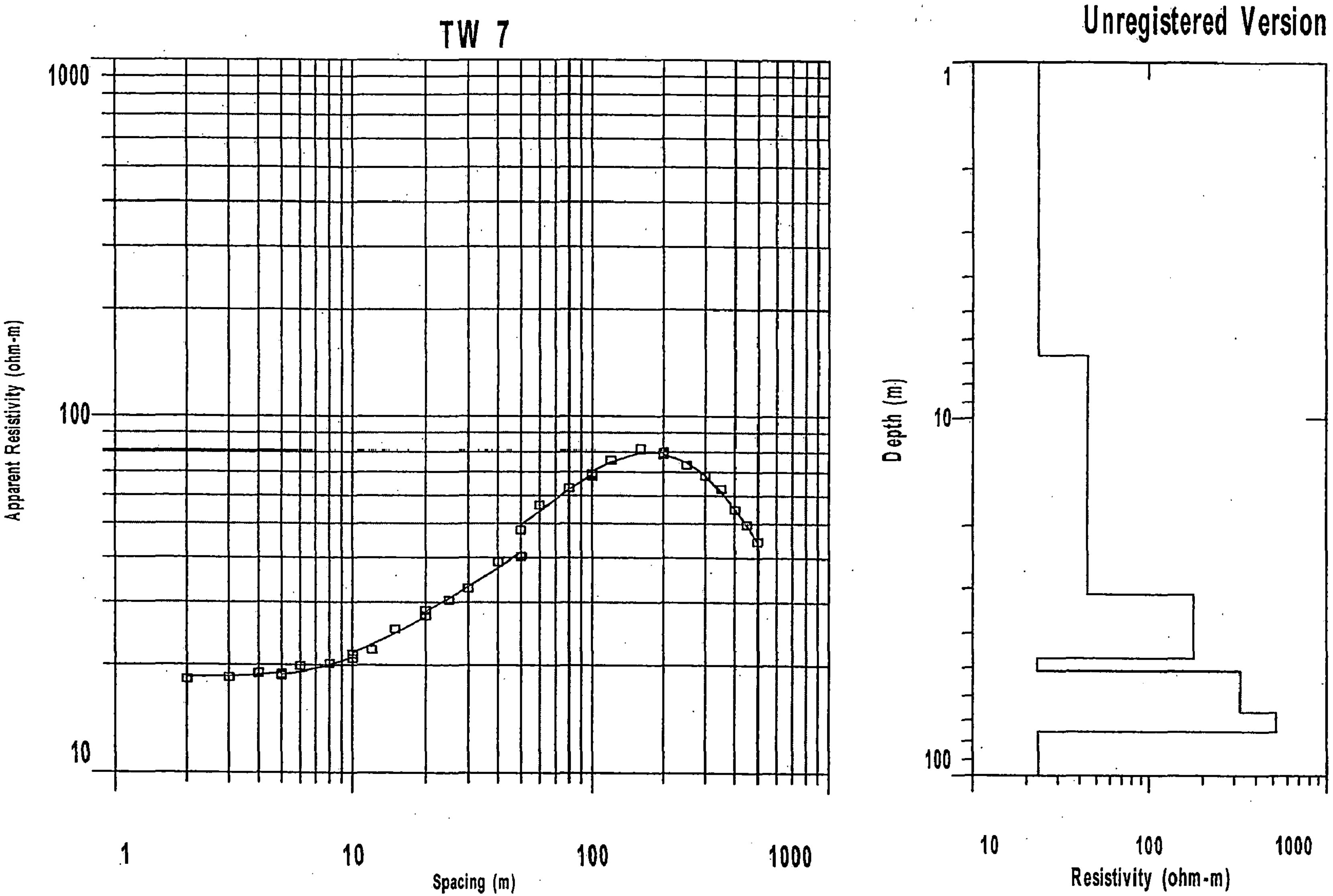


Fig. 7.7: Model output for VES-7

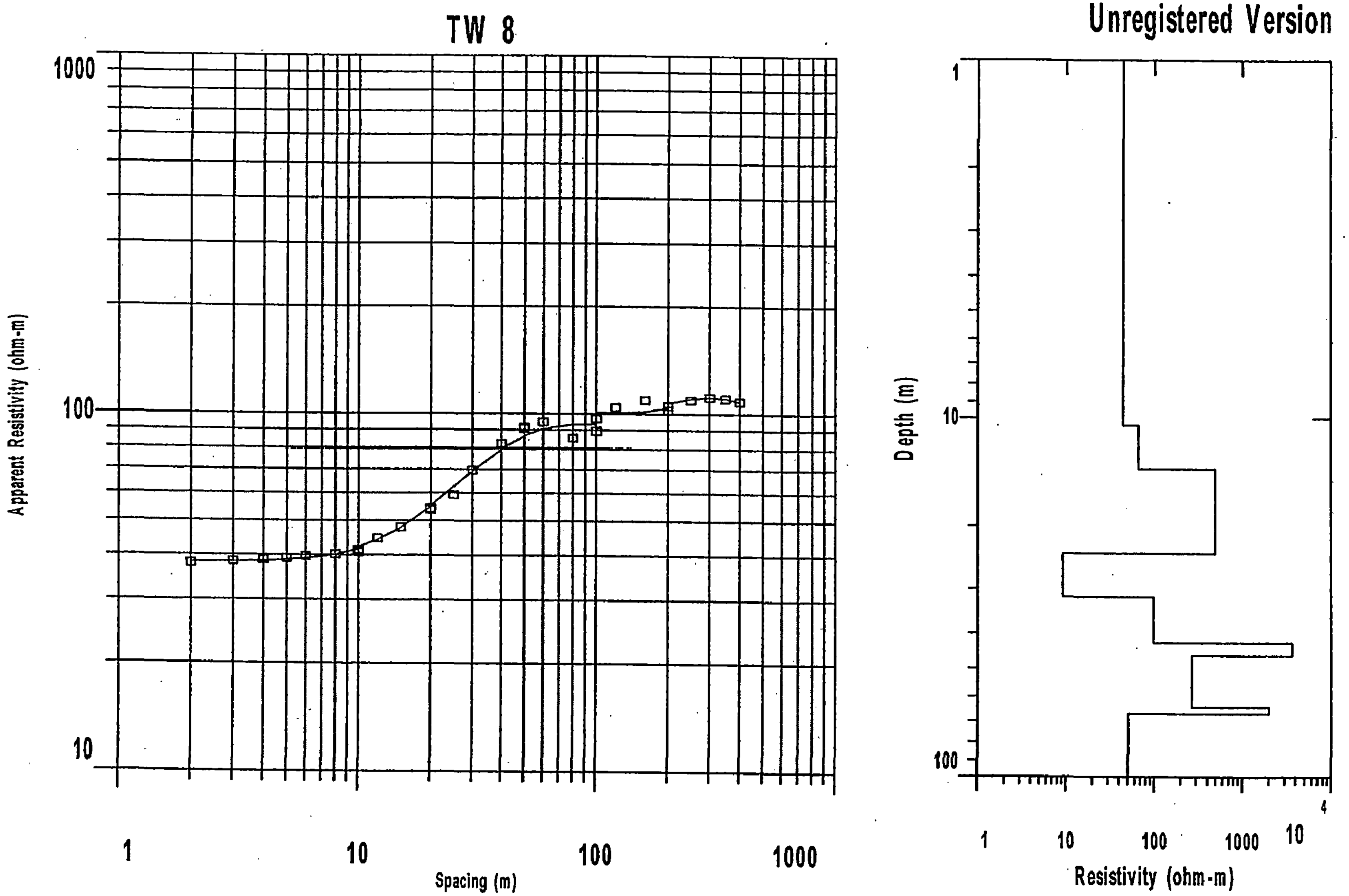


Fig. 7.8: Model output for VES-8

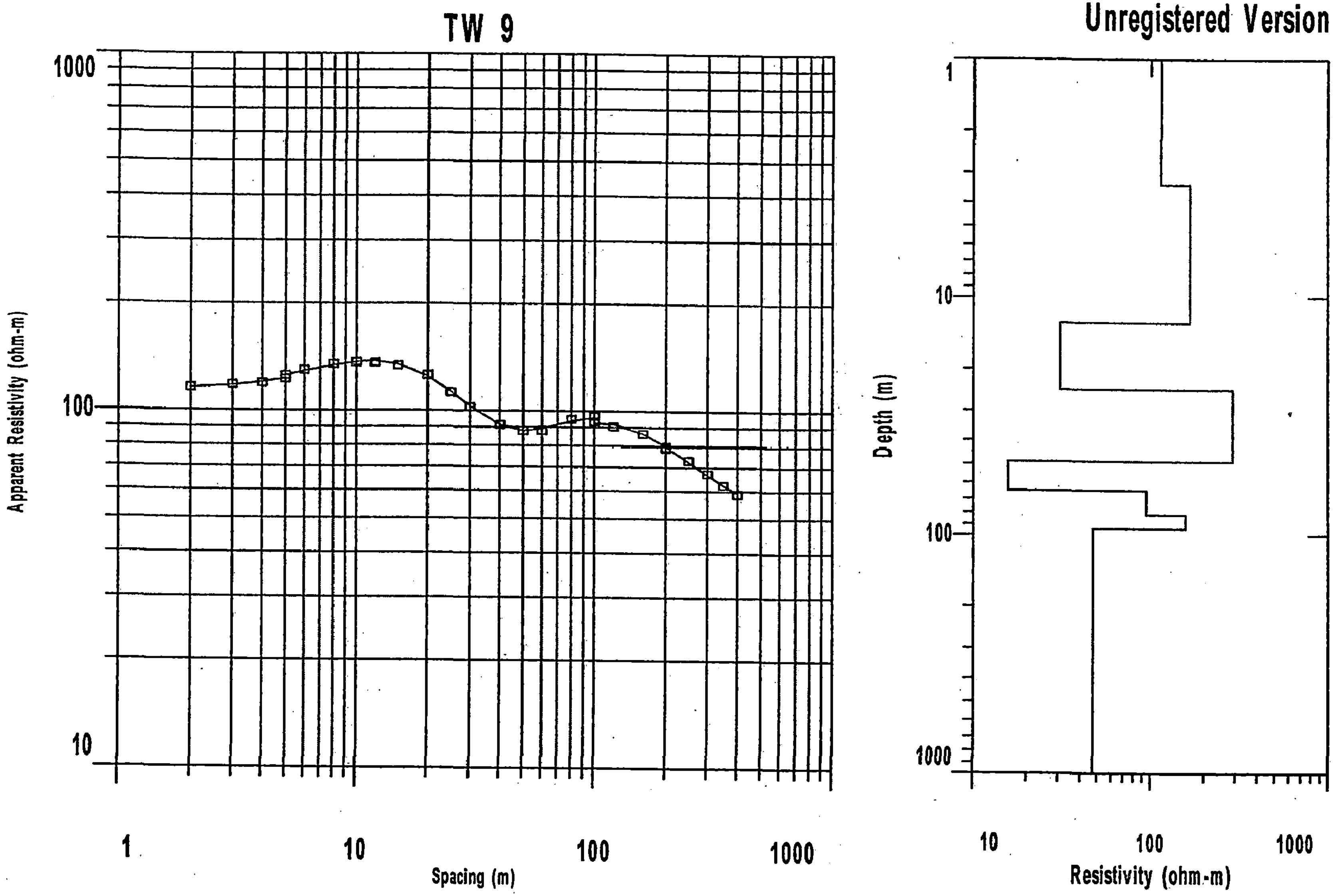


Fig. 7.9: Model output for VES-9

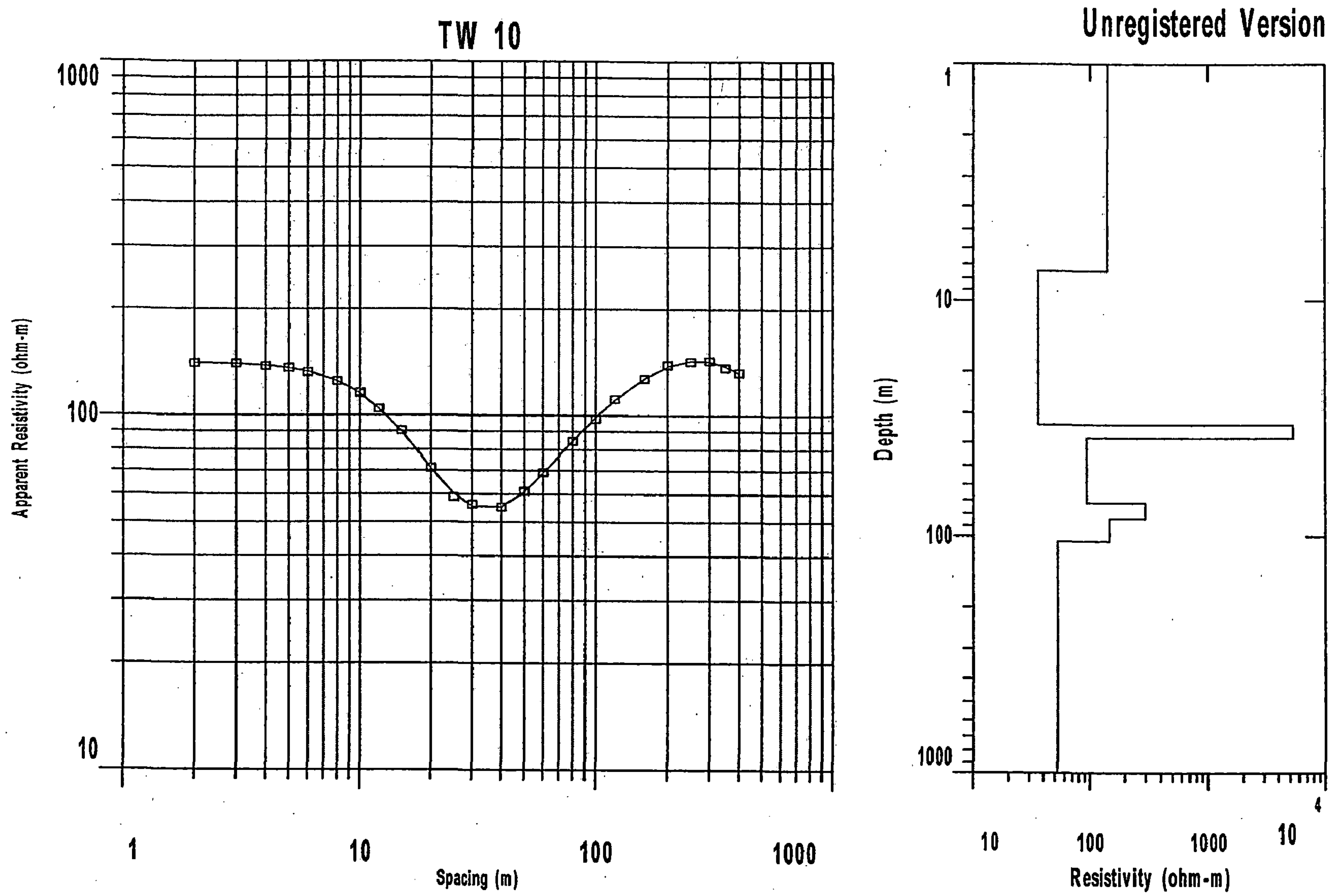


Fig. 7.10: Model output for VES-10

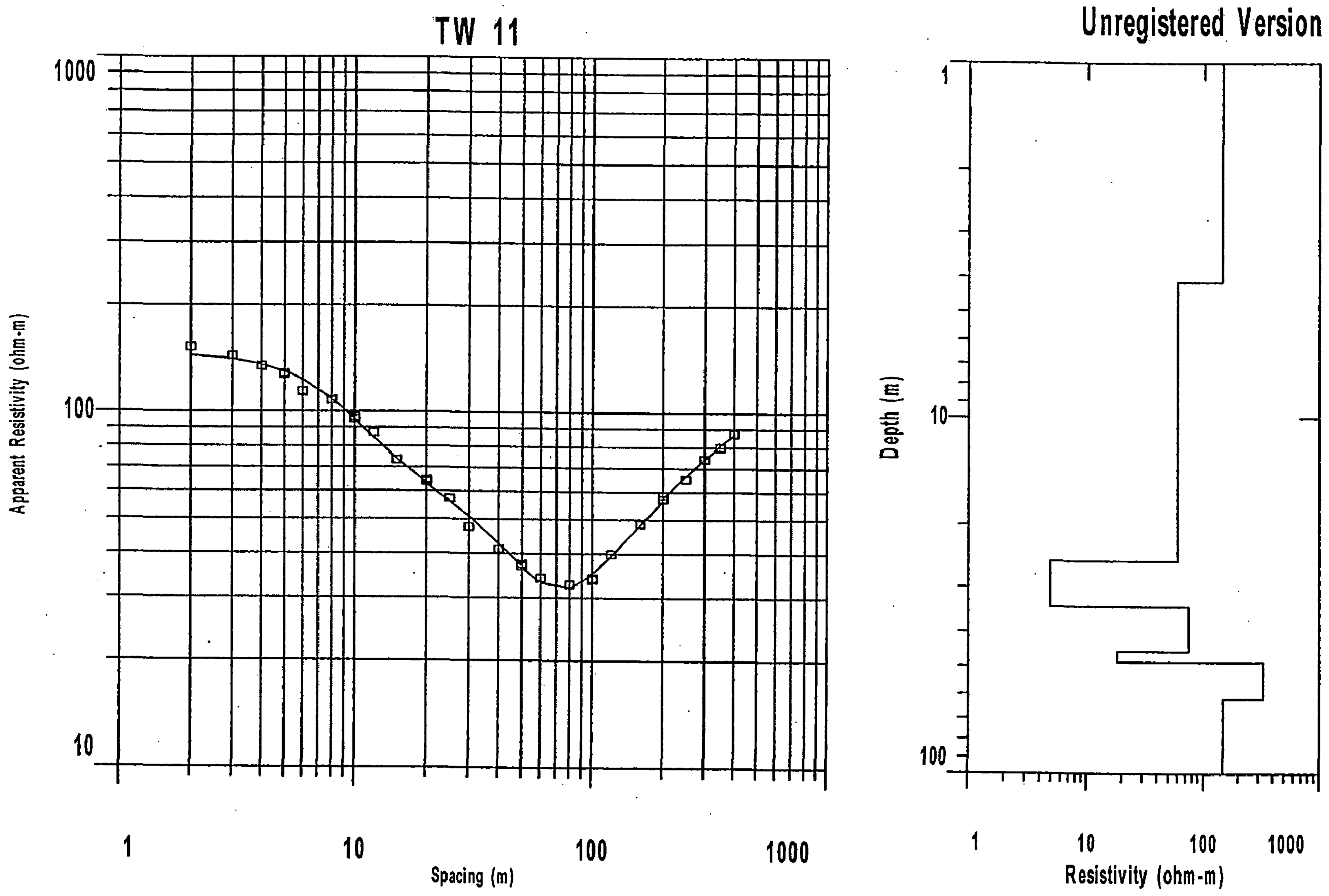


Fig. 7.11: Model output for VES-11

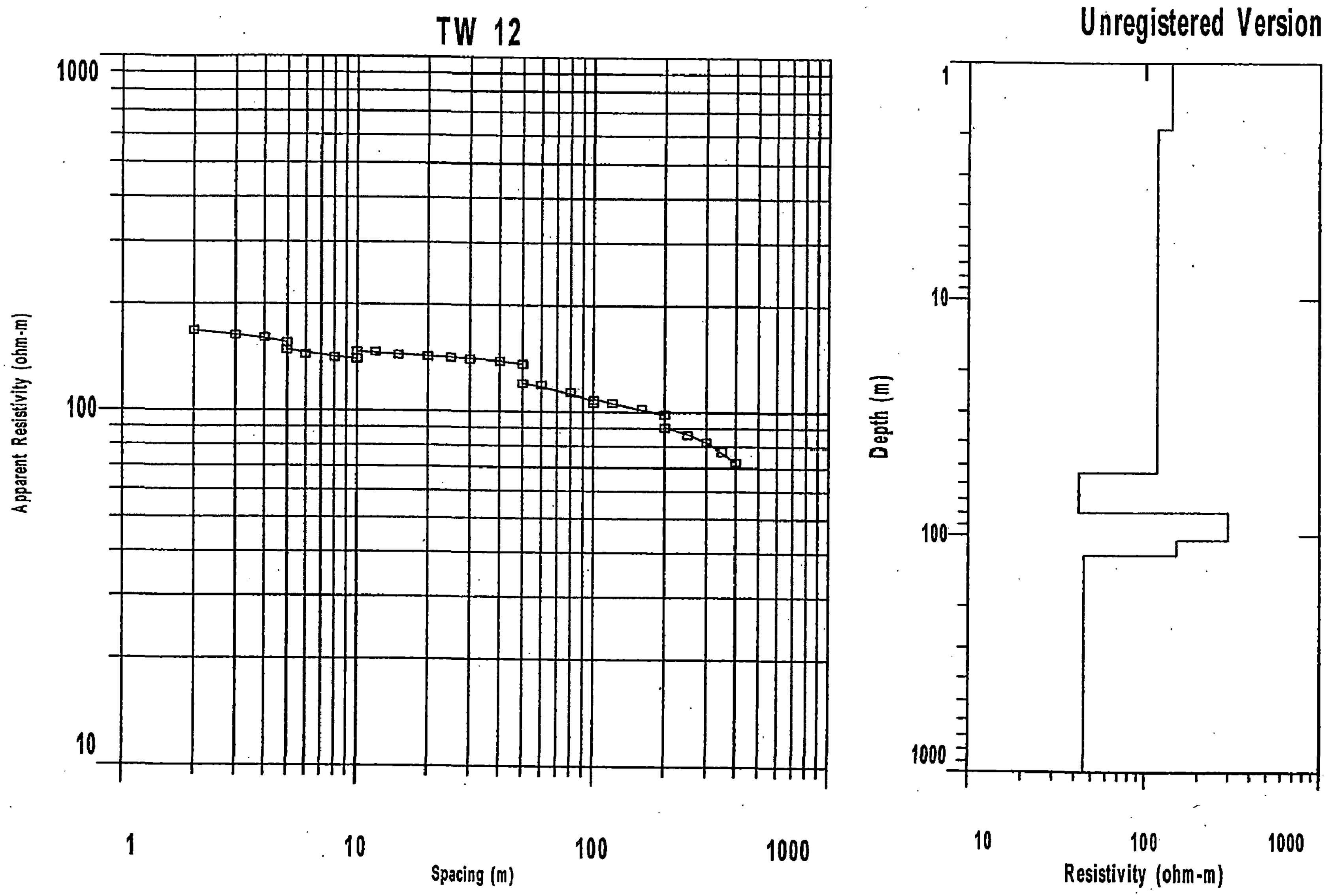


Fig. 7.12: Model output for VES-12

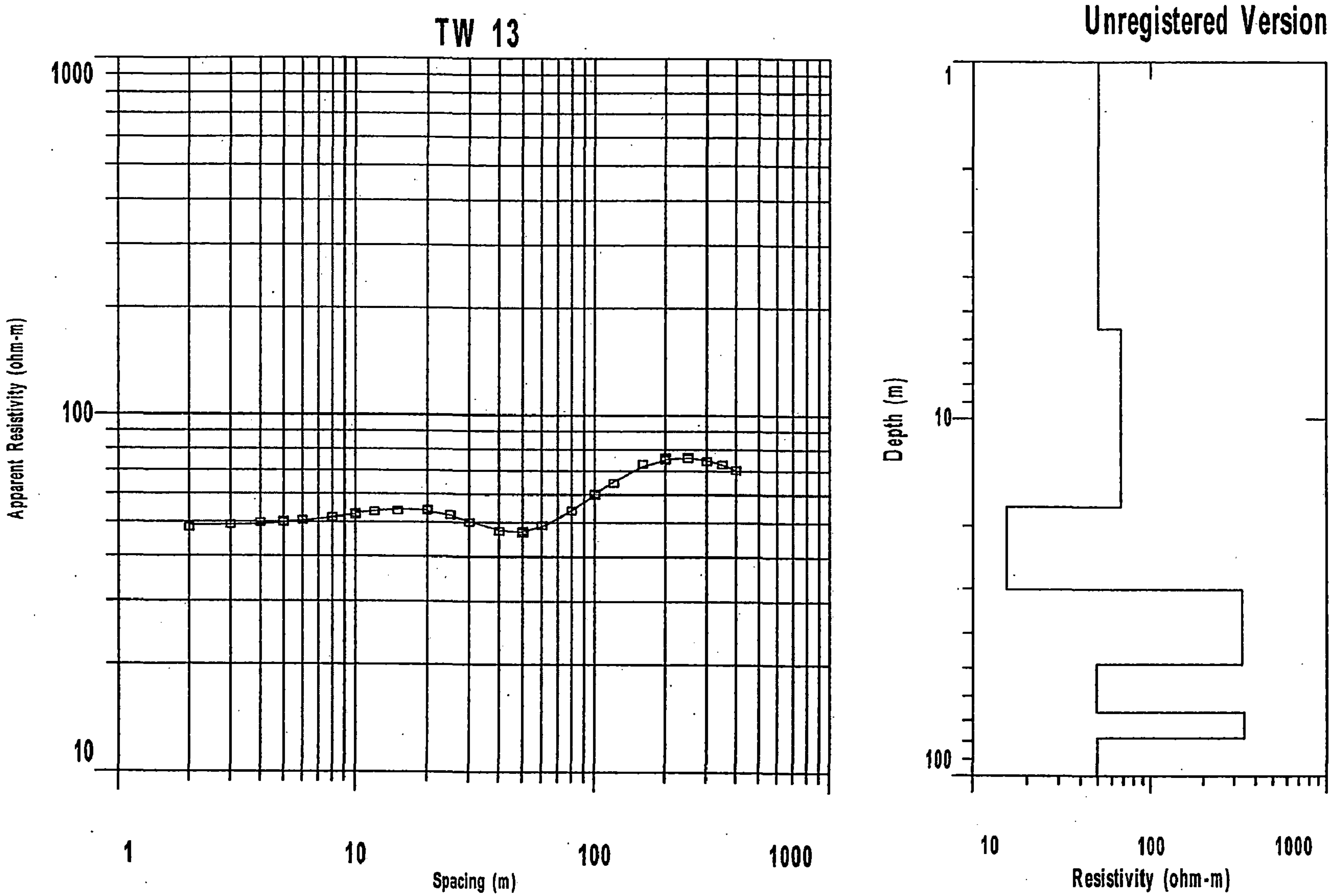
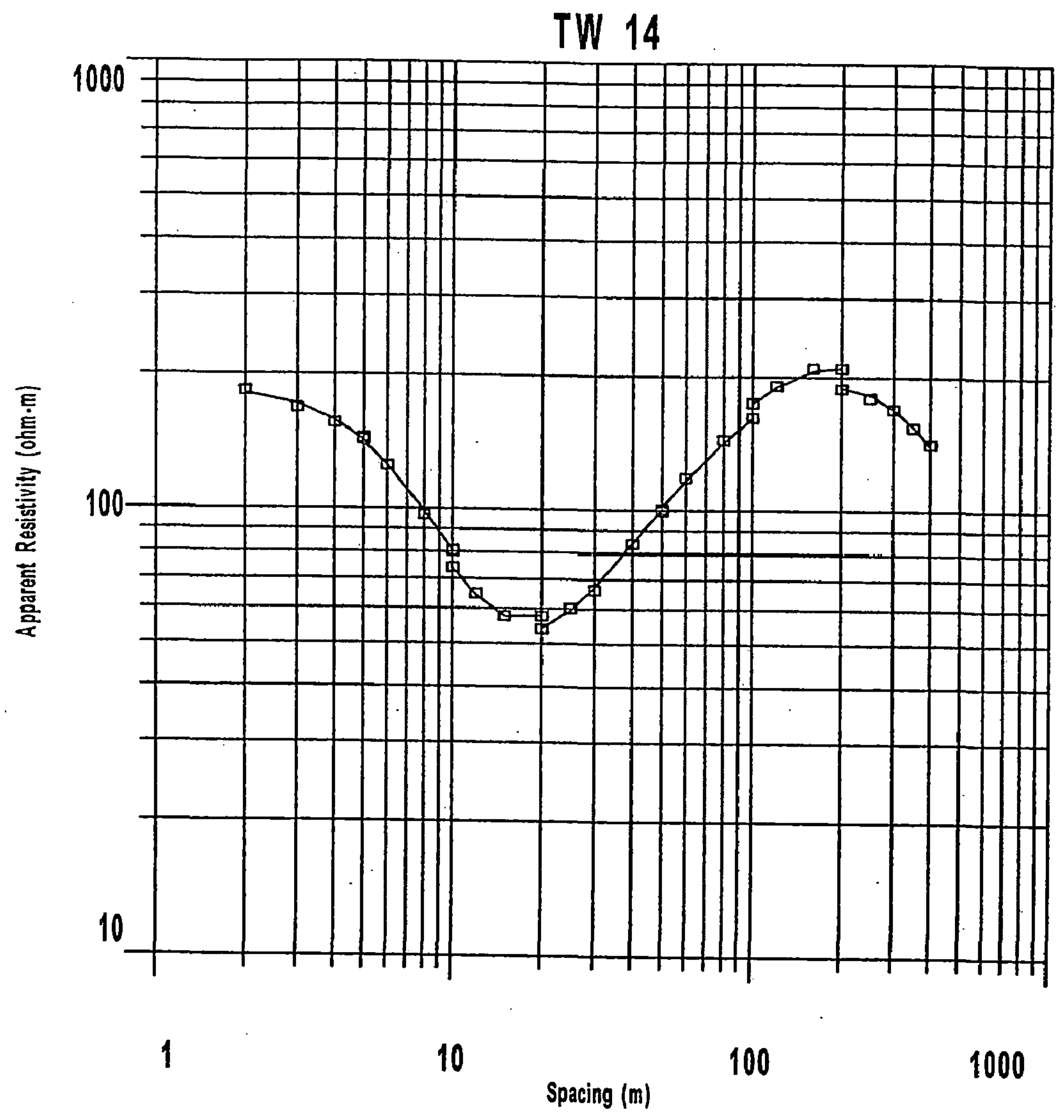


Fig. 7.13: Model output for VES-13



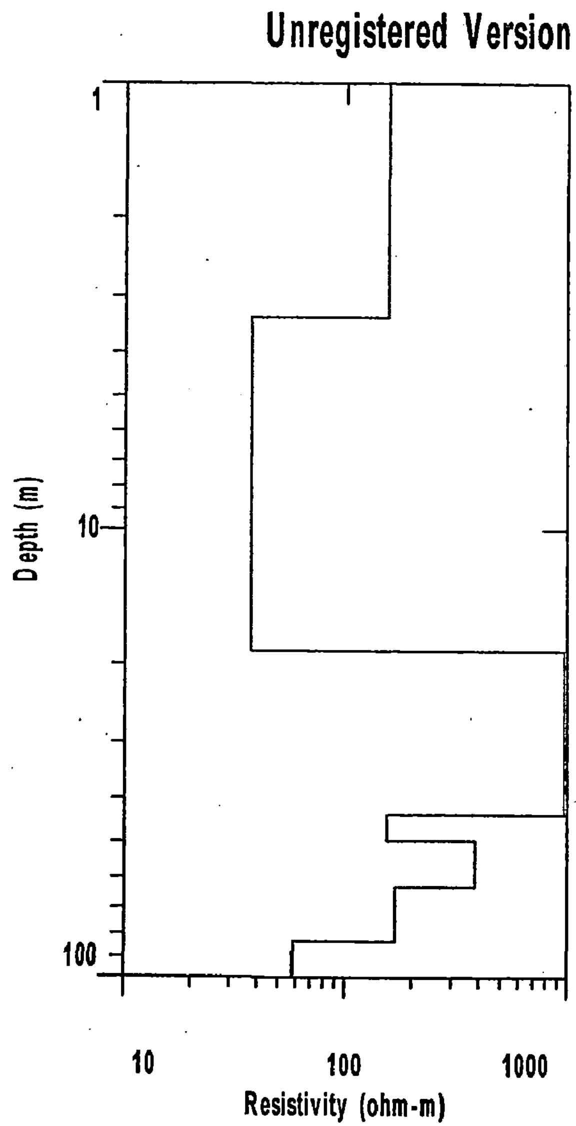


Fig. 7.14: Model output for VES-14

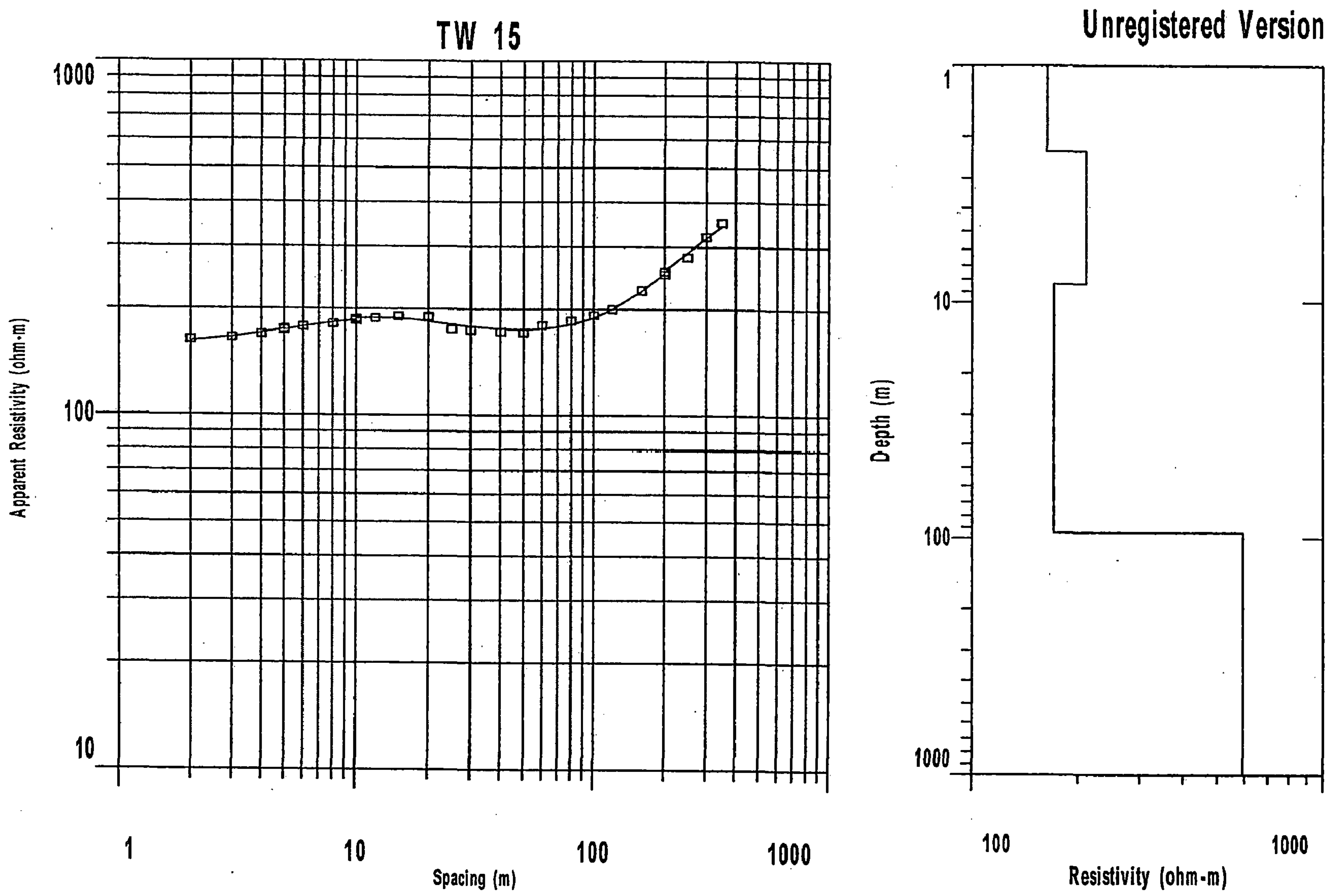
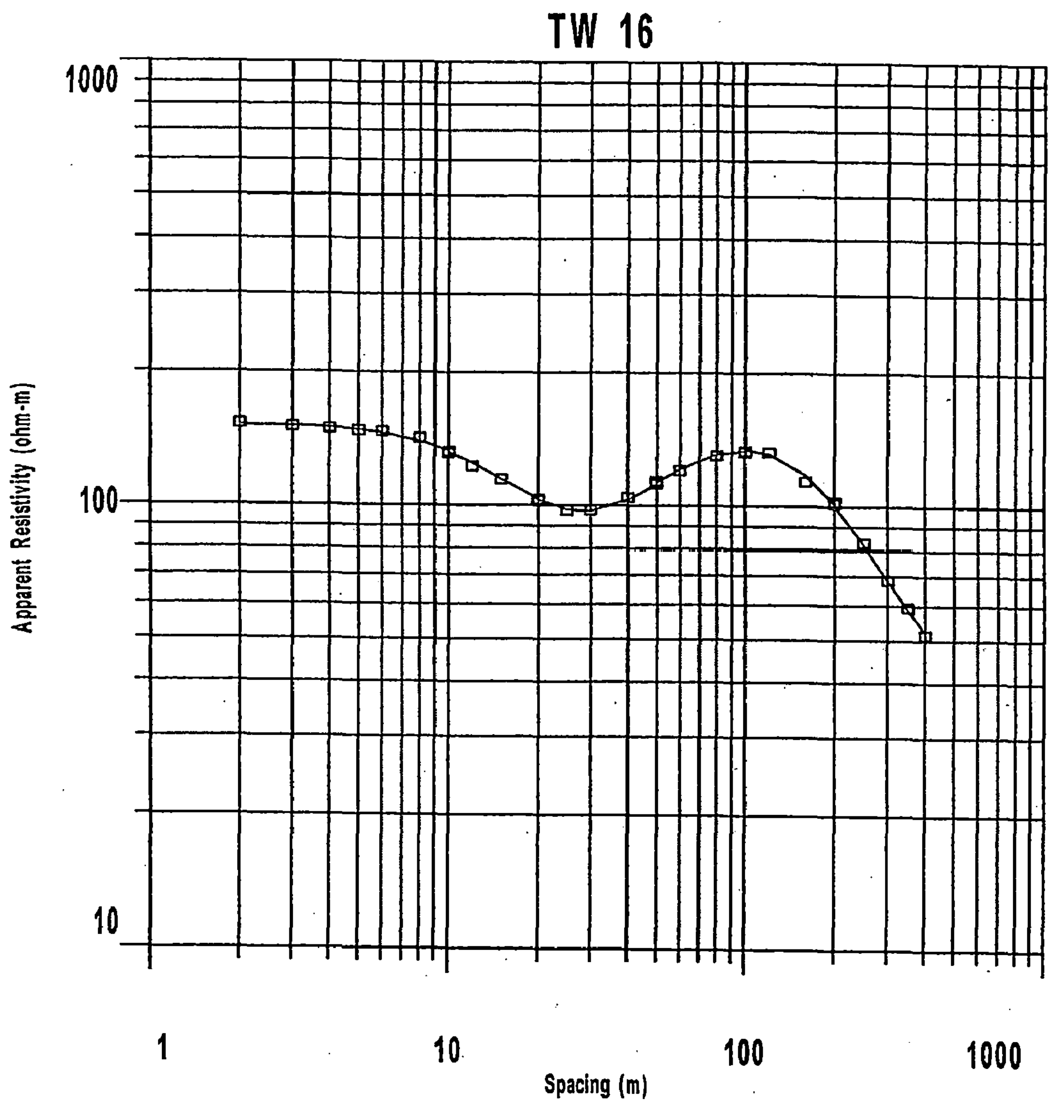


Fig. 7.15: Model output for VES-15



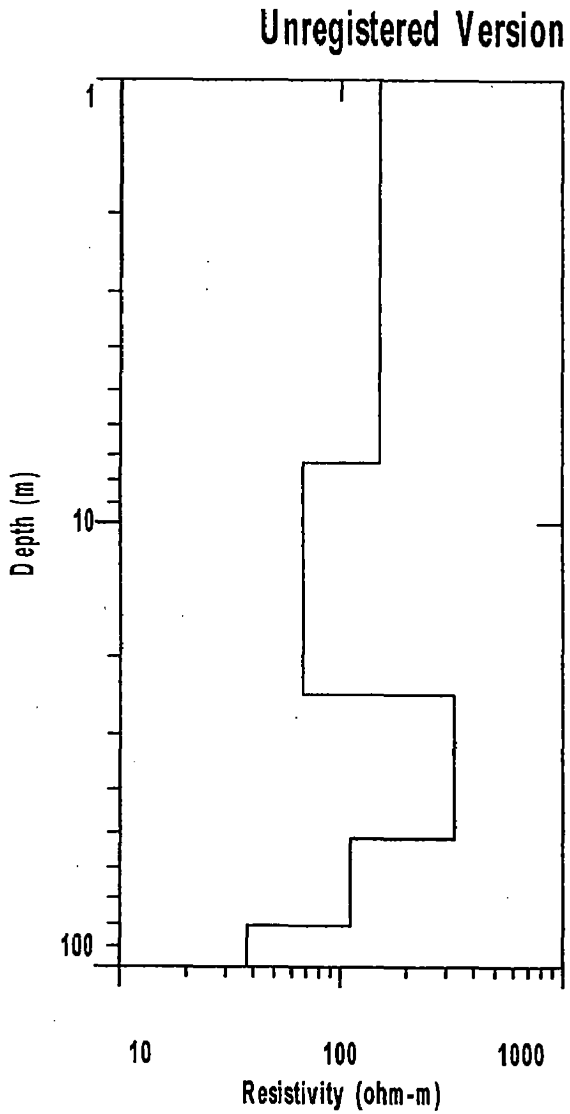


Fig. 7.16: Model output for VES-16

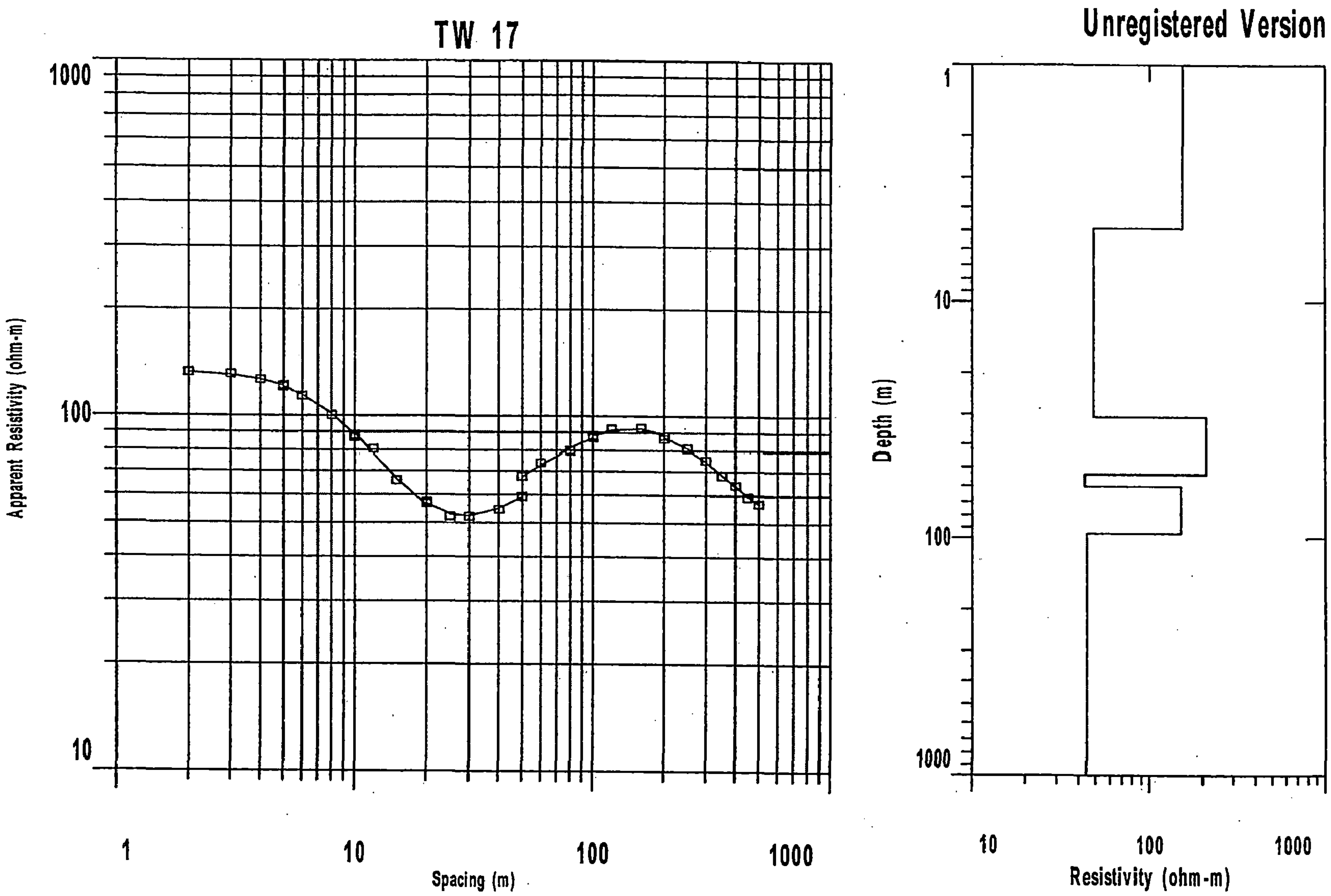


Fig. 7.17: Model output for VES-17

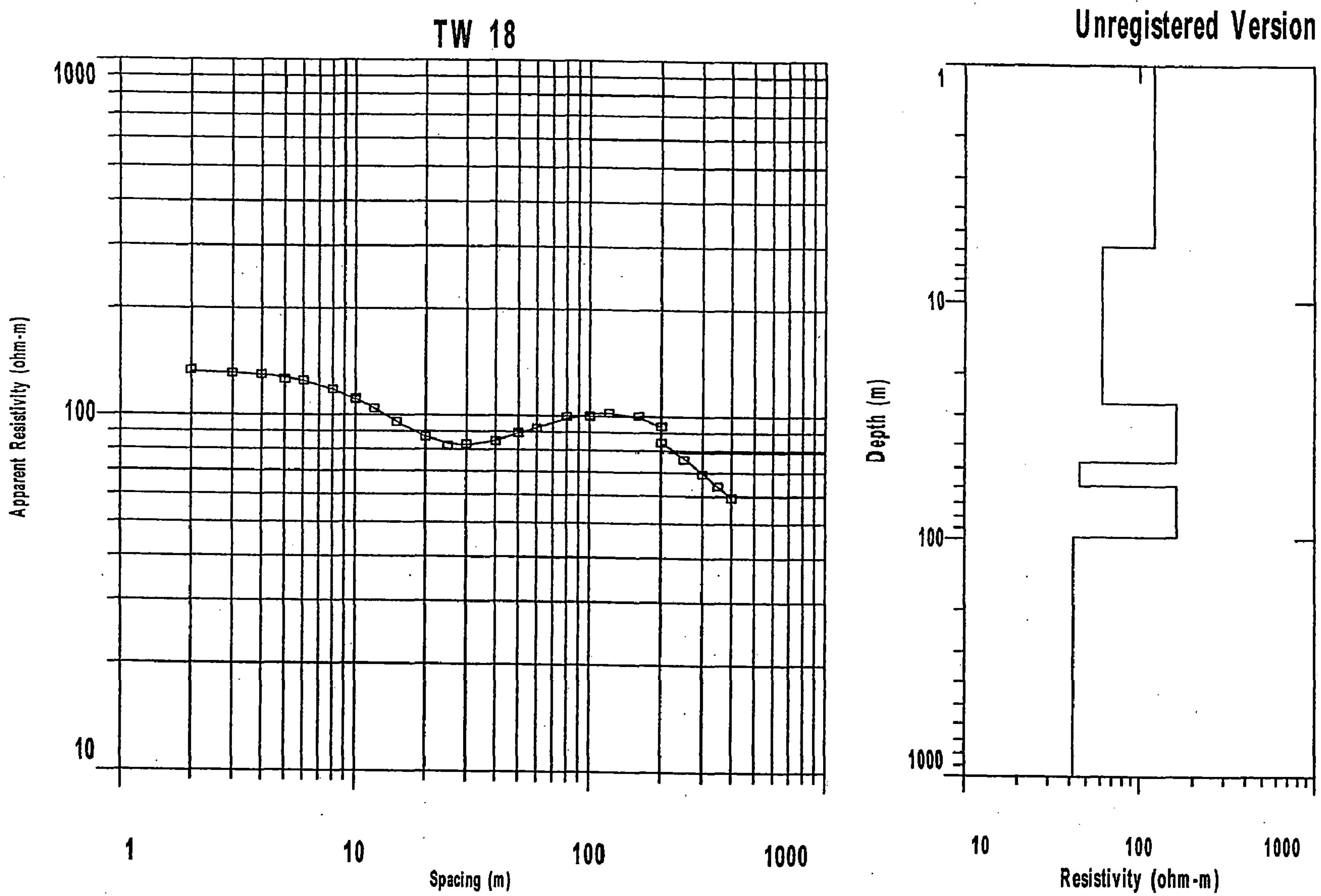


Fig. 7.18: Model output for VES-18

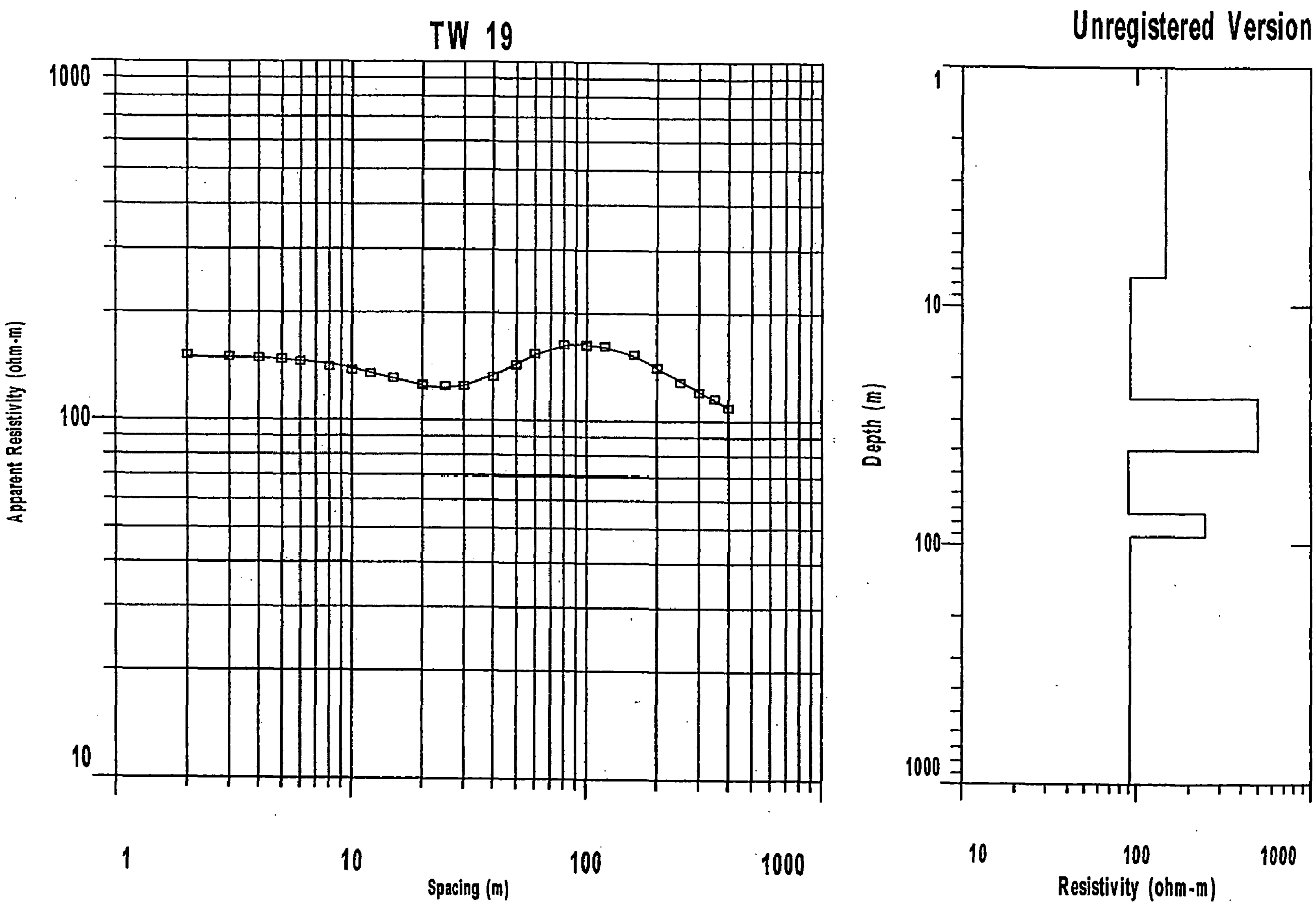


Fig. 7.19: Model output for VES-19

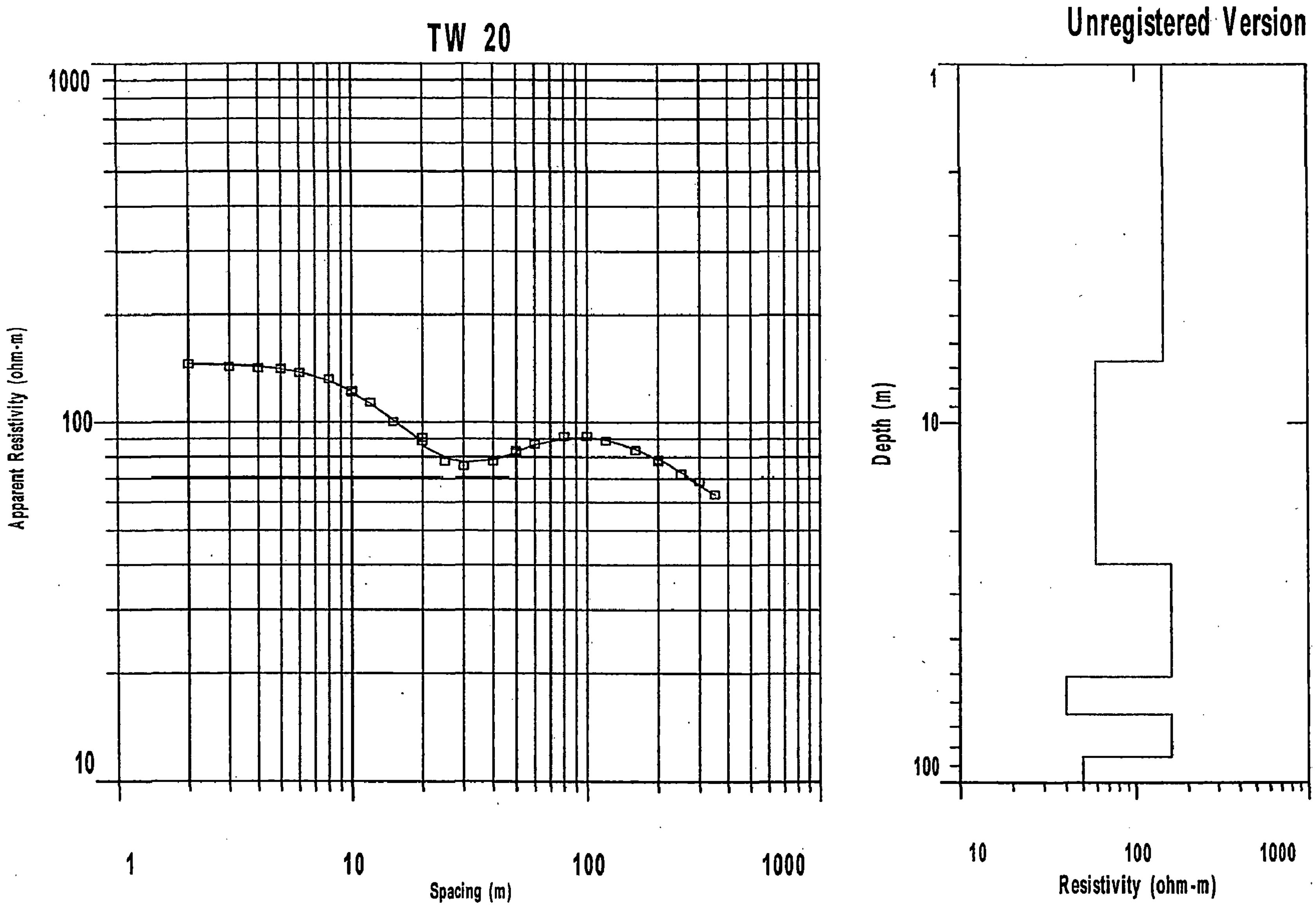


Fig. 7.20: Model output for VES-20

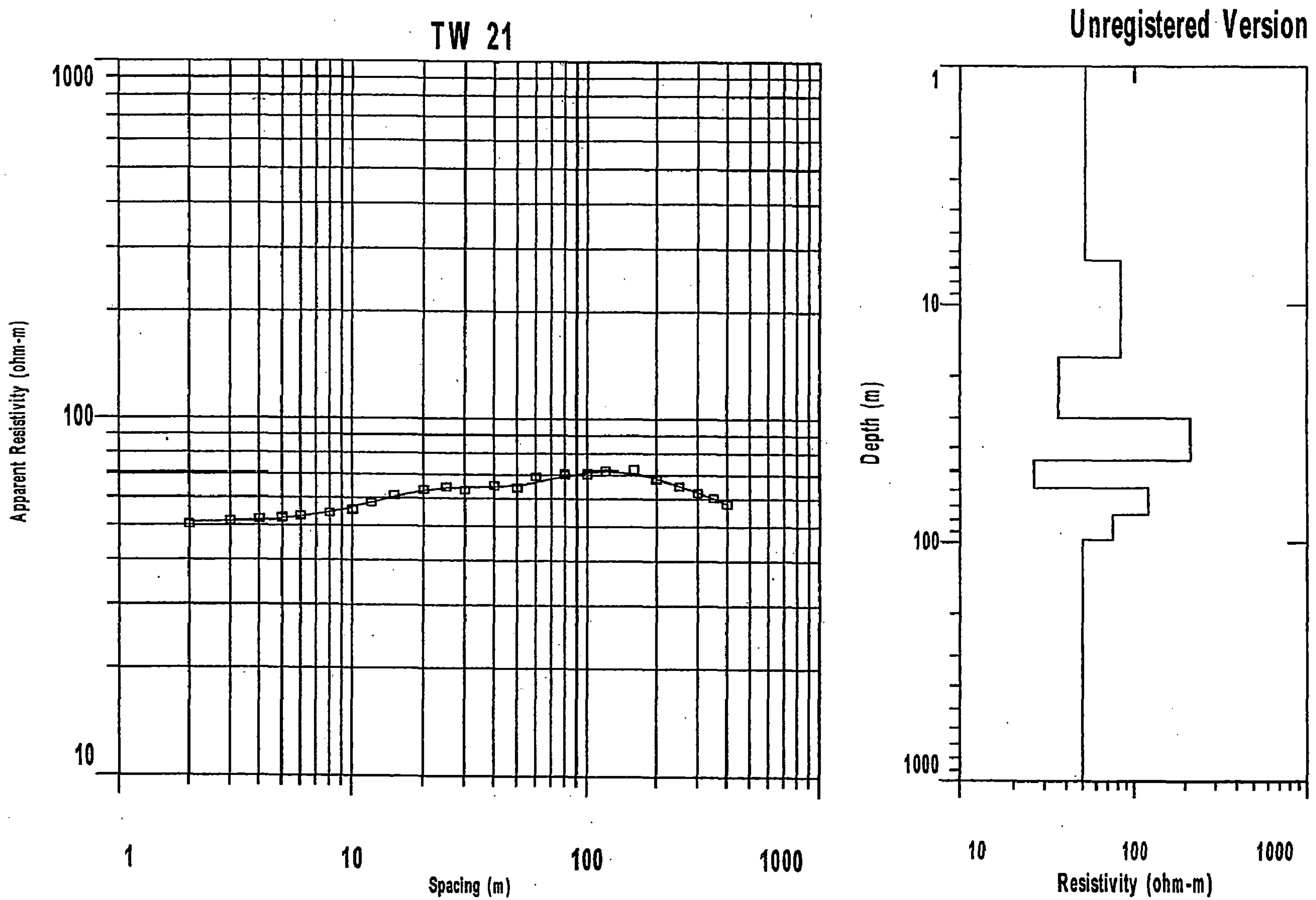


Fig. 7.21: Model output for VES-21

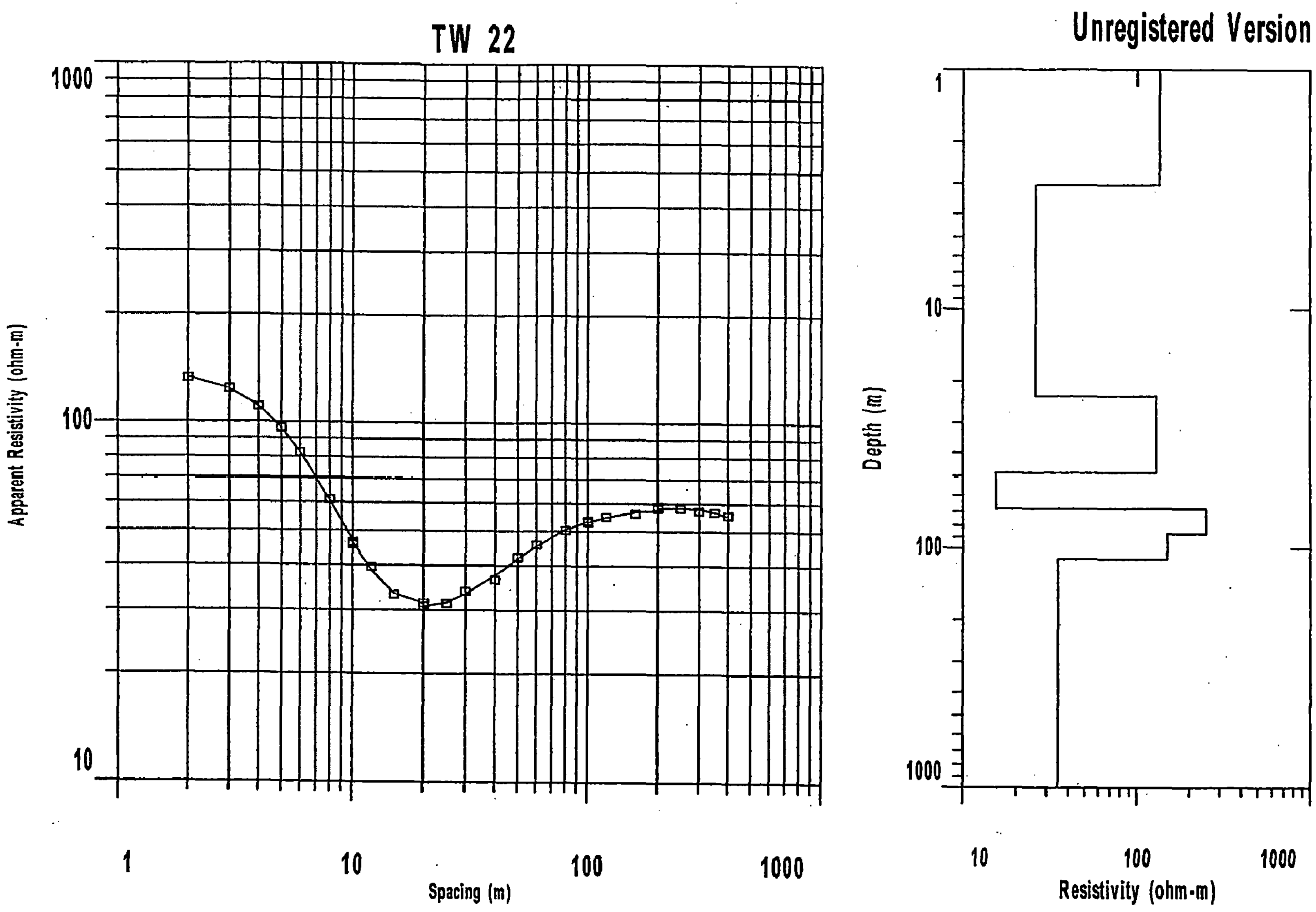


Fig. 7.22: Model output for VES-22

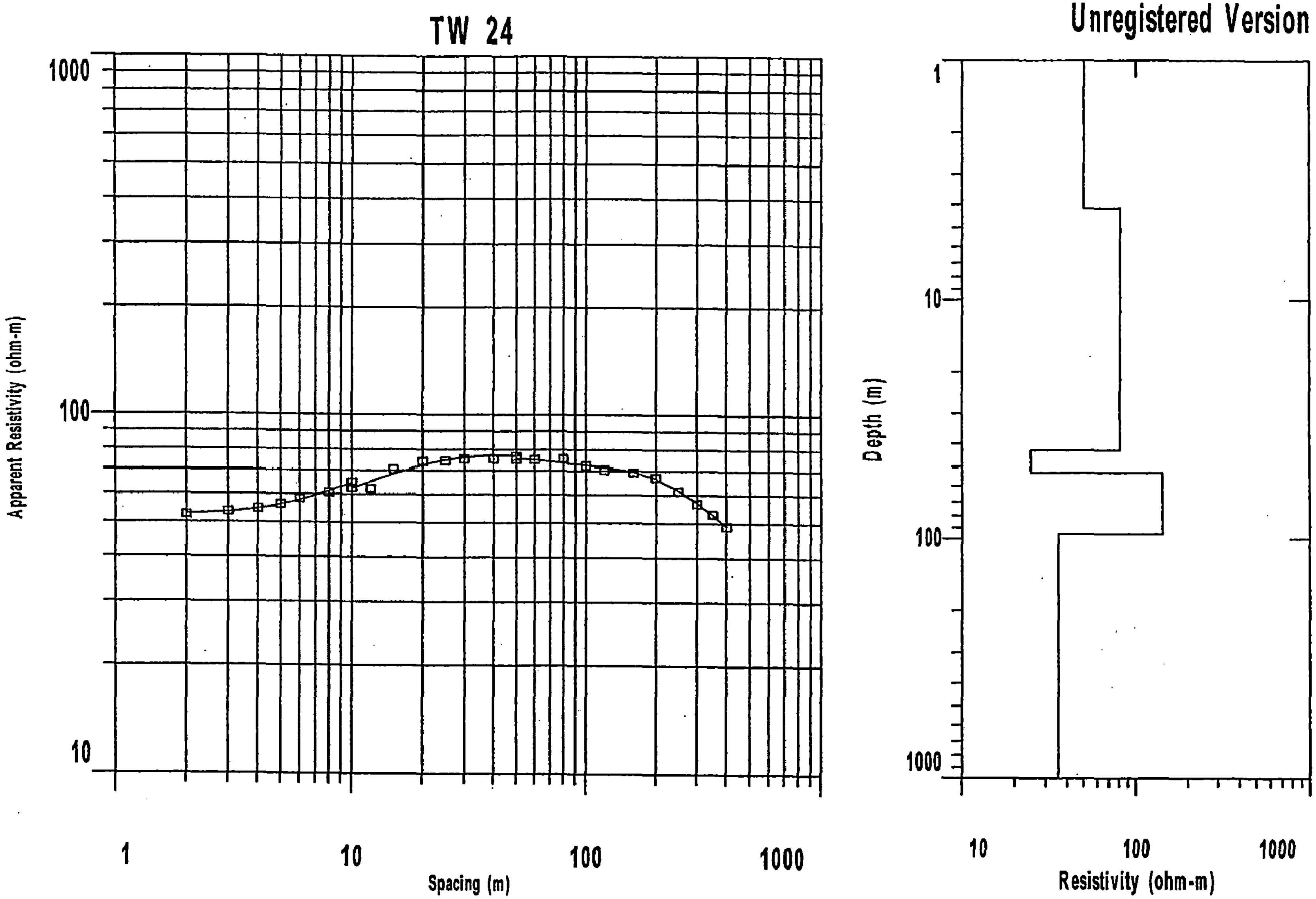


Fig. 7.23: Model output for VES-23

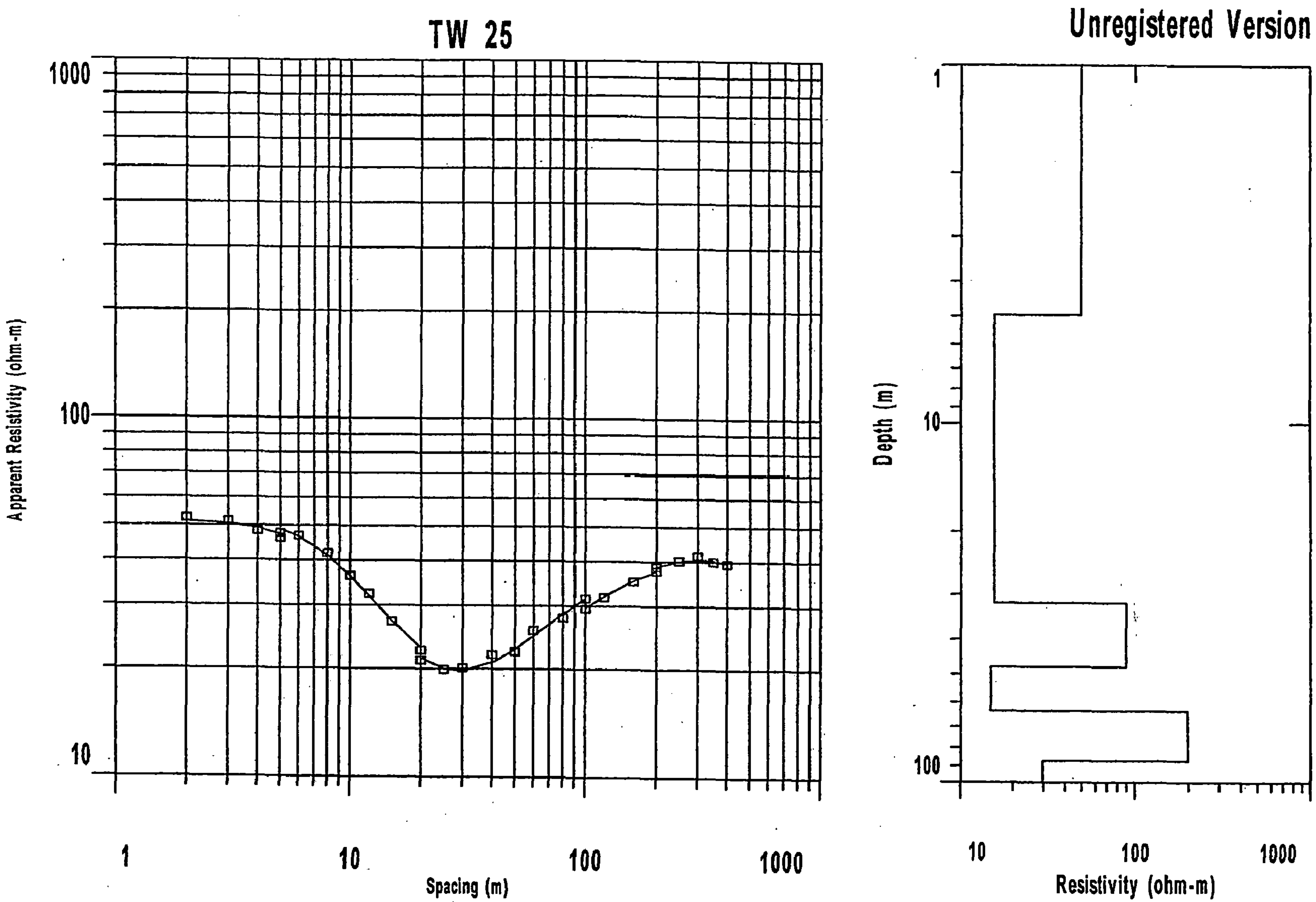


Fig. 7.24: Model output for VES-24

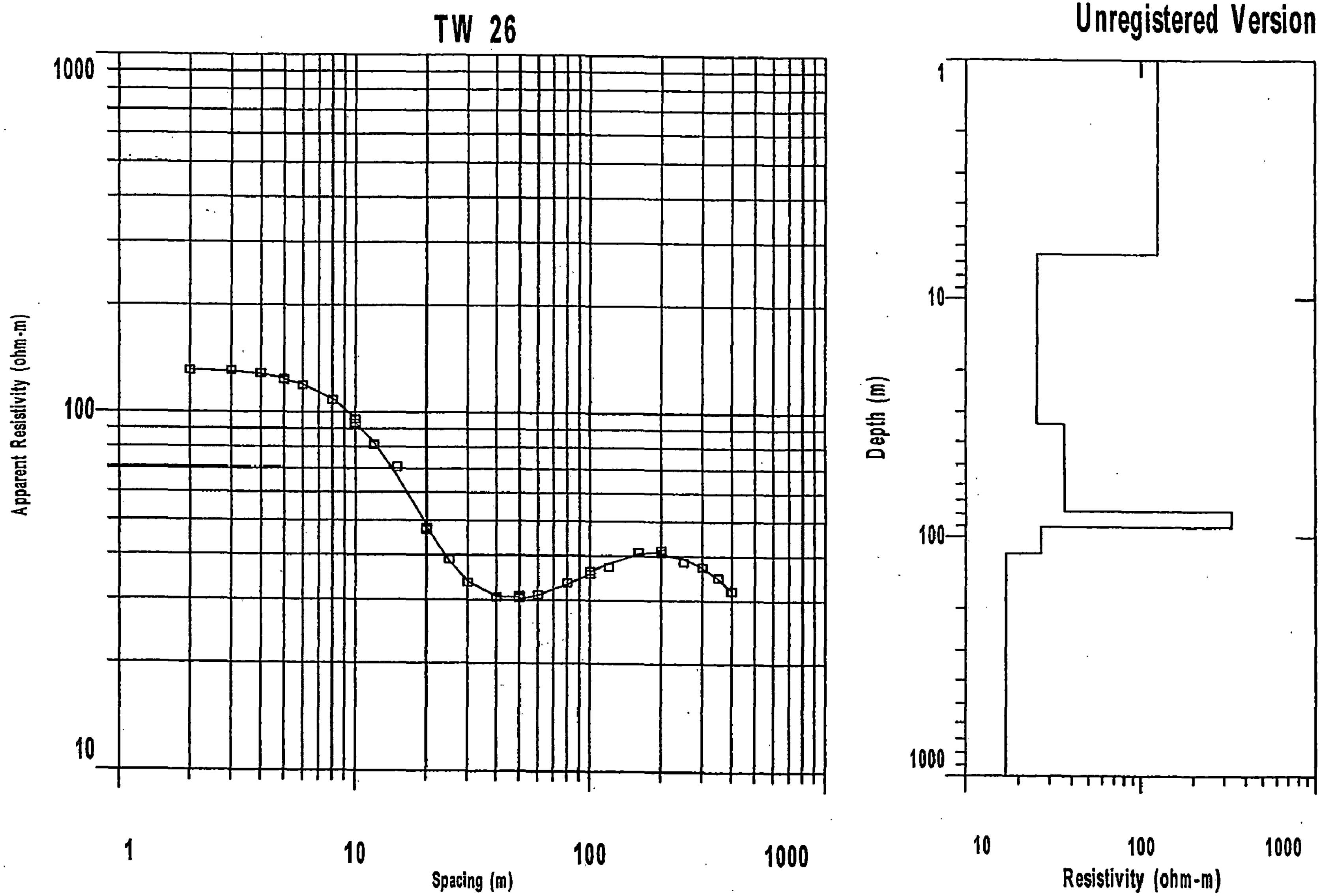


Fig. 7.25: Model output for VES-25

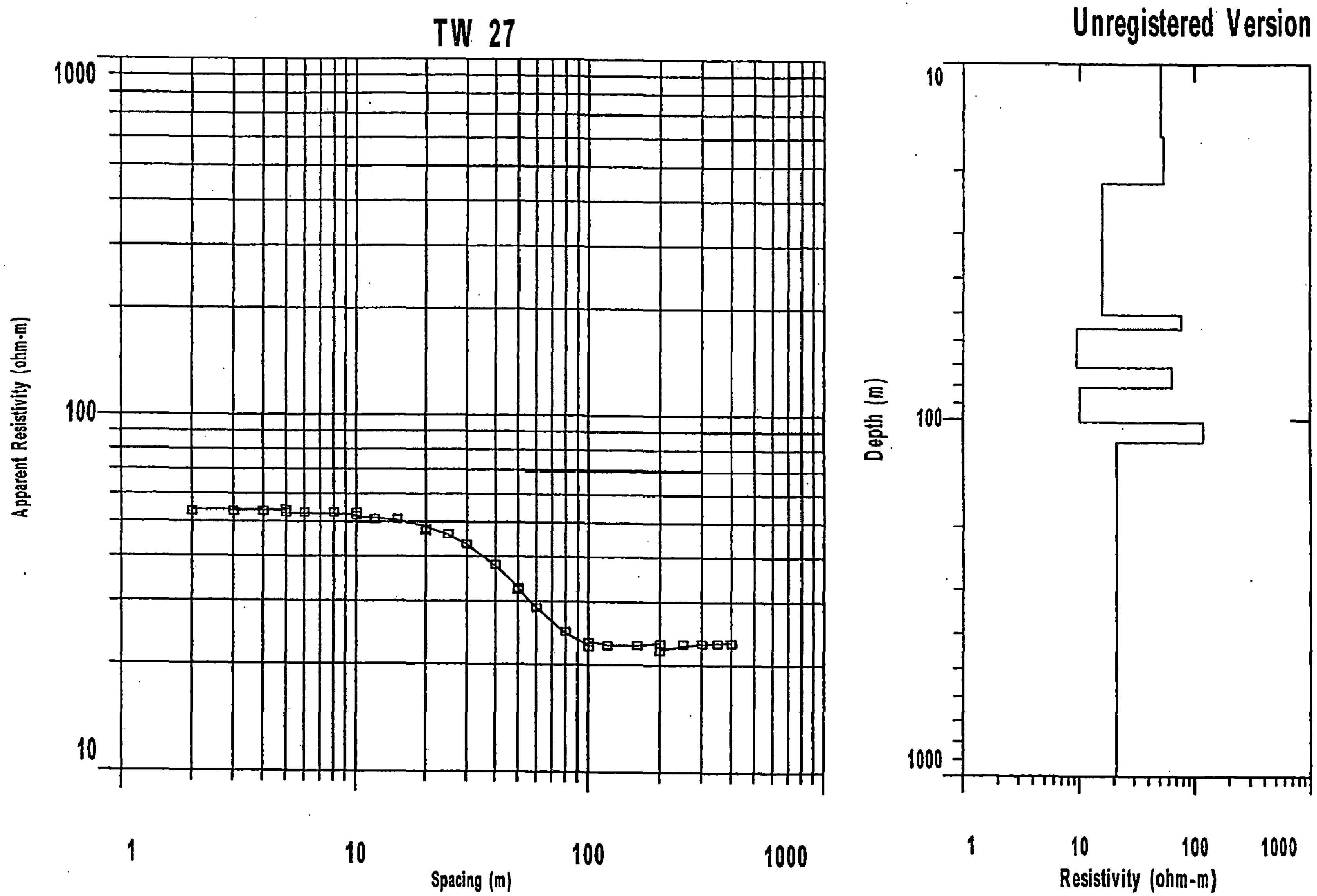


Fig. 7.26: Model output for VES-26

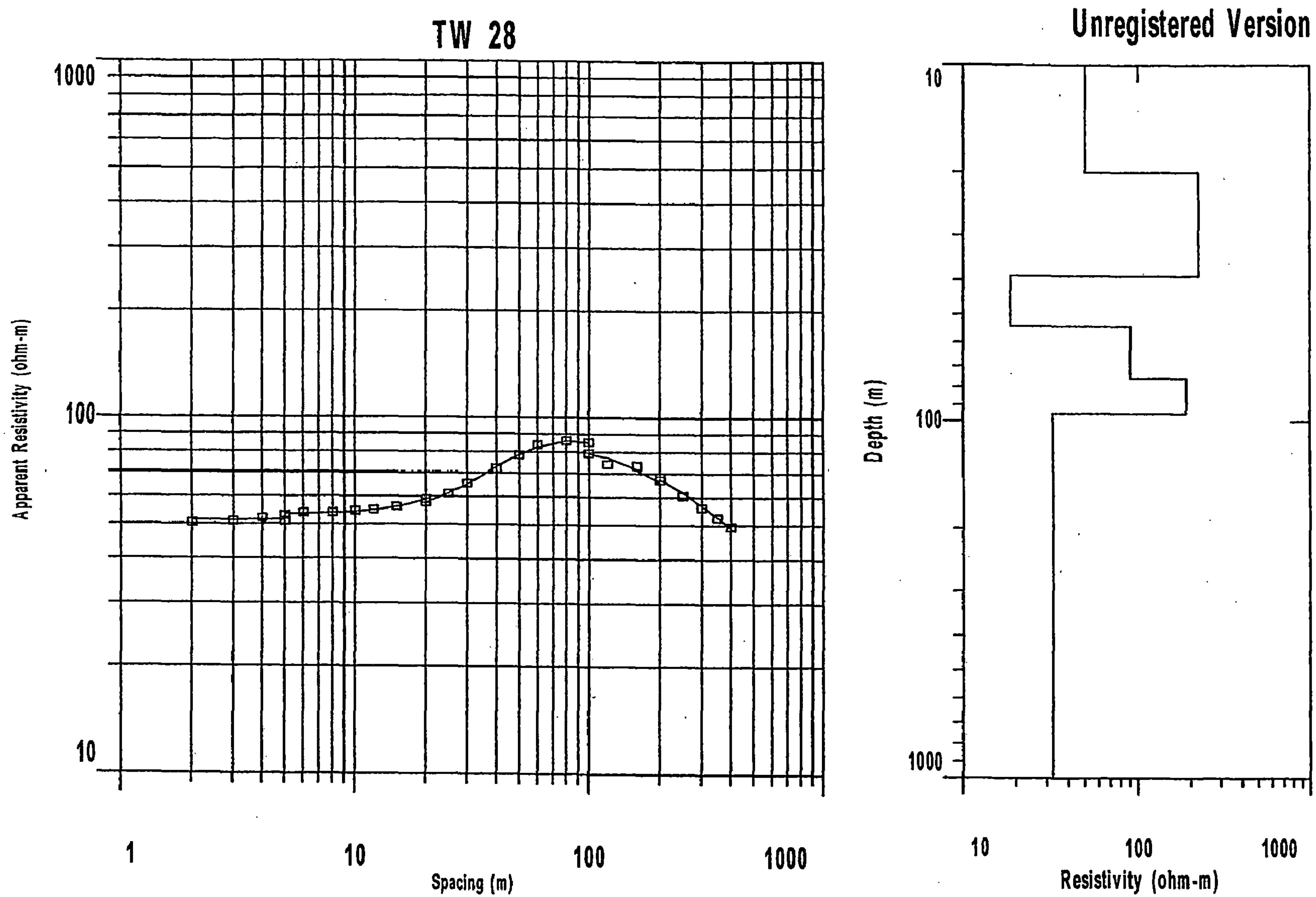


Fig. 7.27: Model output for VES-27

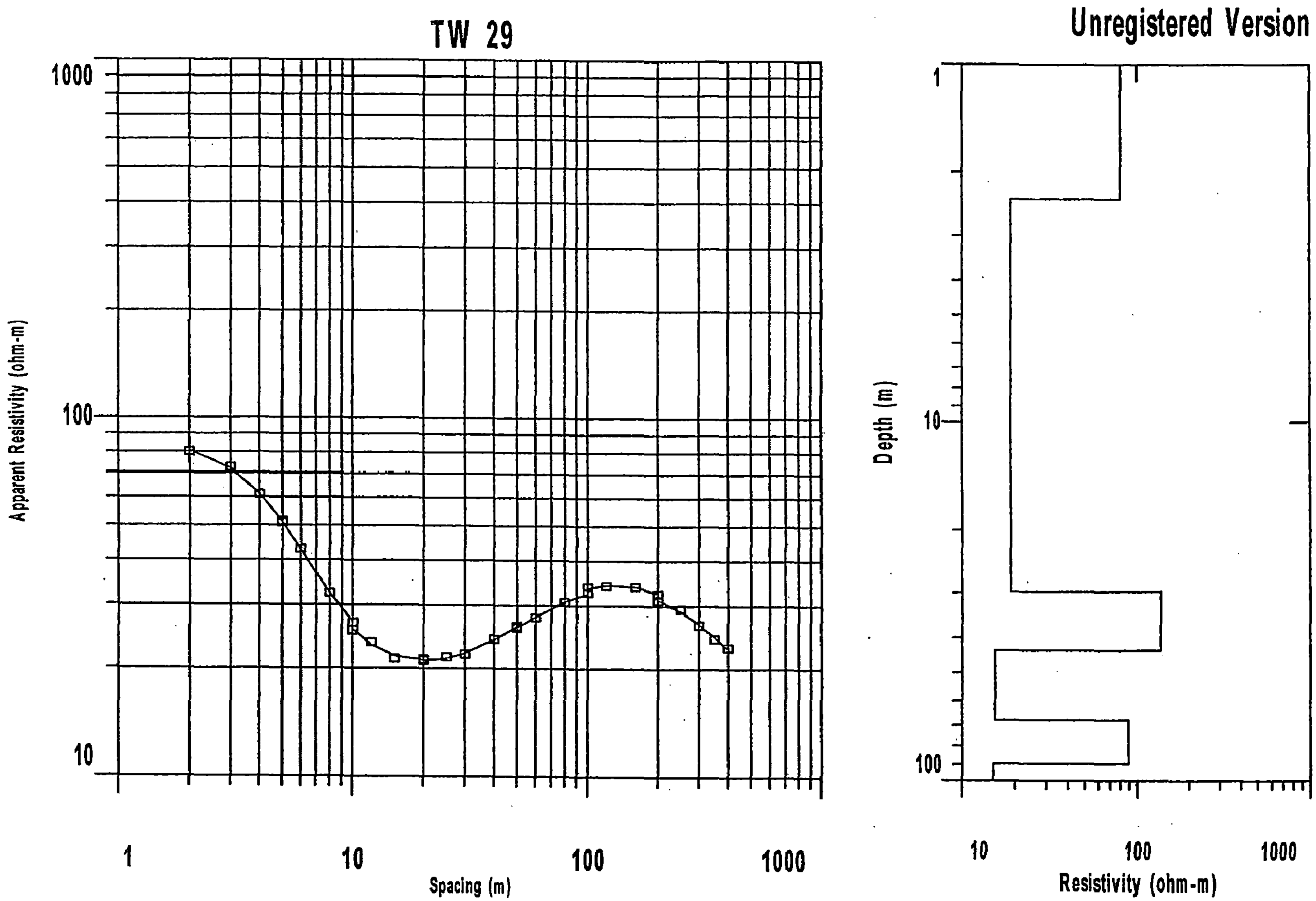


Fig. 7.28: Model output for VES-28

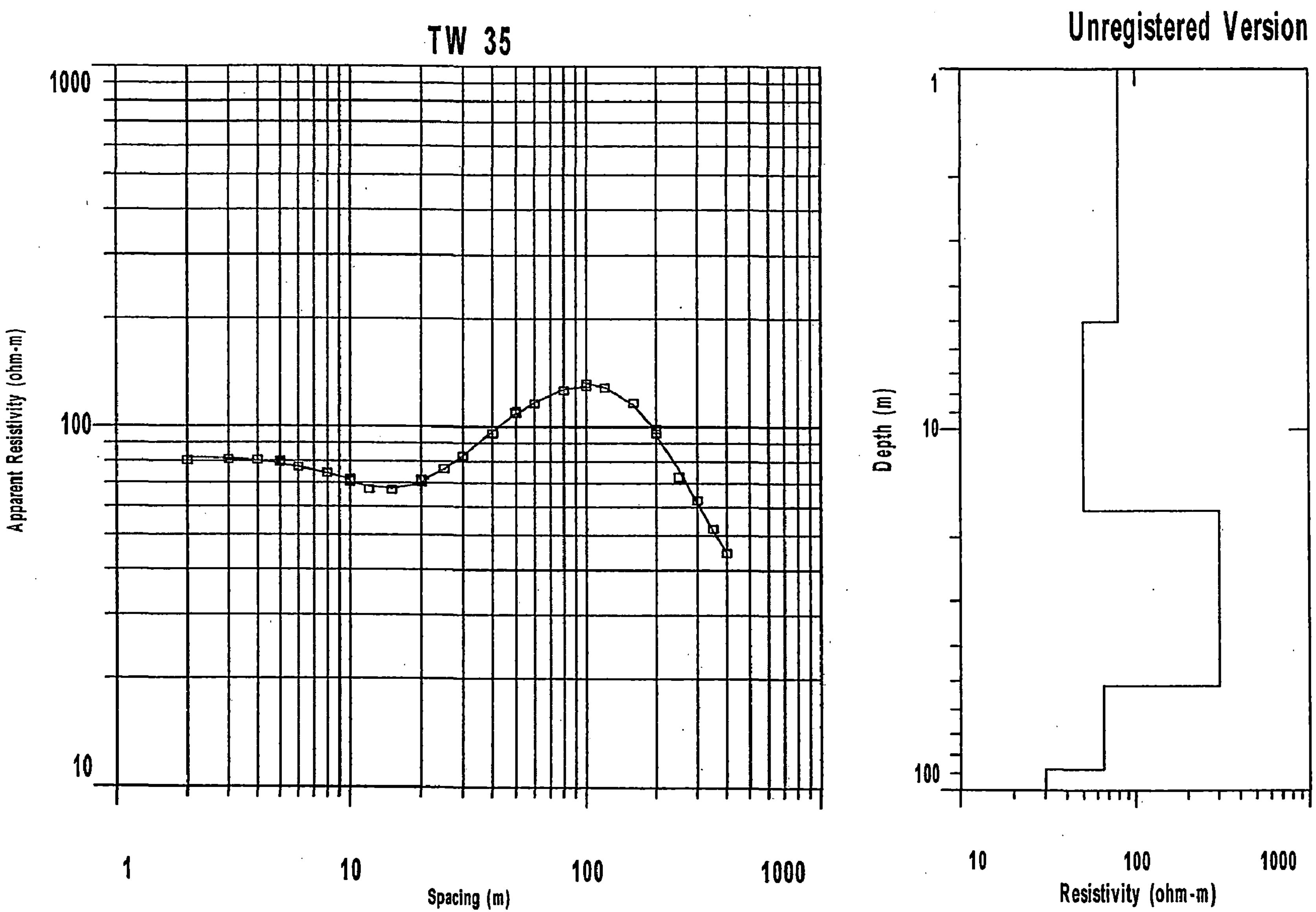


Fig. 7.29: Model output for VES-29

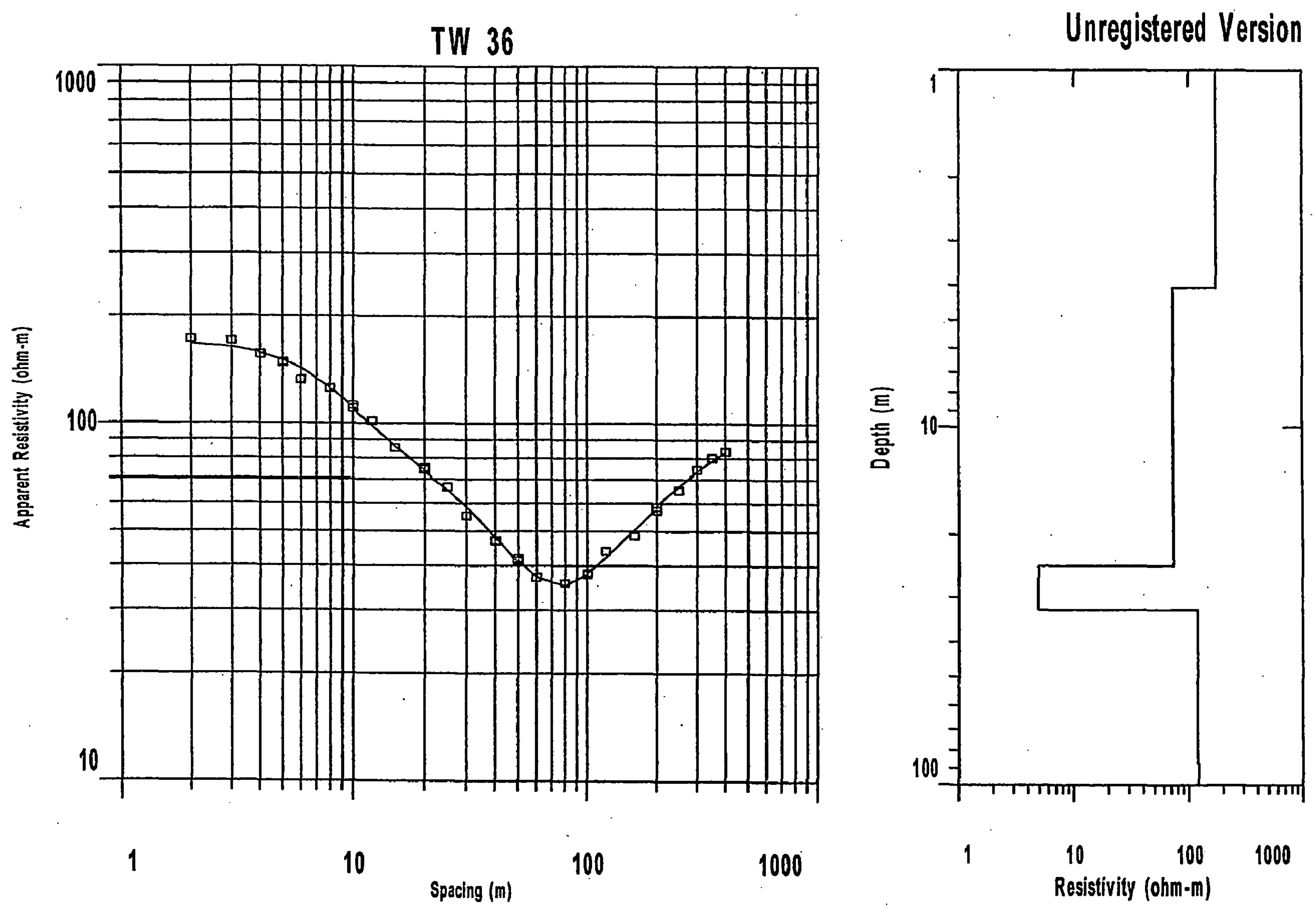


Fig. 7.30: Model output for VES-30

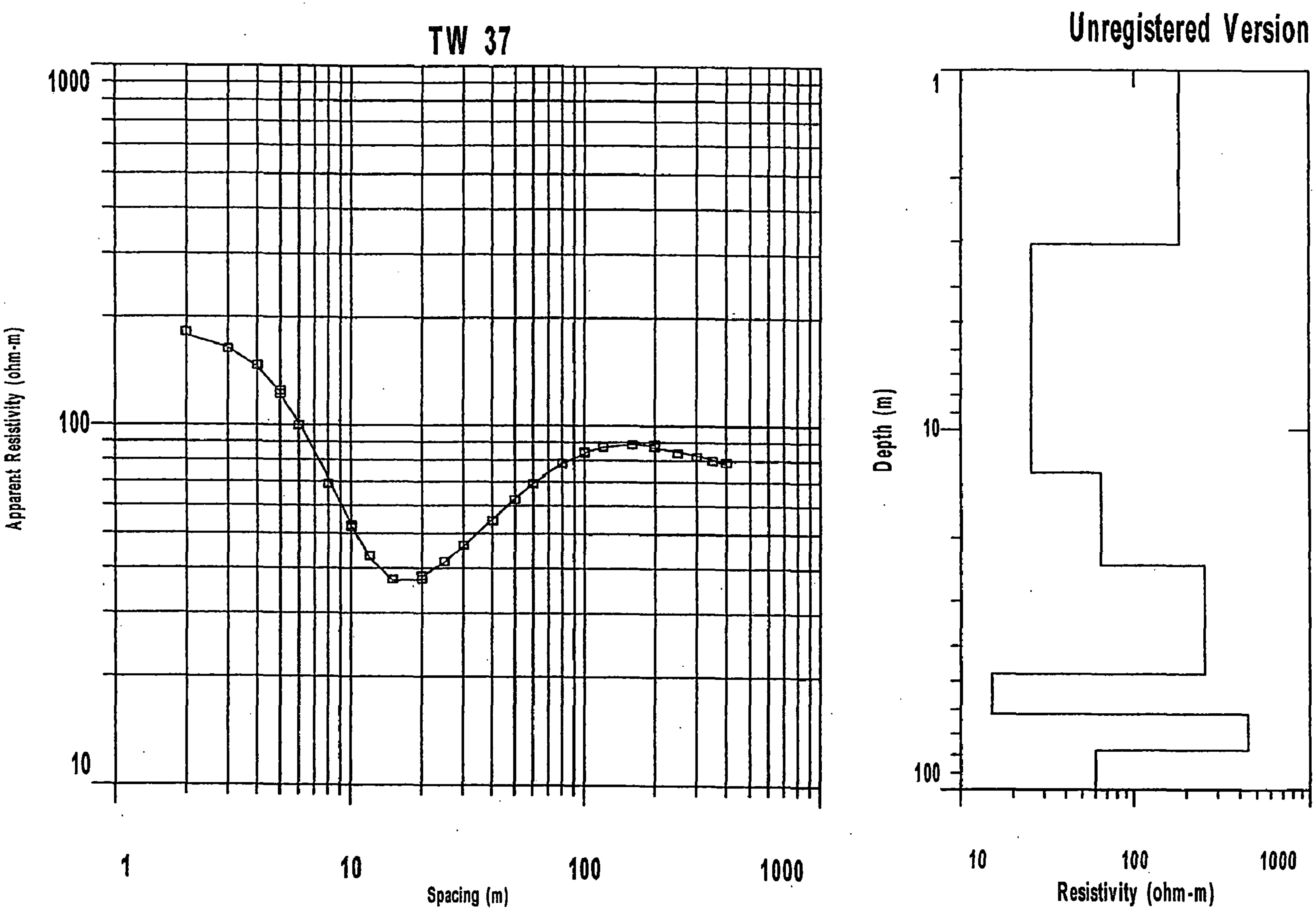


Fig. 7.31: Model output for VES-31

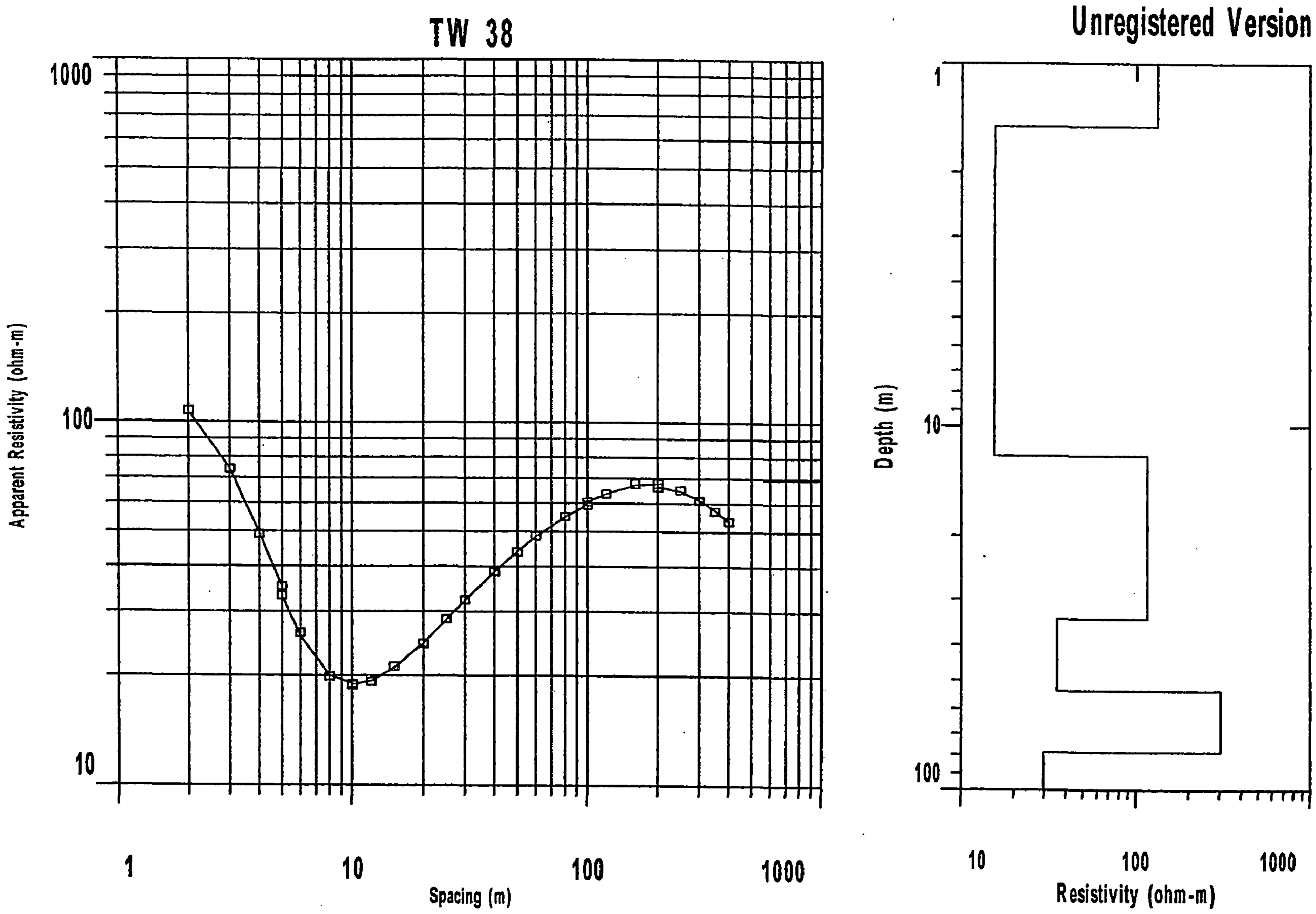


Fig. 7.32: Model output for VES-32

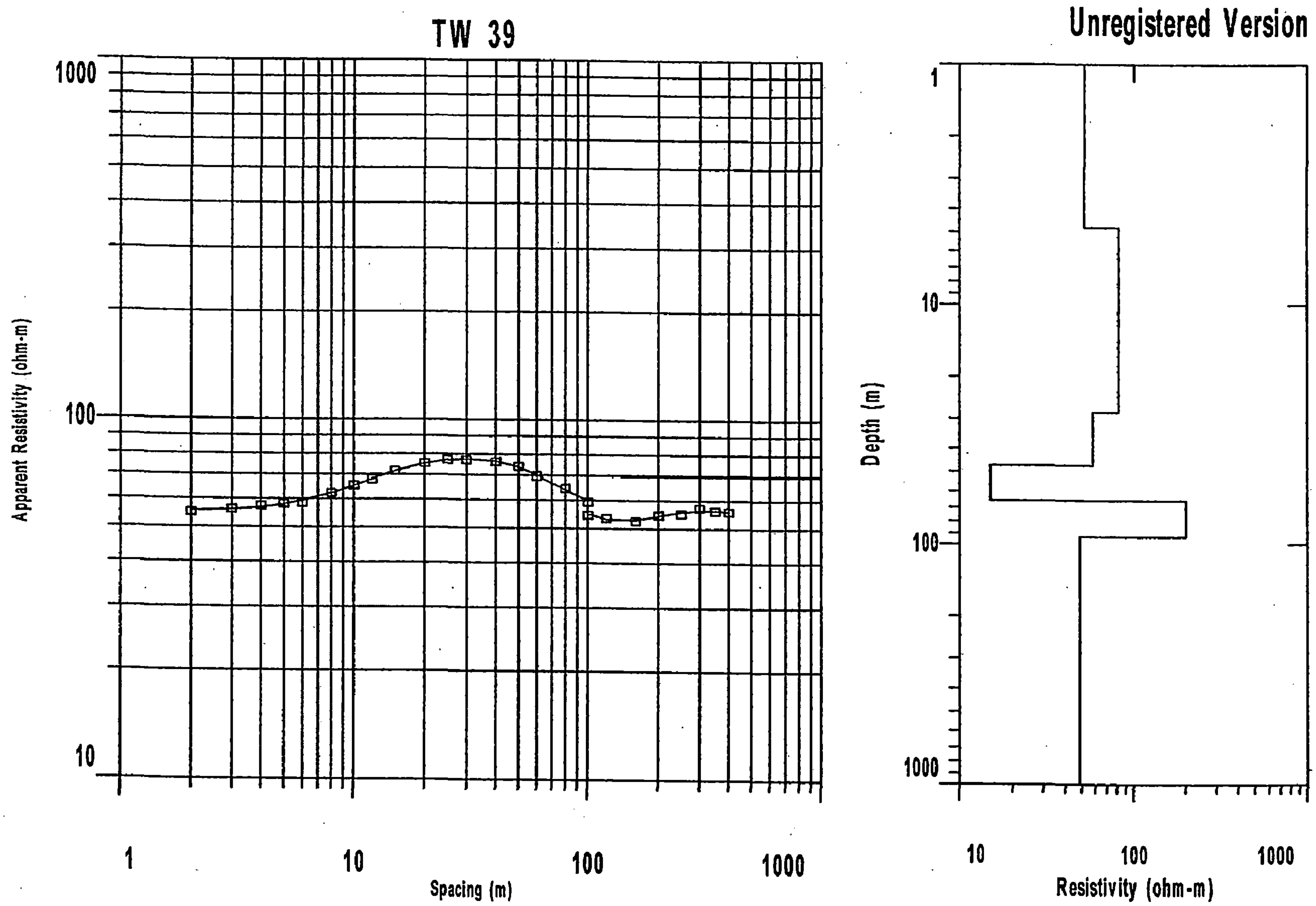


Fig. 7.33: Model output for VES-33

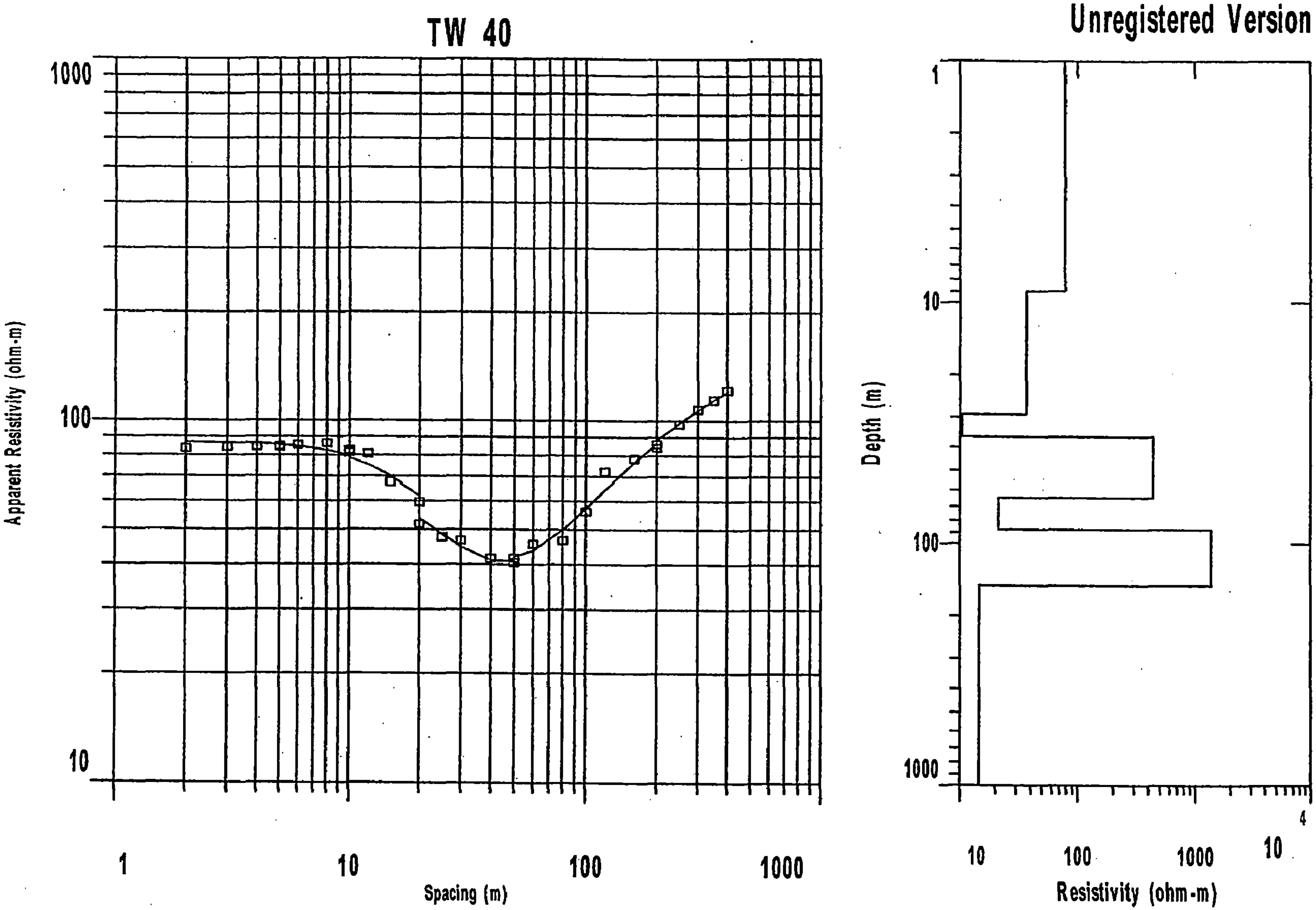


Fig. 7.34: Model output for VES-34

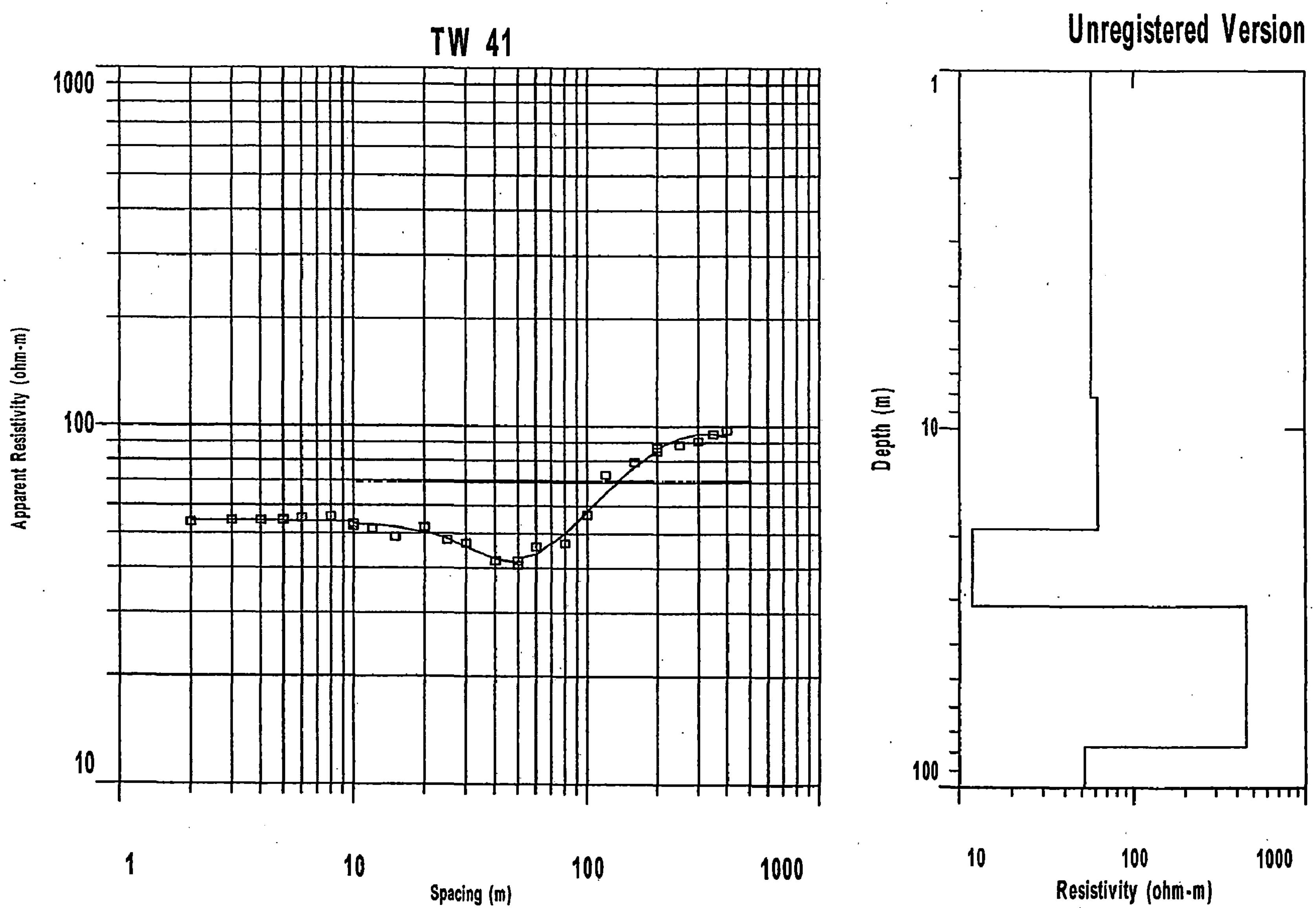


Fig. 7.35: Model output for VES-35

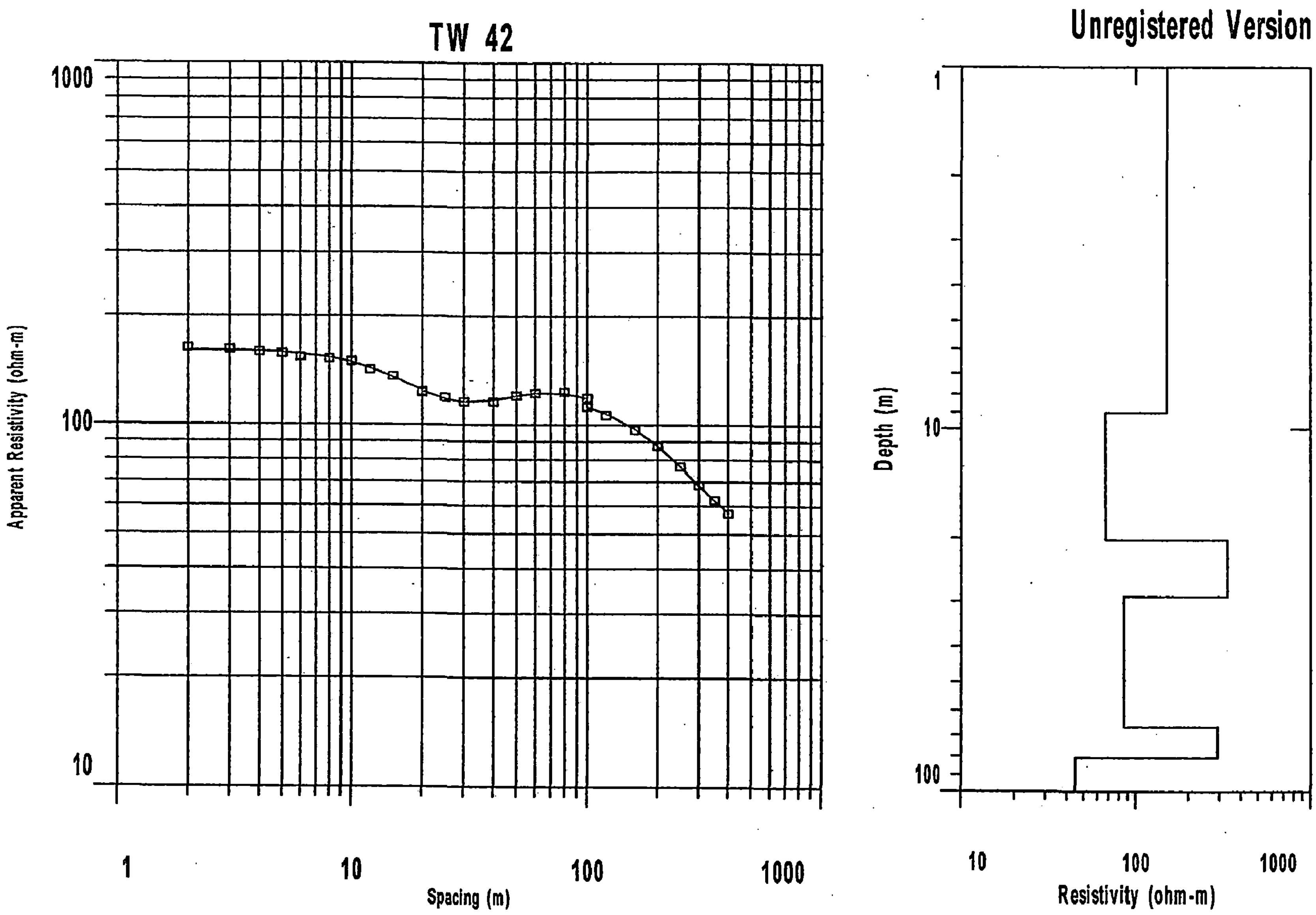


Fig. 7.36: Model output for VES-36

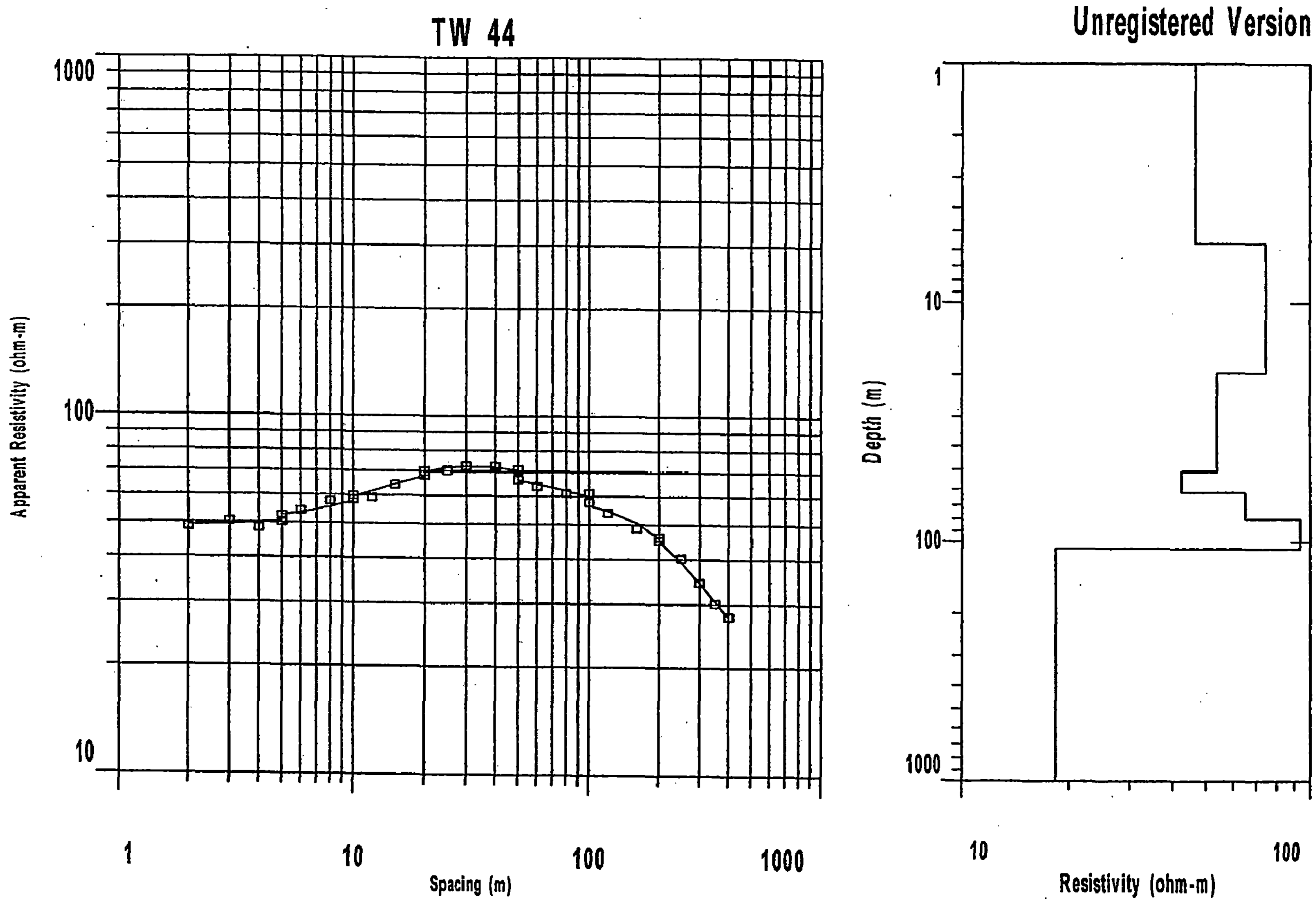


Fig. 7.37: Model output for VES-37

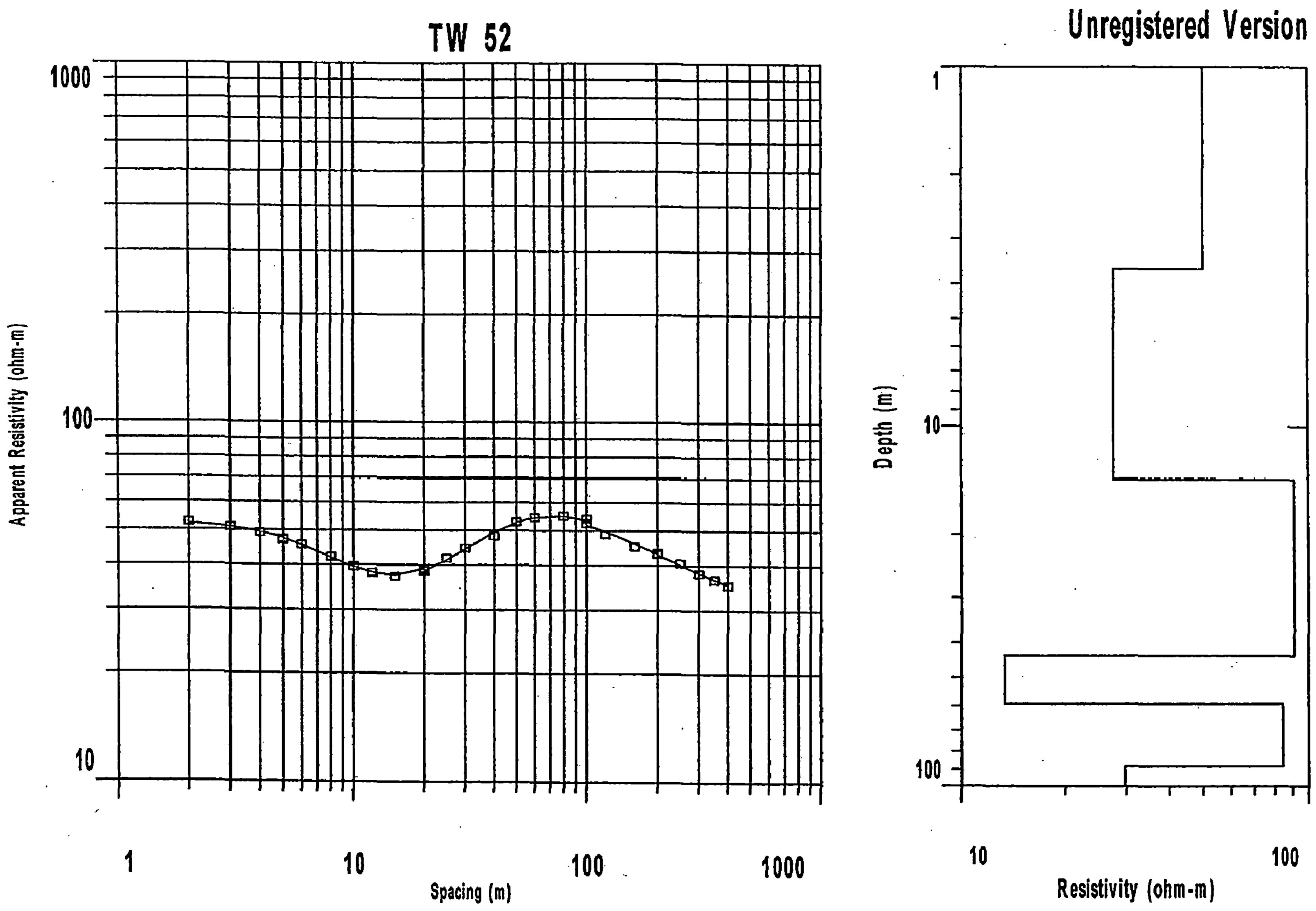


Fig. 7.38: Model output for VES-38

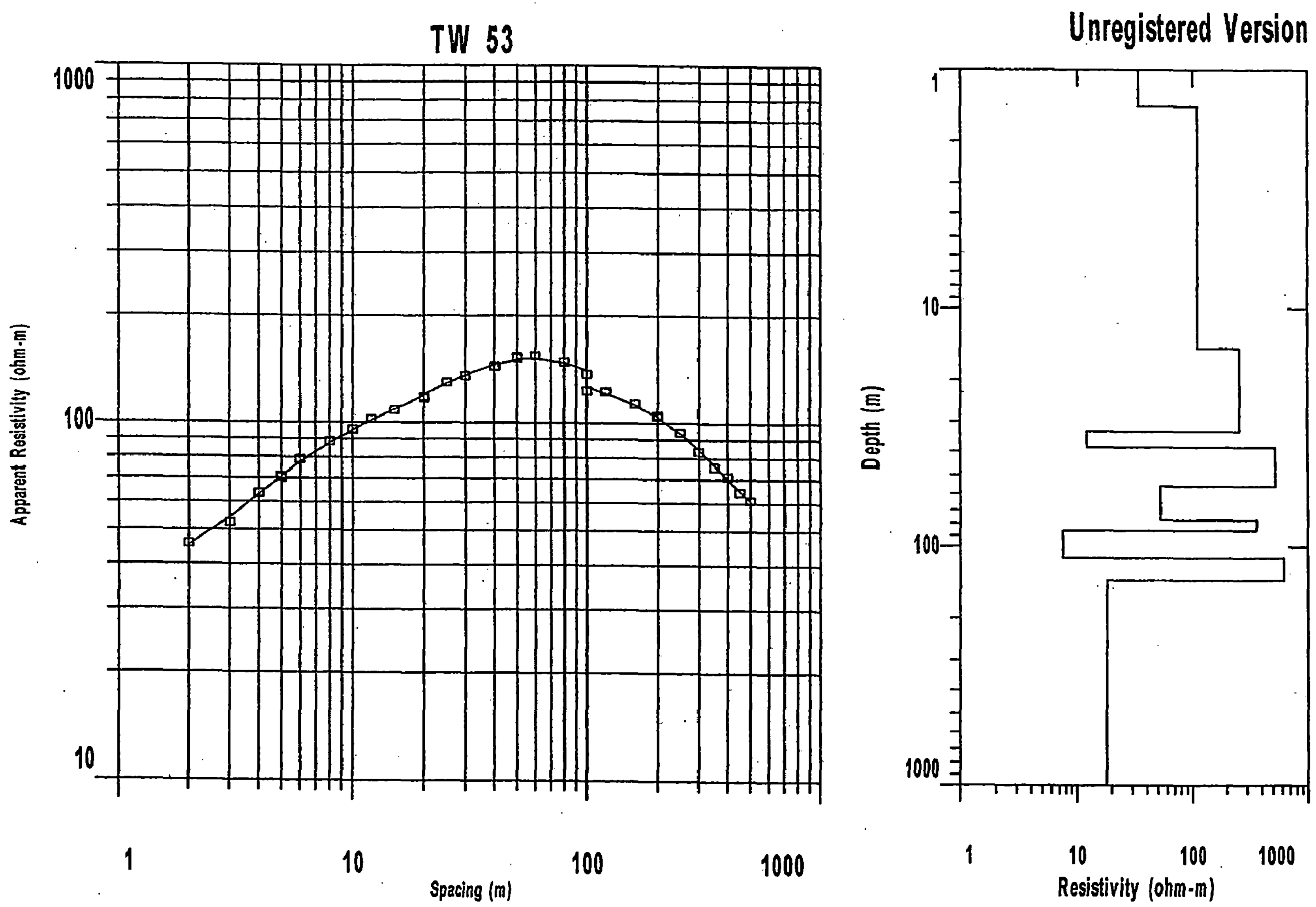


Fig. 7.39: Model output for VES-39

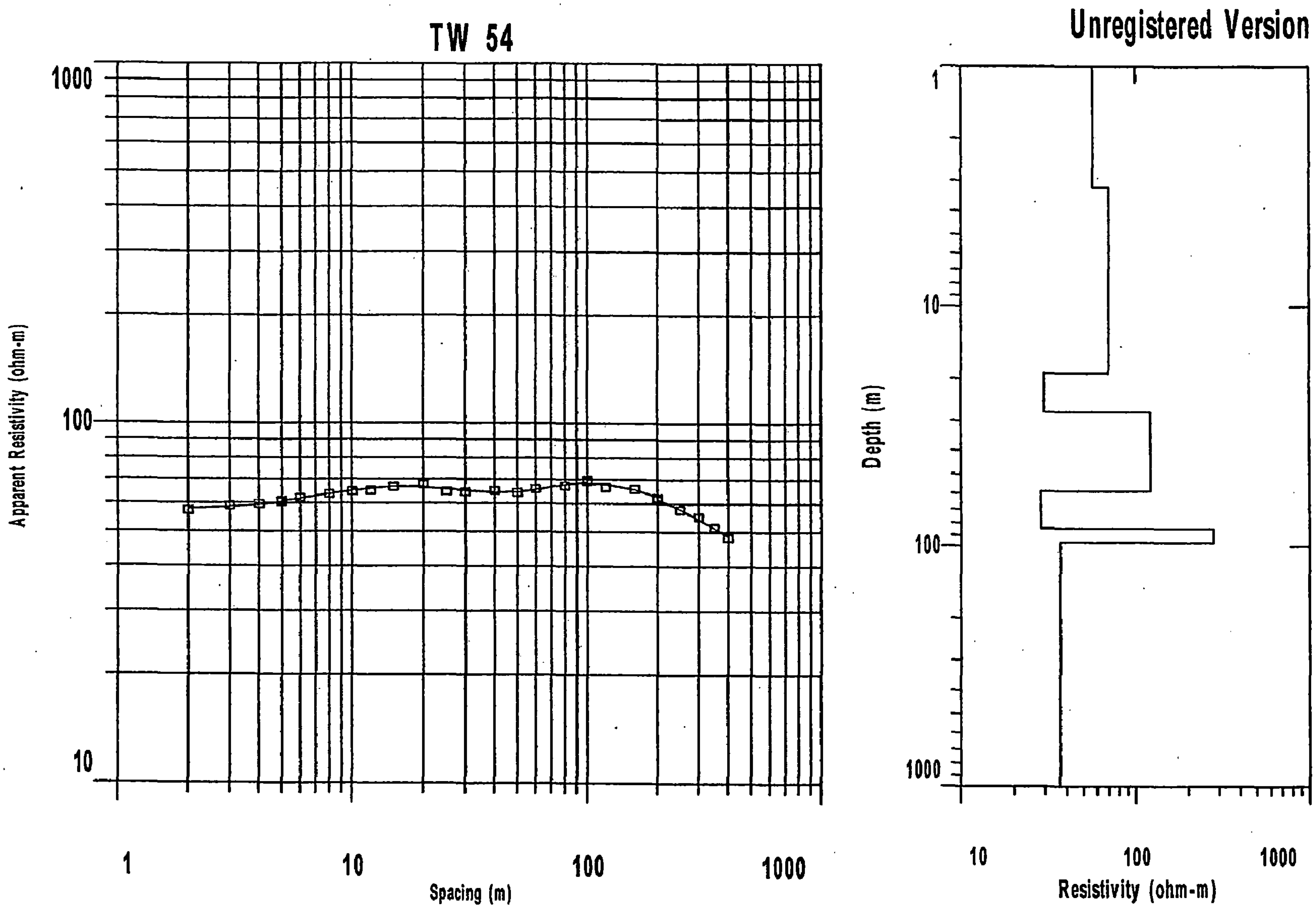


Fig. 7.40: Model output for VES-40

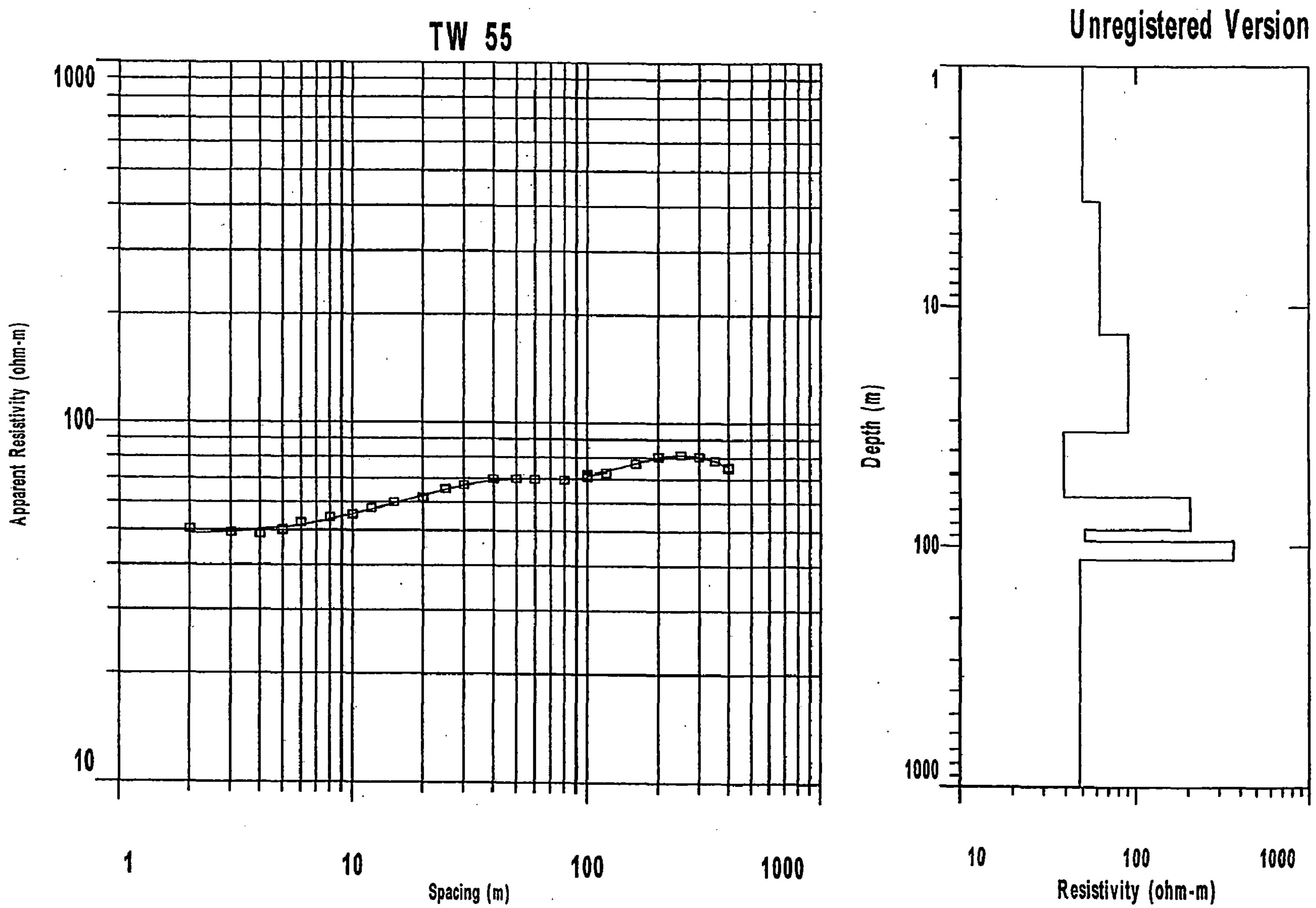


Fig. 7.41: Model output for VES-41

Table 7.42: Layered model from interpretation of sounding curve of VES 1

RMS Error =0.68%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
63.285	9.5397	9.5397
9.5206	8.0089	17.5486
120.45	31.339	48.8876
20.593	15.161	64.0486
122.25	28.825	92.8736
79.429	9.9484	102.822
32.954	Substratum	Infinite

Table 7.43: Layered model from interpretation of sounding curve of VES 2

RMS Error =0.69%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
24.398	6.1907	6.1907
56.171	27.055	33.2457
164.87	17.455	50.7007
28.114	12.367	63.0677
199.03	29.36	92.4277
102.98	14.569	106.9967
33.968	Substratum	Infinite

Table 7.44: Layered model from interpretation of sounding curve of VES 3

RMS Error =1.73%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
33.732	16.646	16.646
117.65	24.008	40.654
43.258	29.485	70.139
180.98	51.381	121.52
26.939	11.843	133.363
42.019	Substratum	Infinite

Table 7.45: Layered model from interpretation of sounding curve of VES 4

RMS Error =1.31%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
30.505	8.7767	8.7767
75.091	10.32	19.0967
22.449	11.984	31.0807
142.33	23.071	54.1517
261.72	11.282	65.4337
34.116	Substratum	Infinite

Table 7.46: Layered model from interpretation of sounding curve of VES 5

RMS Error =1.53%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
124.11	2.9683	2.9683
84.08	19.506	22.4743
14.83	7.5941	30.0684
149.8	23.622	53.6904
95.155	Substratum	Infinite

Table 7.47: Layered model from interpretation of sounding curve of VES 6

RMS Error =1.10%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
109.13	5.5307	5.5307
6.6579	5.6386	11.1693
38.692	9.2457	20.415
1133.9	15.732	36.147
181.46	17.986	54.133
51.628	Substratum	Infinite

Table 7.48: Layered model from interpretation of sounding curve of VES 7

RMS Error =1.84%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
23.278	6.6552	6.6552
44.367	24.423	31.0782
178.82	15.865	46.9432
22.862	4.0236	50.9668
324.97	15.476	66.4428
521.2	8.7222	75.165
23.25	Substratum	Infinite

Table 7.49: Layered model from interpretation of sounding curve of VES 8

RMS Error =3.33%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
44.017	10.473	10.473
65.451	3.3116	13.7846
489.66	10.082	23.8666
9.1593	7.732	31.5986
96.985	10.756	42.3546
3638.3	3.6369	45.9915
266.6	17.984	63.9755
1997.4	2.855	66.8305
50.494	Substratum	Infinite

Table 7.50: Layered model from interpretation of sounding curve of VES 9

RMS Error =0.76%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
114.07	3.3683	3.3683
166.71	9.4339	12.8022
30.723	11.641	24.4432
290.8	24.41	48.8532
15.639	15.979	64.8322
94.138	17.207	82.0392
157.04	12.025	94.0642
47.027	Substratum	Infinite

Table 7.51: Layered model from interpretation of sounding curve of VES 10

RMS Error =0.76%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
141.07	7.5127	7.5127
35.591	26.229	33.7417
5325.7	4.5473	38.289
93.325	33.647	71.936
295.45	11.783	83.719
147.14	20.977	104.696
52.67	Substratum	Infinite

Table 7.52: Layered model from interpretation of sounding curve of VES 11

RMS Error =2.84%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
145.18	4.1212	4.1212
59.697	21.183	25.3042
4.8818	8.6676	33.9718
74.143	11.518	45.4898
18.19	3.1724	48.6622
329.11	13.094	61.7562
147	Substratum	Infinite

Table 7.53: Layered model from interpretation of sounding curve of VES 12

RMS Error =0.59%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
141.01	1.9109	1.9109
117.27	52.054	53.9649
42.329	25.92	79.8849
298.77	24.555	104.4399
151.43	17.344	121.7839
45	Substratum	Infinite

Table 7.54: Layered model from interpretation of sounding curve of VES 13

RMS Error =0.63%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
50.057	5.5953	5.5953
67.622	12.05	17.6453
15.322	12.503	30.1483
333.43	18.665	48.8133
48.927	17.6	66.4133
343.41	11.983	78.3963
49.52	Substratum	Infinite

Table 7.55: Layered model from interpretation of sounding curve of VES 14

RMS Error =1.03%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
154.93	3.3401	3.3401
37.187	15.297	18.6371
968.15	24.766	43.4031
153.93	6.2357	49.6388
383.34	13.214	62.8528
168.27	20.331	83.1838
58.275	Substratum	Infinite

Table 7.56: Layered model from interpretation of sounding curve of VES 15

RMS Error =1.69%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
162.22	2.3073	2.3073
210.08	6.0986	8.4059
169.92	86.316	94.7219
592.24	Substratum	Infinite

Table 7.57: Layered model from interpretation of sounding curve of VES 16

RMS Error =1.00%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
150.58	7.2991	7.2991
67.159	17.082	24.3811
326.97	27.012	51.3931
110.42	29.208	80.6011
37.408	Substratum	Infinite

Table 7.58: Layered model from interpretation of sounding curve of VES 17

RMS Error =1.02%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
154.15	4.9056	4.9056
48.337	25.821	30.7266
208.37	22.804	53.5306
43.165	6.5235	60.0541
151.03	35.437	95.4911
44.253	Substratum	Infinite

Table 7.59: Layered model from interpretation of sounding curve of VES 18

RMS Error =0.70%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
120.5	5.8087	5.8087
61.063	20.952	26.7607
161.69	20.199	46.9597
45.473	12.247	59.2067
162.71	38.662	97.8687
41.788	Substratum	Infinite

Table 7.60: Layered model from interpretation of sounding curve of VES 19

RMS Error =0.79%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
146.68	7.521	7.521
91.802	16.82	24.341
500.07	15.919	40.26
89.576	32.94	73.2
246.95	18.724	91.924
91.231	Substratum	Infinite

Table 7.61: Layered model from interpretation of sounding curve of VES 20

RMS Error=1.25%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
144.01	6.71	6.71
58.946	18	24.71
160	26.22	50.93
40	13.72	64.65
160	20.12	84.77
50	Substratum	Infinite

Table 7.62: Layered model from interpretation of sounding curve of VES 21

RMS Error =1.26%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
51.381	6.5259	6.5259
82.649	10.128	16.6539
36.073	13.407	30.0609
213.35	15.24	45.3009
26.122	13.464	58.7649
120.73	17.584	76.3489
74.362	21.202	97.5509
49.566	Substratum	Infinite

Table 7.63: Layered model from interpretation of sounding curve of VES 22

RMS Error =0.99%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
134.78	3.0476	3.0476
25.784	20.186	23.2336
129.25	25.423	48.6566
15.314	19.643	68.2996
248.05	18.836	87.1356
148.91	24.523	111.6586
34.855	Substratum	Infinite

Table 7.64: Layered model from interpretation of sounding curve of VES 23

RMS Error =1.43%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
49.802	4.154	4.154
81.093	38.568	42.722
24.821	10.228	52.95
142.57	42.502	95.452
35.32	Substratum	Infinite

Table 7.65: Layered model from interpretation of sounding curve of VES 24

RMS Error =1.73%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
48.754	4.9721	4.9721
15.496	26.741	31.7131
89.2	16.07	47.7831
14.855	15.517	63.3001
197.56	23.831	87.1311
29.515	Substratum	Infinite

Table 7.66: Layered model from interpretation of sounding curve of VES 25

RMS Error =1.49%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
124.31	6.5264	6.5264
25.309	27.218	33.7444
36.414	44.204	77.9484
330.71	13.026	90.9744
26.76	26.828	117.8024
16.911	Substratum	Infinite

Table 7.67: Layered model from interpretation of sounding curve of VES 26

RMS Error =0.86%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
50.155	16.007	16.007
53.335	5.6758	21.6828
15.592	28.948	50.6308
76.291	4.7892	55.42
9.313	15.748	71.168
63.162	9.7691	80.9371
10.026	20.355	101.2921
118.98	14.457	115.7491
20.82	Substratum	Infinite

Table 7.68: Layered model from interpretation of sounding curve of VES 27

RMS Error =1.23%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
49.647	20.067	20.067
222.45	18.975	39.042
18.531	14.976	54.018
90.644	21.715	75.733
189.31	19.452	95.185
32.5	Substratum	Infinite

Table 7.69: Layered model from interpretation of sounding curve of VES 28

RMS Error =0.78%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
80.347	2.3775	2.3775
18.877	27.388	29.7655
136.38	13.557	43.3225
15.351	24.461	67.7835
88.914	21.695	89.4785
14.992	Substratum	Infinite

Table 7.70: Layered model from interpretation of sounding curve of VES 29

RMS Error =1.27%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
79.404	5.0328	5.0328
49.773	11.74	16.7728
302.58	34.635	51.4078
64.966	36.163	87.5708
30.068	Substratum	Infinite

Table 7.71: Layered model from interpretation of sounding curve of VES 30

RMS Error =2.62%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
172.87	4.0669	4.0669
72.637	20.371	24.4379
4.8801	8.1268	32.5647
118.24	54.6	87.1647
120.9	Substratum	Infinite

Table 7.72: Layered model from interpretation of sounding curve of VES 31

RMS Error =1.12%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
182.15	3.05	3.05
25.271	10.173	13.223
64.145	10.652	23.875
252.99	23.953	47.828
15.045	14	61.828
447.05	16.056	77.884
60	Substratum	Infinite

Table 7.73: Layered model from interpretation of sounding curve of VES 32

RMS Error =0.61%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
131.41	1.4948	1.4948
15.367	10.589	12.0838
116.18	21.904	33.9878
35.433	19.508	53.4958
304.47	25.224	78.7198
29.725	Substratum	Infinite

Table 7.74: Layered model from interpretation of sounding curve of VES 33

RMS Error =0.70%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
51.132	4.7843	4.7843
81.037	23.374	28.1583
57.922	18.948	47.1063
14.976	18.428	65.5343
199.95	27.449	92.9833
48.516	Substratum	Infinite

Table 7.75: Layered model from interpretation of sounding curve of VES 34

RMS Error =3.81%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
78.013	8.958	8.958
36.609	20.198	29.156
10.382	6.9925	36.1485
436.67	28.323	64.4715
21.258	22.829	87.3005
1377	62.258	149.5585
14.582	Substratum	Infinite

Table 7.76: Layered model from interpretation of sounding curve of VES 35
RMS Error =3.48%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
56.604	8.1391	8.1391
61.649	10.849	18.9881
11.803	12.297	31.2851
453.08	45.616	76.9011
51.709	Substratum	Infinite

Table 7.77: Layered model from interpretation of sounding curve of VES 36
RMS Error =0.77%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
150.43	9.0172	9.0172
66.979	11.229	20.2462
335.21	8.833	29.0792
85.376	37.429	66.5082
292.58	14.229	80.7372
44.497	Substratum	Infinite

Table 7.78: Layered model from interpretation of sounding curve of VES 37
RMS Error =1.75%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
46.567	5.6398	5.6398
74.335	14.003	19.6428
53.913	31.072	50.7148
42.435	11.105	61.8198
64.858	18.305	80.1248
93.015	26.945	107.0698
18.327	Substratum	Infinite

Table 7.79: Layered model from interpretation of sounding curve of VES 38
RMS Error =0.89%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
49.902	3.6437	3.6437
27.603	10.379	14.0227
90.937	29.496	43.5187
13.326	15.625	59.1437
84.213	28.866	88.0097
29.709	Substratum	Infinite

Table 7.80: Layered model from interpretation of sounding curve of VES 39

RMS Error =1.39%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
33.717	1.4282	1.4282
109.97	13.27	14.6982
258.36	18.289	32.9872
12.108	5.4655	38.4527
520.33	17.003	55.4557
52.188	21.796	77.2517
360.94	8.4563	85.708
7.4878	26.319	112.027
617.68	26.841	138.868
18.06	Substratum	Infinite

Table 7.81: Layered model from interpretation of sounding curve of VES 40

RMS Error =1.02%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
56.269	3.1978	3.1978
69.58	15.812	19.0098
29.635	8.5368	27.5466
121.24	31.242	58.7886
28.286	25.572	84.3606
277.2	12.188	96.5486
36.478	Substratum	Infinite

Table 7.82: Layered model from interpretation of sounding curve of VES 41

RMS Error =1.07%

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)
49.405	3.6456	3.6456
62.245	9.343	12.9886
91.067	20.418	33.4066
38.848	28.403	61.8096
205.39	23.061	84.8706
50.786	9.8972	94.7678
365.8	19.033	113.8008
47.854	Substratum	Infinite

CHAPTER - 8

RESULTS AND DISCUSSIONS

8.1 GENERAL

In earlier chapters the methodology of resistivity test has been described. The tests were conducted at 41 sites near to state tube well locations of Roorkee group (RG). These were constructed by Uttar Pradesh Government. State tube wells are constructed for agriculture and designed for 150 m^3/ hour discharge for this it requires 33 m length of medium sand (aquifer) to be tapped. There are detailed data available in terms of geological formations for state tube wells (STW), where strata vary in the range of 7 to 25 layers.

After solving quantitative interpretation of all the 41 soundings; the information deduced from analytical model obtained from IX-1D software are number of layers, resistivity of layers, their thicknesses and their depths from ground level. The output from the model gives resistive layers in the range of 4 to 10. The second part of interpretation (also called qualitative interpretation) is to assign geological identities to different, resistive layers; this part can only be performed with the help of tube well data that is already collected. The tube well data contains the information of layer type, its thickness, and depth from ground level. In fact resistivities of formation mainly depend on quality of water filled in pores and grain size of material. With the help of literature and old dissertations, geological stratified layers may be assigned resistivities values as —

Clay ≤ 20 Ωm, fine sand= 25 to 65 Ωm, medium sand = 65 to 120 Ωm, coarse sand= 120 to 250 Ωm, clay & kankar =250 to 350 Ωm, pebbles =250 to 500 Ωm, sand stone=300 to 900 Ωm and bolder=5000 to 10000. On the basis of this information, a comparison is made between result of quantitative interpretation and respective sate tube well data. A Systematic comparison of models with existing tube well data & analysis and geological interpretation of the models is presented in following section.

8.2 GEOLOGICAL INTERPRETATION OF VERTICAL ELECTRICAL SOUNDINGS BASED ON EXISTING TUBE WELL DATA AND MODEL RESULTS

VES No. 1- The synthetic model obtained from interpretation of sounding curve gives 7 layer, resistivity ranging from 9.52 Ωm to 122.25 Ωm while there are 17 layers (from tube well data) ranging from hard clay to coarse sand. The information deduced from geological interpretation of synthetic model gives 7 layers of the model representing clubbing of many layers of actual geological section. However geological interpretation of model for VES No.1 with 7 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
63.285	9.5397	9.5397	Top surface sandy clay
9.5206	8.0089	17.5486	Clay
120.45	31.339	48.8876	Medium sand
20.593	15.161	64.0486	Clay
122.25	28.825	92.8736	Medium sand
79.429	9.9484	102.822	Fine sand
32.954	Substratum	Infinite	Sandy clay

The layers representing resistivity 120.45 Ωm and 122.25 Ωm are water bearing strata and can be considered as good aquifers & these formations have analogous depth to actual one, which can yield sufficient discharge required for an agricultural tube well.

VES No. 2- The synthetic model obtained from interpretation of sounding curve gives 7 layer, resistivity ranging from 24.39 Ωm to 199.03 Ωm while there are actually 25 layers ranging from hard clay to medium sand with bajri. The 7 layers of

the model are analogous to 25 layers of geological section. However geological interpretation of model for VES No. 2 with 7 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
24.398	6.1907	6.1907	Top surface hard clay
56.171	27.055	33.2457	Fine sand
164.87	17.455	50.7007	Coarse sand
28.114	12.367	63.0677	Clay with fine sand
199.03	29.36	92.4277	Medium sand + bajri
102.98	14.569	106.9967	Medium sand
33.968	Substratum	Infinite	Sandy clay

The layers representing resistivity 164.87 Ωm and 199.03 Ωm are water bearing strata and can be considered as good aquifers & these formations have analogous depth to actual one, which can yield sufficient discharge required for an agricultural tube well.

VES No. 3- The synthetic model obtained from interpretation of sounding curve gives 6 layer, resistivity ranging from 26.94 Ωm to 180.98 Ωm while there are actually 19 layers ranging from clay to coarse sand. The 6 layers of the model are analogous to 19 layers of geological section. However geological interpretation of model for VES No. 3 with 6 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
33.732	16.646	16.646	Top surface clay
117.65	24.008	40.654	Medium to Fine sand
43.258	29.485	70.139	Clay with fine sand
180.98	51.381	121.52	Coarse sand
26.939	11.843	133.363	Clay with fine sand
42.019	Substratum	Infinite	Fine sand with Clay

The layers representing resistivity 117.65 Ωm and 180.98 Ωm are water bearing strata and can be considered as good aquifers & these formations have analogous depth to actual one, which can yield sufficient discharge required for an agricultural tube well.

VES No. 4- The synthetic model obtained from interpretation of sounding curve gives 6 layer, resistivity ranging from 22.45 Ωm to 261.72 Ωm while there are actually 15 layers ranging from clay to medium sand with gravel. The 6 layers of the model are analogous to 15 layers of geological section. However geological interpretation of model for VES No. 4 with 6 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
30.505	8.7767	8.7767	Top surface clay
75.091	10.32	19.0967	Fine sand
22.449	11.984	31.0807	Clay with fine sand
142.33	23.071	54.1517	Fine sand + gravel
261.72	11.282	65.4337	Medium sand + gravel
34.116	Substratum	Infinite	Clay with fine sand

The layers representing resistivity 142.33 Ωm and 261.72 Ωm are water bearing strata and can be considered as good aquifers & these formations have analogous depth to actual one, which can yield sufficient discharge required for an agricultural tube well.

VES No. 5- The synthetic model obtained from interpretation of sounding curve gives 5 layer, resistivity ranging from 14.83 Ωm to 149.8 Ωm while there are actually 5 layers ranging from clay to coarse sand with pebbles. The 5 layers of the model are analogous to 7 layers of geological section. However geological interpretation of model for VES No. 5 with 5 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
124.11	2.9683	2.9683	Surface medium sand
84.08	19.506	22.4743	Medium to Fine sand
14.83	7.5941	30.0684	Clay
149.8	23.622	53.6904	Coarse sand with pebbles
95.155	Substratum	Infinite	Medium sand

The layers representing resistivity 149.8 Ωm is water bearing strata and can be as considered good aquifer & this formation has analogous depth to actual one, which can yield sufficient discharge required for an agricultural tube well.

VES No. 6- The synthetic model obtained from interpretation of sounding curve gives 6 layer, resistivity ranging from 6.65 Ωm to 1133.9 Ωm while there are actually 8 layers ranging from clay to coarse sand with bolder. The 6 layers of the model are analogous to 8 layers of geological section. However geological interpretation of model for VES No. 6 with 6 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
109.13	5.5307	5.5307	Brown sand
6.6579	5.6386	11.1693	Clay
38.692	9.2457	20.415	Clay with fine sand
1133.9	15.732	36.147	Coarse sand + bolder
181.46	17.986	54.133	Medium sand + gravel
51.628	Substratum	Infinite	Fine sand

The layers representing resistivity 1133.9 Ωm and 181.46 Ωm are water bearing strata and can be considered as good aquifers & these formations have analogous depth to actual one, which can yield sufficient discharge required for agricultural tube well.

VES No. 7- The synthetic model obtained from interpretation of sounding curve gives 7 layer, resistivity ranging from 22.86 Ωm to 521.2 Ωm while there are actually 25 layers ranging from clay to medium sand with hard stone. The 7 layers of the model are analogous to 25 layers of geological section. However geological interpretation of model for VES No. 7 with 7 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
23.278	6.6552	6.6552	Top surface clay
44.367	24.423	31.0782	Fine sand
178.82	15.865	46.9432	Medium sand+sand stone
22.862	4.0236	50.9668	Clay with fine sand
324.97	15.476	66.4428	Medium sand+bajri
521.2	8.7222	75.165	Medium sand + pebbles
23.25	Substratum	Infinite	Sandy clay

The layers representing resistivity 178.82 Ωm, 324.97 Ωm and 521.2 Ωm are water bearing strata and can be considered as good aquifers & these formations have analogous depth to actual one, which can yield sufficient discharge required for an agricultural tube well.

VES No. 8- The synthetic model obtained from interpretation of sounding curve gives 9 layer, resistivity ranging from 9.15 Ωm to 3638.3 Ωm while there are actually 19 layers ranging from clay to hard stone. The 9 layers of the model are analogous to 19 layers of geological section. However geological interpretation of model for VES No. 8 with 9 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
44.017	10.473	10.473	Surface sand
65.451	3.3116	13.7846	Brown Medium to Fine sand
489.66	10.082	23.8666	Medium sand + pebbles
9.1593	7.732	31.5986	Sticky clay
96.985	10.756	42.3546	Medium sand
3638.3	3.6369	45.9915	Very hard stone
266.6	17.984	63.9755	Medium sand + pebbles
1997.4	2.855	66.8305	Hard stone
50.494	Substratum	Infinite	Fine sand

The layers representing resistivity 489.66 Ωm, 96.98 Ωm and 266.6 Ωm are water bearing strata and can be considered as good aquifers & these formations have analogous depth to actual one, which can yield sufficient discharge required for an agricultural tube well.

VES No. 9- The synthetic model obtained from interpretation of sounding curve gives 8 layer, resistivity ranging from 15.63 Ωm to 166.71 Ωm while there are actually 23 layers ranging from clay to hard sand stone. The 8 layers of the model are analogous to 23 layers of geological section. However geological interpretation of model for VES No. 9 with 8 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
114.07	3.3683	3.3683	Surface sand
166.71	9.4339	12.8022	Fine sand with clay & kankar
30.723	11.641	24.4432	Clay with fine sand
290.8	24.41	48.8532	Medium sand + pebbles
15.639	15.979	64.8322	Clay
94.138	17.207	82.0392	Medium sand
157.04	12.025	94.0642	Medium sand
47.027	Substratum	Infinite	Fine sand

The geological section assigned to certain value of resistivity is not an acute representation of earth layer as shown in table; it has effect of neighbouring earth layers. For the sake of ease, the clubbing effect is shown by one type of strata, which has dominating effecting in actual bore well data.

The layers representing resistivity 290.8 Ωm, 94.14 Ωm and 157.04 Ωm are water bearing strata and can be considered as good aquifers & these formations have analogous depth to actual one, which can yield sufficient discharge required for an agricultural tube well.

VES No. 10- The synthetic model obtained from interpretation of sounding curve gives 7 layer, resistivity ranging from 35.59 Ωm to 5325.7 Ωm while there are actually 21 layers ranging from clay to hard sand stone. The 7 layers of the model are analogous to 21 layers of geological section. However geological interpretation of model for VES No. 10 with 7 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
141.07	7.5127	7.5127	Surface sand
35.591	26.229	33.7417	Clay with fine sand
5325.7	4.5473	38.289	Hard sand stone
93.325	33.647	71.936	Fine sand + pebbles
295.45	11.783	83.719	Fine sand + sand stone
147.14	20.977	104.696	Medium sand
52.67	Substratum	Infinite	Fine sand

The geological section assigned to certain value of resistivity is not an acute representation of earth layer as shown in table; it has effect of neighbouring earth layers. For the sake of ease the clubbing effect is shown by one type of strata, which has dominating effecting in actual bore well data.

The layers representing resistivity 93.33 Ωm, 295.45 Ωm and 147.14 Ωm are water bearing strata and can be considered as good aquifers & these formations have analogous depth to actual one, which can yield sufficient discharge required for agricultural tube well.

VES No. 11- The synthetic model obtained from interpretation of sounding curve gives 7 layer, resistivity ranging from 18.19 Ωm to 329.11 Ωm while there are actually 20 layers ranging from clay to medium sand with sand stone. The 7 layers of the model are analogous to 20 layers of geological section. However geological interpretation of model for VES No. 11 with 7 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
145.18	4.1212	4.1212	Surface sand
59.697	21.183	25.3042	Fine sand
4.8818	8.6676	33.9718	Clay
74.143	11.518	45.4898	Fine to medium sand
18.19	3.1724	48.6622	Clay
329.11	13.094	61.7562	Medium sand+sand stone
147	Substratum	Infinite	Medium sand

The layers representing resistivity 74.143 Ωm and 329.11 Ωm are water bearing strata and can be considered as good aquifers & these formations have analogous depth to actual one, which can yield sufficient discharge required for an agricultural tube well.

VES No. 12- The synthetic model obtained from interpretation of sounding curve gives 6 layer, resistivity ranging from 42.33 Ωm to 298.77 Ωm while there are actually 21 layers ranging from clay to hard sand stone. The 6 layers of the model are analogous to 21 layers of geological section. However geological interpretation of model for VES No. 12 with 6 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
141.01	1.9109	1.9109	Surface sand
117.27	52.054	53.9649	Medium sand
42.329	25.92	79.8849	Fine sand
298.77	24.555	104.4399	Medium sand + gravel
151.43	17.344	121.7839	Medium sand
45	Substratum	Infinite	Fine sand

The layers representing resistivity 117.27 Ωm, 298.77 Ωm and 151.43 Ωm are water bearing strata and can be considered as good aquifers & these formations have analogous depth to actual one, which can yield sufficient discharge required for an agricultural tube well.

VES No. 13- The synthetic model obtained from interpretation of sounding curve gives 7 layer, resistivity ranging from 15.322 Ωm to 343.41 Ωm while there are actually 16 layers ranging from clay to hard sand stone. The 7 layers of the model are analogous to 16 layers of geological section. However geological interpretation of model for VES No. 13 with 7 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
50.057	5.5953	5.5953	Surface clay
67.622	12.05	17.6453	Fine sand
15.322	12.503	30.1483	Clay
333.43	18.665	48.8133	Coarse sand + pebbles
48.927	17.6	66.4133	Fine sand
343.41	11.983	78.3963	Coarse sand + pebbles
49.52	Substratum	Infinite	Fine sand

The layers representing resistivity 333.43 Ωm and 343.41 Ωm are water bearing strata and can be considered as good aquifers & these formations have analogous depth to actual one, which can yield sufficient discharge required for an agricultural tube well.

VES No. 14- The synthetic model obtained from interpretation of sounding curve gives 7 layer, resistivity ranging from 37.187 Ωm to 968.15 Ωm while there are actually 18 layers ranging from clay to Medium sand with pebbles. The 7 layers of

the model are analogous to 18 layers of geological section. However geological interpretation of model for VES No. 14 with 7 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
154.93	3.3401	3.3401	Surface sand
37.187	15.297	18.6371	Fine sand
968.15	24.766	43.4031	Medium sand + pebbles
153.93	6.2357	49.6388	F.M sand + pebbles
383.34	13.214	62.8528	Medium sand+sand stone
168.27	20.331	83.1838	Medium sand
58.275	Substratum	Infinite	Fine sand

The layers representing resistivity 968.15 Ωm, 383.34 Ωm and 168.27 Ωm are water bearing strata and can be considered as good aquifers & these formations have analogous depth to actual one, which can yield sufficient discharge required for an agricultural tube well.

VES No. 15- The synthetic model obtained from interpretation of sounding curve gives 4 layer, resistivity ranging from 162.22 Ωm to 592.24 Ωm while there are actually 19 layers ranging from clay to very hard sand stone. The 4 layers of the model are analogous to 19 layers of geological section. However geological interpretation of model for VES No. 15 with 4 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
162.22	2.3073	2.3073	Surface sand
210.08	6.0986	8.4059	Medium sand + pebbles
169.92	86.316	94.7219	Medium sand
592.24	Substratum	Infinite	Sand stone

The layers representing resistivity 210.08 Ωm and 169.92 Ωm are water bearing strata and can be considered good as aquifers & these formations have analogous depth to actual one, which can yield sufficient discharge required for an agricultural tube well.

VES No. 16- The synthetic model obtained from interpretation of sounding curve gives 5 layer, resistivity ranging from 37.41 Ωm to 326.97 Ωm while there are actually 13 layers ranging from clay to hard sand stone. The 5 layers of the model are analogous to 13 layers of geological section. However geological interpretation of model for VES No. 16 with 5 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
150.58	7.2991	7.2991	Surface sand
67.159	17.082	24.3811	Fine sand
326.97	27.012	51.3931	Coarse sand +sand stone
110.42	29.208	80.6011	Medium sand
37.408	Substratum	Infinite	Clay with Fine sand

The layers representing resistivity 326.97 Ωm and 110.42 Ωm are water bearing strata and can be considered as good aquifers & these formations have analogous depth to actual one, which can yield sufficient discharge required for an agricultural tube well.

VES No. 17- The synthetic model obtained from interpretation of sounding curve gives 6 layer, resistivity ranging from 43.165 Ωm to 208.37 Ωm while there are actually 25 layers ranging from clay to medium sand with bajri. The 6 layers of the model are analogous to 25 layers of geological section. However geological interpretation of model for VES No. 17 with 6 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
154.15	4.9056	4.9056	Surface sand
48.337	25.821	30.7266	Fine sand with clay
208.37	22.804	53.5306	Medium coarse sand
43.165	6.5235	60.0541	Fine sand
151.03	35.437	95.4911	Medium sand
44.253	Substratum	Infinite	Fine sand

The layers representing resistivity 208.37 Ωm and 151.03 Ωm are water bearing strata and can be considered as good aquifers & these formations have analogous depth to actual one, which can yield sufficient discharge required for an agricultural tube well.

VES No. 18- The synthetic model obtained from interpretation of sounding curve gives 6 layer, resistivity ranging from 41.788 Ωm to 162.71 Ωm while there are actually 25 layers ranging from clay to coarse sand with bajri. The 6 layers of the model are analogous to 25 layers of geological section. However geological interpretation of model for VES No. 18 with 6 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
120.5	5.8087	5.8087	Surface sand
61.063	20.952	26.7607	Fine sand
161.69	20.199	46.9597	Medium coarse sand
45.473	12.247	59.2067	Fine sand
162.71	38.662	97.8687	Medium sand
41.788	Substratum	Infinite	Fine sand

The layers representing resistivity 161.69 Ωm and 162.71 Ωm are water bearing strata and can be considered as good aquifers & these formations have analogous depth to actual one, which can yield sufficient discharge required for an agricultural tube well.

VES No. 19- The synthetic model obtained from interpretation of sounding curve gives 6 layer, resistivity ranging from 91.23 Ωm to 500.07 Ωm while there are actually 19 layers ranging from clay to hard sand stone. The 6 layers of the model are analogous to 19 layers of geological section. However geological interpretation of model for VES No. 19 with 6 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
146.68	7.521	7.521	Surface sand
91.802	16.82	24.341	Medium to Fine sand
500.07	15.919	40.26	Fine sand stone
89.576	32.94	73.2	Medium to Fine sand
246.95	18.724	91.924	Medium sand + pebbles
91.231	Substratum	Infinite	Medium to Fine sand

The layers representing resistivity 500.07 Ωm and 246.05 Ωm are water bearing strata and can be considered as good aquifers & these formations have analogous depth to actual one, which can yield sufficient discharge required for an agricultural tube well.

VES No. 20- the synthetic model obtained from interpretation of sounding curve gives 6 layer, resistivity ranging from 40 Ωm to 160 Ωm while there are actually 19 layers ranging from clay to sand stone. The 6 layers of the model are analogous to 19 layers of geological section. However geological interpretation of model for VES No. 20 with 6 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
144.01	6.71	6.71	Surface sand
58.946	18	24.71	Fine sand
160	26.22	50.93	Medium coarse sand
40	13.72	64.65	Fine sand with Clay
160	20.12	84.77	Medium sand + pebbles
50	Substratum	Infinite	Fine sand

The layers representing resistivity 160 Ωm and 160 Ωm are water bearing strata and can be considered as good aquifers & these formations have analogous depth to actual one, which can yield sufficient discharge required for an agricultural tube well.

VES No. 21- The synthetic model obtained from interpretation of sounding curve gives 8 layer, resistivity ranging from 26.12 Ωm to 213.35 Ωm while there are actually 25 layers ranging from clay to coarse sand with bajri. The 8 layers of the model are analogous to 25 layers of geological section. However geological interpretation of model for VES No. 21 with 8 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
51.381	6.5259	6.5259	Surface clay
82.649	10.128	16.6539	Fine to medium sand
36.073	13.407	30.0609	Fine sand with Clay
213.35	15.24	45.3009	Medium sand + bajri
26.122	13.464	58.7649	Clay with fine sand
120.73	17.584	76.3489	Medium sand
74.362	21.202	97.5509	Fine to medium sand
49.566	Substratum	Infinite	Fine sand

The layers representing resistivity 82.65 Ωm, 213.35 Ωm, 120.73 Ωm and 74.36 Ωm are water bearing strata and can be considered as good aquifers & these formations have analogous depth to actual one, which can yield sufficient discharge required for an agricultural tube well.

VES No. 22- The synthetic model obtained from interpretation of sounding curve gives 7 layer, resistivity ranging from 15.314 Ωm to 248.05 Ωm while there are actually 23 layers ranging from clay to grey medium sand with sand stone. The 7 layers of the model are analogous to 23 layers of geological section. However geological interpretation of model for VES No. 22 with 7 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
134.78	3.0476	3.0476	Surface sand
25.784	20.186	23.2336	Clay with fine sand
129.25	25.423	48.6566	Fine sand witth clay+kankar
15.314	19.643	68.2996	Clay
248.05	18.836	87.1356	Medium sand + pebbles
148.91	24.523	111.6586	Fine sand +sand stone
34.855	Substratum	Infinite	Clay with fine sand

The layers representing resistivity 248.05 Ωm and 148.91 Ωm are water bearing strata and can be considered good as aquifers & these formations have analogous depth to actual one, which can yield sufficient discharge required for an agricultural tube well.

VES No. 23- The synthetic model obtained from interpretation of sounding curve gives 5 layer, resistivity ranging from 24.82 Ωm to 142.57 Ωm while there are actually 17 layers ranging from clay to grey medium sand with sand stone. The 5 layers of the model are analogous to 17 layers of geological section. However geological interpretation of model for VES No. 23 with 5 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
49.802	4.154	4.154	Surface clay
81.093	38.568	42.722	Fine sand
24.821	10.228	52.95	Clay with fine sand
142.57	42.502	95.452	Fine sand with sand stone
35.32	Substratum	Infinite	Fine sand with Clay

The layer representing resistivity 148.91 Ωm is water bearing strata. This particular site does not has ample water yielding potential up to the depth of geophysical investigation probably it may has potential beyond this depth.

VES No. 24- The synthetic model obtained from interpretation of sounding curve gives 6 layer, resistivity ranging from 15.496 Ωm to 197.56 Ωm while there are actually 13 layers ranging from clay to medium sand with bolder. The 6 layers of the model are analogous to 13 layers of geological section. However geological interpretation of model for VES No. 24 with 6 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
48.754	4.9721	4.9721	Surface clay
15.496	26.741	31.7131	Clay
89.2	16.07	47.7831	Fine sand
14.855	15.517	63.3001	Clay
197.56	23.831	87.1311	Medium sand
29.515	Substratum	Infinite	Clay with fine sand

The layer representing resistivity 197.56 Ωm is water bearing strata. This particular site does not has ample water yielding potential up to the depth of geophysical investigation probably it may has potential beyond this depth.

VES No. 25- The synthetic model obtained from interpretation of sounding curve gives 6 layer, resistivity ranging from 25.31 Ωm to 330.71 Ωm while there are actually 17 layers ranging from clay to grey fine sand with sand stone. The 6 layers of the model are analogous to 17 layers of geological section. However geological interpretation of model for VES No. 25 with 6 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
124.31	6.5264	6.5264	Surface clay
25.309	27.218	33.7444	Clay with fine sand
36.414	44.204	77.9484	Fine sand with Clay
330.71	13.026	90.9744	Fine sand with sand stone
26.76	26.828	117.8024	Clay with fine sand
16.911	Substratum	Infinite	Fine sand with Clay

The layer representing resistivity 330.414 Ωm is water bearing strata. This particular site does not has ample water yielding potential up to the depth of geophysical investigation probably it may has potential beyond this depth.

VES No. 26- The synthetic model obtained from interpretation of sounding curve gives 9 layer, resistivity ranging from 9.313 Ωm to 118.98 Ωm while there are actually 17 layers ranging from clay to brown medium sand. The 9 layers of the model are analogous to 17 layers of geological section. However geological interpretation of model for VES No. 26 with 9 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
50.155	16.007	16.007	Surface clay
53.335	5.6758	21.6828	Fine sand with Clay
15.592	28.948	50.6308	Clay
76.291	4.7892	55.42	Fine sand
9.313	15.748	71.168	Clay
63.162	9.7691	80.9371	Fine sand
10.026	20.355	101.2921	Clay
118.98	14.457	115.7491	Medium sand
20.82	Substratum	Infinite	Clay

The layer representing resistivity 118.98 Ωm is water bearing strata. This particular site does not has ample water yielding potential up to the depth of geophysical investigation probably it may has potential beyond this depth.

VES No. 27- The synthetic model obtained from interpretation of sounding curve gives 6 layer, resistivity ranging from 18.53 Ωm to 222.45 Ωm while there are actually 17 layers ranging from clay to grey fine sand with sand stone. The 6 layers of the model are analogous to 17 layers of geological section. However geological interpretation of model for VES No. 27 with 6 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
49.647	20.067	20.067	Surface clay
222.45	18.975	39.042	Fine sand+sand stone
18.531	14.976	54.018	Clay
90.644	21.715	75.733	Fine sand with sand stone
189.31	19.452	95.185	Fine sand+sand stone
32.5	Substratum	Infinite	Clay with fine sand

The layers representing resistivity 222.45 Ωm, 90.64 Ωm and 189.31 Ωm are water bearing strata and can be considered good aquifers & these formations have analogous depth to actual one, which can yield sufficient discharge required for an agricultural tube well.

VES No. 28- The synthetic model obtained from interpretation of sounding curve gives 6 layer, resistivity ranging from 15.35 Ωm to 136.38 Ωm while there are actually 18 layers ranging from clay to grey fine sand with sand stone. The 6 layers of the model are analogous to 18 layers of geological section. However geological interpretation of model for VES No. 28 with 6 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
80.347	2.3775	2.3775	Surface sandy clay
18.877	27.388	29.7655	Clay
136.38	13.557	43.3225	Medium sand
15.351	24.461	67.7835	Clay
88.914	21.695	89.4785	Fine sand+ pebbles
14.992	Substratum	Infinite	Clay

The layers representing resistivity 136.38 Ωm and 88.914 Ωm are water bearing strata.

VES No. 29- The synthetic model obtained from interpretation of sounding curve gives 5 layer, resistivity ranging from 30.1 Ωm to 302.58 Ωm while there are actually 19 layers ranging from clay to grey medium sand with sand stone. The 5 layers of

the model are analogous to 19 layers of geological section. However geological interpretation of model for VES No. 29 with 5 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
79.404	5.0328	5.0328	Surface sandy clay
49.773	11.74	16.7728	Fine sand with Clay
302.58	34.635	51.4078	Medium sand +sand stone
64.966	36.163	87.5708	Fine sand
30.068	Substratum	Infinite	Clay with fine sand

The layer representing resistivity 302.58 Ωm is water bearing strata, this can yield sufficient discharge required for an agricultural tube well.

VES No. 30- The synthetic model obtained from interpretation of sounding curve gives 5 layer, resistivity ranging from 4.88 Ωm to 172.87 Ωm while there are actually 16 layers ranging from clay to grey medium sand with sand stone. The 5 layers of the model are analogous to 16 layers of geological section. However geological interpretation of model for VES No. 30 with 5 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
172.87	4.0669	4.0669	Surface sand
72.637	20.371	24.4379	Fine sand
4.8801	8.1268	32.5647	Clay
118.24	54.6	87.1647	Medium sand
120.9	Substratum	Infinite	Medium sand

The layers representing resistivity 118.24 Ωm and 120.9 Ωm are water bearing strata, these can yield sufficient discharge required for an agricultural tube well.

VES No. 31- The synthetic model obtained from interpretation of sounding curve gives 7 layer, resistivity ranging from 15.045 Ωm to 447.05 Ωm while there are actually 16 layers ranging from clay to medium sand with sand stone. The 7 layers of the model are analogous to 16 layers of geological section. However geological interpretation of model for VES No. 31 with 7 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
182.15	3.05	3.05	Surface medium sand
25.271	10.173	13.223	Clay with fine sand
64.145	10.652	23.875	Fine sand
252.99	23.953	47.828	Medium sand + sand stone
15.045	14	61.828	Clay
447.05	16.056	77.884	Medium sand + sand stone
60	Substratum	Infinite	Fine sand

The layers representing resistivity 252.99 Ωm and 447.05 Ωm are water bearing strata, these can yield sufficient discharge required for an agricultural tube well.

VES No. 32- The synthetic model obtained from interpretation of sounding curve gives 6 layer, resistivity ranging from 15.367 Ωm to 304.47 Ωm while there are actually 16 layers ranging from clay to medium sand with sand stone. The 6 layers of the model are analogous to 16 layers of geological section. However geological interpretation of model for VES No. 32 with 6 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
131.41	1.4948	1.4948	Surface fine sand
15.367	10.589	12.0838	Clay
116.18	21.904	33.9878	Medium sand
35.433	19.508	53.4958	Clay with fine sand
304.47	25.224	78.7198	Medium sand + sand stone
29.725	Substratum	Infinite	Clay with fine sand

The layers representing resistivity 116.18 Ωm and 304.47 Ωm are water bearing strata, these can yield sufficient discharge required for an agricultural tube well.

VES No. 33- The synthetic model obtained from interpretation of sounding curve gives 6 layer, resistivity ranging from 14.976 Ωm to 19.95 Ωm while there are actually 14 layers ranging from clay to grey medium fine sand with sand stone. The 6 layers of the model are analogous to 14 layers of geological section. However geological interpretation of model for VES No. 33 with 6 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
51.132	4.7843	4.7843	Surface sandy clay
81.037	23.374	28.1583	Fine to Medium sand
57.922	18.948	47.1063	Fine sand
14.976	18.428	65.5343	Clay
199.95	27.449	92.9833	M. F. sand + sand stone
48.516	Substratum	Infinite	Clay with fine sand

The layers representing resistivity 81.037 Ωm and 199.95 Ωm are water bearing strata, these can yield sufficient discharge required for an agricultural tube well.

VES No. 34- The synthetic model obtained from interpretation of sounding curve gives 7 layer, resistivity ranging from 10.38 Ωm to 436.67 Ωm while there are actually 14 layers ranging from clay to hard sand stone. The 7 layers of the model are analogous to 14 layers of geological section. However geological interpretation of model for VES No. 34 with 7 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
78.013	8.958	8.958	Surface fine sand
36.609	20.198	29.156	Clay with fine sand
10.382	6.9925	36.1485	Clay
436.67	28.323	64.4715	Medium sand + sand stone
21.258	22.829	87.3005	Clay
1377	62.258	149.5585	Hard sand stone
14.582	Substratum	Infinite	Clay

The layers representing resistivity 436.67 Ωm is water bearing strata, this can yield sufficient discharge required for an agricultural tube well.

VES No. 35- The synthetic model obtained from interpretation of sounding curve gives 5 layer, resistivity ranging from 11.803 Ωm to 453.08 Ωm while there are actually 16 layers ranging from clay to grey medium sand with sand stone. The 5 layers of the model are analogous to 16 layers of geological section. However geological interpretation of model for VES No. 35 with 5 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
56.604	8.1391	8.1391	Surface clay
61.649	10.849	18.9881	Fine sand
11.803	12.297	31.2851	Clay
453.08	45.616	76.9011	G.M.F. sand +sand stone
51.709	Substratum	Infinite	Fine sand

The layer representing resistivity 453.08 Ωm is water bearing strata, this can yield sufficient discharge required for an agricultural tube well.

VES No. 36- The synthetic model obtained from interpretation of sounding curve gives 6 layer, resistivity ranging from 44.497 Ωm to 335.21 Ωm while there are actually 17 layers ranging from clay to sand stone with pebbles. The 6 layers of the model are analogous to 17 layers of geological section. However geological interpretation of model for VES No. 36 with 6 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
150.43	9.0172	9.0172	Surface brown sand
66.979	11.229	20.2462	Fine to Medium sand
335.21	8.833	29.0792	Medium sand + sand stone
85.376	37.429	66.5082	Medium sand
292.58	14.229	80.7372	M. F. sand + sand stone
44.497	Substratum	Infinite	Clay with fine sand

The layers representing resistivity 335.21 Ωm, 85.376 Ωm and 292.58 Ωm are water bearing strata, these can yield sufficient discharge required for an agricultural tube well.

VES No. 37- The synthetic model obtained from interpretation of sounding curve gives 7 layer, resistivity ranging from 18.33 Ωm to 93.015 Ωm while there are actually 21 layers ranging from clay to medium sand with bajri. The 7 layers of the model are analogous to 21 layers of geological section. However geological interpretation of model for VES No. 37 with 7 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
46.567	5.6398	5.6398	Surface clay
74.335	14.003	19.6428	Fine sand
53.913	31.072	50.7148	Fine sand with Clay
42.435	11.105	61.8198	Clay with fine sand
64.858	18.305	80.1248	Fine sand with Clay
93.015	26.945	107.0698	Medium sand
18.327	Substratum	Infinite	Clay

The layer representing resistivity 93.015 Ωm is water bearing strata, this can yield sufficient discharge required for an agricultural tube well.

VES No. 38- The synthetic model obtained from interpretation of sounding curve gives 6 layer, resistivity ranging from 13.326 Ωm to 90.937 Ωm while there are actually 17 layers ranging from clay to medium sand. The 6 layers of the model are analogous to 17 layers of geological section. However geological interpretation of model for VES No. 38 with 6 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
49.902	3.6437	3.6437	Surface clay
27.603	10.379	14.0227	Clay with fine sand
90.937	29.496	43.5187	Medium sand
13.326	15.625	59.1437	Clay
84.213	28.866	88.0097	Medium sand
29.709	Substratum	Infinite	Clay with fine sand

The layers representing resistivity 90.937 Ωm and 84.213 Ωm are water bearing strata, these can yield sufficient discharge required for an agricultural tube well.

VES No. 39- The synthetic model obtained from interpretation of sounding curve gives 10 layer, resistivity ranging from 7.488 Ωm to 617.68 Ωm while there are actually 18 layers ranging from clay to medium sand with sand stone. The 10 layers of the model are analogous to 18 layers of geological section. However geological interpretation of model for VES No. 39 with 10 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
33.717	1.4282	1.4282	Surface clay
109.97	13.27	14.6982	Medium sand
258.36	18.289	32.9872	Fine sand with kankar
12.108	5.4655	38.4527	Clay
520.33	17.003	55.4557	Medium sand + sand stone
52.188	21.796	77.2517	Fine sand with Clay
360.94	8.4563	85.708	Medium sand + sand stone
7.4878	26.319	112.027	Clay
617.68	26.841	138.868	Medium sand + sand stone
18.06	Substratum	Infinite	Clay

The layers representing resistivity 520.33 Ωm, 360.94 Ωm and 617.68 Ωm are water bearing strata, these can yield sufficient discharge required for an agricultural tube well.

VES No. 40- The synthetic model obtained from interpretation of sounding curve gives 7 layer, resistivity ranging from 28.286 Ωm to 277.2 Ωm while there are actually 16 layers ranging from clay to fine medium sand with sand stone. The 7 layers of the model are analogous to 16 layers of geological section. However geological interpretation of model for VES No. 40 with 7 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
56.269	3.1978	3.1978	Surface clay
69.58	15.812	19.0098	Fine sand
29.635	8.5368	27.5466	Clay with fine sand
121.24	31.242	58.7886	Medium sand
28.286	25.572	84.3606	Clay with fine sand
277.2	12.188	96.5486	F. M. sand + sand stone
36.478	Substratum	Infinite	Clay with fine sand

The layers representing resistivity 121.24 Ωm and 277.2 Ωm are water bearing strata, these can yield sufficient discharge required for an agricultural tube well.

VES No. 41- The synthetic model obtained from interpretation of sounding curve gives 8 layer, resistivity ranging from 38.85 Ωm to 365.8 Ωm while there are actually 16 layers ranging from clay to medium sand with sand stone. The 8 layers of the model are analogous to 16 layers of geological section. However geological interpretation of model for VES No. 41 with 8 layers can be done as given below;

Resistivity of layer (Ωm)	Thickness of layer (m)	Depth from G.I. (m)	Geological section
49.405	3.6456	3.6456	Surface clay
62.245	9.343	12.9886	Fine sand
91.067	20.418	33.4066	Medium sand
38.848	28.403	61.8096	Clay with fine sand
205.39	23.061	84.8706	Medium sand + sand stone
50.786	9.8972	94.7678	Clay with fine sand
365.8	19.033	113.8008	Medium sand + sand stone
47.854	Substratum	Infinite	Clay with fine sand

The layers representing resistivity 91.1 Ωm, 205.39 Ωm and 365.8 Ωm are water bearing strata, these can yield sufficient discharge required for an agricultural tube well.

CHAPTER - 9

CONCLUSIONS

In this work, vertical electrical soundings are conducted at 41 sites in the study area; development block Roorkee and Narsan; nearby state public tube well of known strata chart. The objective of VES is to deduce the variation of resistivity with the depth below a given point on the ground surface, and to correlate it with the available geological information in order to infer the depths and resistivities of the layers (formation) present, so as to identify the aquifer location.

The solution of resistivity surveys is obtained in two parts (1) Interpretation in terms of various layers of actual (as distinguished from apparent) resistivities and their depths (2) interpretation of the actual resistivities in terms of subsurface geologic and ground water conditions. Comparing actual resistivity variations with depth to data from a nearby state tube well, enables a correlation to be established with subsurface geologic and ground water condition, which is necessary to delineate aquifer location and depth.

The data obtained from vertical electrical soundings are interpreted by using IX-1D software; which is a WINDOWS based software and gives layered model of VES in the graphical and analytical form. The analytical results contain resistivity of layers and their thicknesses and depths of layers from ground level. The results obtained from interpretation of sounding curves of VES are correlated with respective strata chart of nearby state tube well. Analyzing result of VES and stratified layers of nearby state tube well, geological interpretation of model is carried out. An analysis is also performed that how for results obtained from interpretation of VES match with existing data.

Results of some of the sites are very close to strata charts of state tube wells, whereas few are deviated from actual geological section. Actually in all geological sections there is more number of layers than inferred from interpretation of D.C resistivity survey. In present case, strata charts of all tube wells have 7 to 25 stratified layers of clay, fine sand, medium sand, coarse sand, gravel, medium/ coarse sand with pebbles and bajri, fine sand with sand stone, medium/ coarse sand with sand stone, hard sand stone, bolder and very hard stone while models of all VES have 4 to10 layers of different resistivities, these layers of the model representing clubbing of many layers of actual geological section. However these layers of model are explained as analogous layer equivalent to single layer composed of many layers of different resistivities and different thicknesses.

The information deduced from geological interpretation of synthetic models is given in detail in the Chapter-8.

The quantitative interpretation of resistivity data is one of the most intricate problems and one should constantly guard against simple rules of thumb in this respect. This is because the theory developed can only be applied to simple plane-layered models, whereas in practice the variation in resistivity are usually much more complex both in lateral and vertical directions. Different places, different layered ground may not have unique sounding representation. Two different layered models may have a common sounding curve, thus interpretation of a sounding curve may be misleading, faulty, incorrect etc.

In addition, the "Principle of equivalence" and the "Principle of suppression" introduce other types of ambiguity in the interoperation. For example a relatively thin conductive layer sandwiched between two layers of higher resistivities will tend to concentrate current flow in it. The total current carried by it will be unaltered if we increase its resistivity 'ρ' but at the same time increase it's thickness 'h' so the ratio h/ρ is constant.

On the other hand, a resistant bed is introduced between two more conductive layers is characterized by it's product of thickness and resistivity ($h\rho$). Thus all middle layers for which the product $h\rho$ is constant are electrically equivalent. In either case a unique determination of h and ρ would be difficult if not impossible.

This work is an attempt to verify that how closely results can be obtained from D.C. resistivity survey and this method can be used in future to locate layers of water bearing strata for delineation of aquifers.

The conclusions drawn from the study may be summarized as follows:

1. Results of some of the sites are very close to the actual geological section, whereas few are deviated from actual geological section.
2. In general, aquifers are available in two and three segments. However, at few locations only one segment is also observed. Even at few locations four segments are available.
3. Models obtained from qualitative and quantitative interpretation have 4 to 10 layers representing actual geological section of 7 to 25 layers.
4. Some sites are identified as water deficit sites from agricultural tube well point of view. This fact is actually confirmed from tube well division, Roorkee that state tube wells of these sites are either failed or not giving good yield.
5. Depth of investigation by resistivity survey ranges from 53.69 m to 149.56 m.

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APPENDIX

State Tube Well No. 1   Village: Paniala Chandapur

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Sandy clay	30	9.15	9.15
Red sand	56	17.07	7.93
Sandy clay	65	19.82	2.74
Medium sand	86	26.22	6.40
Hard clay +kankar	123	37.50	11.28
Fine sand	143	43.60	6.10
Medium sand	154	46.95	3.35
Hard clay	205	62.50	15.55
Fine sand	214	65.24	2.74
Medium sand	246	75.00	9.76
Fine sand	263	80.18	5.18
Medium sand	275	83.84	3.66
Coarse sand	302	92.07	8.23
Hard clay	316	96.34	4.27
Fine sand	327	99.70	3.35
Medium sand	335	102.13	2.44
Hard clay	345	105.18	3.05

State Tube Well No. 2   Village: Lathardeva Shekh

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Hard clay	19	5.79	5.79
Fine sand	35	10.67	4.88
Hard clay	50	15.24	4.57
Fine sand with clay	65	19.82	4.57
Fine sand	88	26.83	7.01
Clay +kankar	98	29.88	3.05
Fine sand	110	33.54	3.66
Medium sand	125	38.11	4.57
Coarse sand	150	45.73	7.62
Coarse sand + bajri	158	48.17	2.44
Hard clay	180	54.88	6.71
Fine sand	185	56.40	1.52
Hard clay	204	62.20	5.79
Medium sand	212	64.63	2.44
Medium sand + bajri	226	68.90	4.27
Medium sand + clay	250	76.22	7.32
Fine sand	262	79.88	3.66
Clay +kankar	270	82.32	2.44
Fine sand	278	84.76	2.44
Medium sand	293	89.33	4.57
Hard clay	302	92.07	2.74
Fine sand	308	93.90	1.83
Medium sand	312	95.12	1.22
Clay +kankar	320	97.56	2.44
Medium sand	340	103.66	6.10

State Tube Well No. 3 Village: Harajauli Jhojna

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Clay	44	13.41	13.41
Fine sand	66	20.12	6.71
Medium sand	78	23.78	3.66
Hard clay	99	30.18	6.40
Fine sand	102	31.10	0.91
Hard clay	116	35.37	4.27
Fine sand	122	37.20	1.83
Medium sand	132	40.24	3.05
Clay	144	43.90	3.66
Fine sand	157	47.87	3.96
Coarse sand	162	49.39	1.52
Hard clay	208	63.41	14.02
Brown sand	226	68.90	5.49
Hard clay	246	75.00	6.10
Coarse sand	289	88.11	13.11
Clay	300	91.46	3.35
Fine sand	305	92.99	1.52
Coarse sand	325	99.09	6.10
Hard clay	328	100.00	1.10

State Tube Well No. 4 Village: Landaura

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface clay	23	7.01	7.01
Clay with sand	30	9.15	2.13
Fine sand	38	11.59	2.44
Fine sand with clay	45	13.72	2.13
Fine sand	85	25.91	12.20
Clay	103	31.40	5.49
Clay +kankar	126	38.41	7.01
Fine sand	162	49.39	10.98
Fine sand + gravel	185	56.40	7.01
Sticky clay	190	57.93	1.52
Medium sand + gravel	205	62.50	4.57
Clay +kankar	212	64.63	2.13
Clay sand + kankar	220	67.07	2.44
Medium sand + gravel	240	73.17	6.10
Sticky clay	260	79.27	6.10

State Tube Well No. 5 **Village: Landaura**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Medium sand	60	18.29	18.29
Clay	70	21.34	3.05
Medium sand	120	36.59	15.24
Coarse sand	150	45.73	9.15
Coarse sand + pebbles	186	56.71	10.98
Fine sand	207	63.11	6.40
Clay	212	64.63	1.52

State Tube Well No. 6 **Village: Daulatpur**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Brown sand	16	4.88	4.88
Clay	30	9.15	4.27
Fine sand	41	12.50	3.35
Clay	65	19.82	7.32
Coarse sand + bolder	119	36.28	16.46
Medium sand	159	48.48	12.20
Medium sand + gravel	176	53.66	5.18
Clay	180	54.88	1.22

State Tube Well No. 7 **Village: Nanglai Marti**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface clay	12	3.66	3.66
Clay	35	10.67	7.01
Brown medium sand	54	16.46	5.79
Fine medium sand	74	22.56	6.10
F.M. sand+ sand stone	89	27.13	4.57
Clay +kankar	112	34.15	7.01
M. sand + sand stone	127	38.72	4.57
Clay +kankar	135	41.16	2.44
M. sand + sand stone	156	47.56	6.40
Medium sand	170	51.83	4.27
Clay	176	53.66	1.83
Fine sand	182	55.49	1.83
Clay +kankar	187	57.01	1.52
Fine sand	198	60.37	3.35
Medium sand	226	68.90	8.54
Clay	233	71.04	2.13
Hard clay	236	71.95	0.91
Medium sand +shingle	251	76.52	4.57
Fine sand	259	78.96	2.44
Medium sand +pebbles	262	79.88	0.91
Fine sand	264	80.49	0.61
Medium sand +pebbles	275	83.84	3.35
Clay +hard stone	290	88.41	4.57
Hard stone	293	89.33	0.91
Med. Sand +hard stone	300	91.46	2.13

State Tube Well No. 8 **Village: Jaurasi**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Brown surface sand	19	5.79	5.79
Clay	35	10.67	4.88
Brown fine sand	50	15.24	4.57
Brown Medium sand	65	19.82	4.57
Clay +kankar	88	26.83	7.01
Coarse sand	98	29.88	3.05
Black sticky clay	110	33.54	3.66
Grey fine sand	125	38.11	4.57
Medium sand +pebbles	150	45.73	7.62
Black sticky clay	158	48.17	2.44
Medium sand	180	54.88	6.71
Brown fine sand	185	56.40	1.52
Very hard stone	204	62.20	5.79
Fine sand	212	64.63	2.44
Medium sand	226	68.90	4.27
Medium sand +pebbles	250	76.22	7.32
Hard clay +kankar	262	79.88	3.66
Fine sand +sand stone	270	82.32	2.44
Hard stone	278	84.76	2.44

State Tube Well No. 9 **Village: Dandhera**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Brown surface sand	10	3.05	3.05
Clay +kankar	28	8.54	5.49
Brown fine sand	45	13.72	5.18
Clay	65	19.82	6.10
Clay +kankar	86	26.22	6.40
Fine sand	96	29.27	3.05
Fine sand + sand stone	114	34.76	5.49
Fine sand	120	36.59	1.83
Fine medium sand	148	45.12	8.54
Medium sand + pebbles	163	49.70	4.57
Coarse sand	170	51.83	2.13
Clay	225	68.60	16.77
Fine sand	235	71.65	3.05
Medium sand	257	78.35	6.71
Clay	259	78.96	0.61
Fine sand + sand stone	283	86.28	7.32
Clay + kankar	290	88.41	2.13
Grey fine medium sand	295	89.94	1.52
Grey medium sand	316	96.34	6.40
Hard sand stone	319	97.26	0.91
Fine medium sand	328	100.00	2.74
Hard clay	334	101.83	1.83
Fine sand	340	103.66	1.83

State Tube Well No. 10 **Village: Dandhera**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface sand	25	7.62	7.62
Brown fine sand	51	15.55	7.93
Clay	85	25.91	10.37
Fine sand	110	33.54	7.62
Hard sand stone	124	37.80	4.27
Fine sand	136	41.46	3.66
Clay +kankar	140	42.68	1.22
Fine sand + pebbles	167	50.91	8.23
Hard sticky clay	188	57.32	6.40
Brown fine sand	224	68.29	10.98
Hard clay + pebbles	238	72.56	4.27
Stone + kankar	245	74.70	2.13
Clay + kankar	256	78.05	3.35
Fine sand +sand stone	274	83.54	5.49
Clay + kankar	295	89.94	6.40
Fine sand	301	91.77	1.83
Fine medium sand	328	100.00	8.23
Clay +kankar	333	101.52	1.52
Stone + kankar	336	102.44	0.91
Fine medium sand	352	107.32	4.88
Clay +kankar	363	110.67	3.35

State Tube Well No. 11 **Village: Dandhera**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface sand	25	7.62	7.62
Clay + kankar	56	17.07	9.45
Fine sand	85	25.91	8.84
Fine sand + kankar	95	28.96	3.05
Medium sand	109	33.23	4.27
Fine sand	120	36.59	3.35
Medium sand	164	50.00	13.41
Clay	180	54.88	4.88
Brown fine sand	184	56.10	1.22
Brown M.F. sand	194	59.15	3.05
Brown medium sand	222	67.68	8.54
Brown fine sand	224	68.29	0.61
Brown medium sand	229	69.82	1.52
Clay	240	73.17	3.35
Fine sand + sand stone	246	75.00	1.83
Clay + Gravel	250	76.22	1.22
F.M. sand + sand stone	255	77.74	1.52
M. sand + sand stone	275	83.84	6.10
Fine sand	277	84.45	0.61
Clay	283	86.28	1.83

State Tube Well No. 12 **Village: Bijoulli**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface sand	8	2.44	2.44
Brown sand	35	10.67	8.23
Medium sand	62	18.90	8.23
Clay + kankar	75	22.87	3.96
Fine sand + sand stone	139	42.38	19.51
Medium sand	171	52.13	9.76
Clay	185	56.40	4.27
Brown fine sand	242	73.78	17.38
Clay	256	78.05	4.27
Fine sand + sand stone	272	82.93	4.88
Clay + kankar	290	88.41	5.49
Sticky clay	305	92.99	4.57
Fine sand	316	96.34	3.35
Clay + kankar	330	100.61	4.27
Hard stone	334	101.83	1.22
Clay	340	103.66	1.83
Hard stone	354	107.93	4.27
Clay + kankar	376	114.63	6.71
Fine sand	383	116.77	2.13
Coarse sand	394	120.12	3.35
Clay	400	121.95	1.83

State Tube Well No.13 **Village: Kambora**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface clay	19	5.79	5.79
Brown fine sand	43	13.11	7.32
Fine sand	59	17.99	4.88
Clay	101	30.79	12.80
Fine sand + sand stone	123	37.50	6.71
Medium sand	141	42.99	5.49
Coarse sand	159	48.48	5.49
Coarse sand +pebbles	165	50.30	1.83
Clay	179	54.57	4.27
Brown fine sand	196	59.76	5.18
Brown medium sand	208	63.41	3.66
Clay	222	67.68	4.27
Medium sand	230	70.12	2.44
M. coarse sand +pebbles	259	78.96	8.84
Hard sand stone	262	79.88	0.91
Clay	270	82.32	2.44

State Tube Well No.14 **Village: Manglore**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface sand	11	3.35	3.35
Brown fine sand	58	17.68	14.33
Hard sand stone	72	21.95	4.27
Fine sand + sand stone	106	32.32	10.37
Clay + kankar	116	35.37	3.05
Fine medium sand	126	38.41	3.05
Fine sand	130	39.63	1.22
Medium sand + pebbles	159	48.48	8.84
F. M. sand + pebbles	170	51.83	3.35
Clay	175	53.35	1.52
Fine sand	183	55.79	2.44
Fine medium sand	195	59.45	3.66
F.M. sand + sand stone	207	63.11	3.66
Fine medium sand	214	65.24	2.13
Clay	218	66.46	1.22
Brown medium sand	225	68.60	2.13
Medium sand	247	75.30	6.71
Clay	260	79.27	3.96

State Tube Well No.15 **Village: Nathur Khera**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface sand	15	4.57	4.57
Brown fine sand	50	15.24	10.67
Clay + kankar	85	25.91	10.67
Fine medium sand	106	32.32	6.40
Medium sand	125	38.11	5.79
Fine sand	134	40.85	2.74
Medium sand	146	44.51	3.66
Medium fine sand	159	48.48	3.96
Medium sand + pebbles	163	49.70	1.22
Clay	177	53.96	4.27
Brown fine sand	195	59.45	5.49
Fine medium sand	205	62.50	3.05
Brown fine sand	216	65.85	3.35
Clay + sand	223	67.99	2.13
Brown fine sand	235	71.65	3.66
Medium sand	242	73.78	2.13
Clay + sand	247	75.30	1.52
Fine medium sand	270	82.32	7.01
Very hard sand stone	272	82.93	0.61

State Tube Well No.16 **Village: Akbarpur**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface brown fine sand	24	7.32	7.32
Fine sand	52	15.85	8.54
Very fine sand	75	22.87	7.01
Fine sand + sand stone	110	33.54	10.67
Very fine sand	130	39.63	6.10
Medium fine sand	155	47.26	7.62
Crs. sand & sand stone	164	50.00	2.74
Hard clay	183	55.79	5.79
Fine sand	197	60.06	4.27
Clay & hard stone	220	67.07	7.01
Medium fine sand	240	73.17	6.10
Medium sand	257	78.35	5.18
Clay	270	82.32	3.96

State Tube Well No.17 **Village: Mundalana**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface sand	15	4.57	4.57
Brown sand	17	5.18	0.61
Clay	30	9.15	3.96
Fine sand	65	19.82	10.67
Clay	75	22.87	3.05
Fine sand	84	25.61	2.74
Clay	96	29.27	3.66
Fine sand	105	32.01	2.74
Fine medium sand	121	36.89	4.88
Medium coarse sand	142	43.29	6.40
Fine medium sand	154	46.95	3.66
Fine sand + pebbles	166	50.61	3.66
Clay	178	54.27	3.66
Fine sand + sand stone	190	57.93	3.66
Fine medium sand	206	62.80	4.88
Clay + kankar	220	67.07	4.27
Fine sand	226	68.90	1.83
Fine medium sand	235	71.65	2.74
Fine sand	243	74.09	2.44
Coarse sand	248	75.61	1.52
Fine Medium sand	272	82.93	7.32
Clay	277	84.45	1.52
Medium sand	286	87.20	2.74
Medium sand + bajri	299	91.16	3.96
Fine sand	309	94.21	3.05

State Tube Well No.18 **Village: Ghoshipur**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface brown sand	19	5.79	5.79
Grey fine sand	35	10.67	4.88
Hard clay	50	15.24	4.57
Fine sand with clay	65	19.82	4.57
Fine sand	88	26.83	7.01
Clay +kankar	98	29.88	3.05
Fine sand	110	33.54	3.66
Medium sand	125	38.11	4.57
Coarse sand	150	45.73	7.62
Coarse sand + bajri	158	48.17	2.44
Hard clay	180	54.88	6.71
Fine sand	185	56.40	1.52
Hard clay	204	62.20	5.79
Medium sand	212	64.63	2.44
Medium sand + bajri	226	68.90	4.27
Medium sand + clay	250	76.22	7.32
Fine sand	262	79.88	3.66
Clay +kankar	270	82.32	2.44
Fine sand	278	84.76	2.44
Medium sand	293	89.33	4.57
Hard clay	302	92.07	2.74
Fine sand	308	93.90	1.83
Medium sand	312	95.12	1.22
Clay +kankar	320	97.56	2.44
Medium sand	340	103.66	6.10

State Tube Well No.19 **Village: Gadharouna**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface fine sand	25	7.62	7.62
F.M. brown sand	44	13.41	5.79
Brown fine sand	78	23.78	10.37
Clay +kankar	95	28.96	5.18
Fine sand	105	32.01	3.05
Hard sand stone	110	33.54	1.52
Fine sand stone	130	39.63	6.10
Fine medium sand	142	43.29	3.66
Hard clay	150	45.73	2.44
Medium sand	165	50.30	4.57
Clay	179	54.57	4.27
Brown fine sand	201	61.28	6.71
Hard clay	220	67.07	5.79
Fine medium sand	238	72.56	5.49
Coarse sand	255	77.74	5.18
Medium sand + pebbles	260	79.27	1.52
Fine sand	276	84.15	4.88
Medium sand + pebbles	300	91.46	7.32
Fine sand	310	94.51	3.05

State Tube Well No. 20 **Village: Landaura**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface brown fine sand	22	6.71	6.71
Fine sand	55	16.77	10.06
Brown fine sand	65	19.82	3.05
Clay	80	24.39	4.57
Fine medium sand	109	33.23	8.84
Sand stone	115	35.06	1.83
Fine medium sand	140	42.68	7.62
Medium sand	154	46.95	4.27
Coarse sand	166	50.61	3.66
Clay	180	54.88	4.27
Brown fine sand	203	61.89	7.01
Hard clay	211	64.33	2.44
Fine sand	224	68.29	3.96
Medium sand	234	71.34	3.05
Fine sand	250	76.22	4.88
Fine medium sand	255	77.74	1.52
Medium sand + bajri	260	79.27	1.52
Medium sand	270	82.32	3.05
Fine sand	277	84.45	2.13

State Tube Well No. 21 **Village: Landaura**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface clay	19	5.79	5.79
Brown fine sand	35	10.67	4.88
Fine sand	50	15.24	4.57
Fine medium sand	65	19.82	4.57
Clay	88	26.83	7.01
Clay + kankar	98	29.88	3.05
Fine sand	110	33.54	3.66
Medium sand	125	38.11	4.57
Coarse sand	150	45.73	7.62
Coarse sand + bajri	158	48.17	2.44
Hard clay	180	54.88	6.71
Fine sand	185	56.40	1.52
Hard clay	204	62.20	5.79
Medium sand	212	64.63	2.44
Medium sand + bajri	226	68.90	4.27
Medium sand + clay	250	76.22	7.32
Fine sand	262	79.88	3.66
Clay +kankar	270	82.32	2.44
Fine sand	278	84.76	2.44
Medium sand	293	89.33	4.57
Hard clay	302	92.07	2.74
Fine sand	308	93.90	1.83
Medium sand	312	95.12	1.22
Clay +kankar	320	97.56	2.44
Medium sand	340	103.66	6.10

State Tube Well No. 22 **Village: Salempur**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Brown fine sand	10	3.05	3.05
Clay	52	15.85	12.80
Brown fine sand	58	17.68	1.83
Clay	64	19.51	1.83
Grey Fine sand	68	20.73	1.22
Clay	74	22.56	1.83
Grey fine sand	95	28.96	6.40
Fine medium sand	114	34.76	5.79
Clay +kankar	131	39.94	5.18
Hard clay	138	42.07	2.13
Grey fine sand	146	44.51	2.44
Grey M. F. sand	155	47.26	2.74
Clay	212	64.63	17.38
Clay +hard kankar	222	67.68	3.05
Gy. fine sand + pebbles	255	77.74	10.06
Grey M. F. sand	265	80.79	3.05
G.M.Crs sand + pebbles	287	87.50	6.71
Clay	308	93.90	6.40
Grey brown M. sand	315	96.04	2.13
Gy. fine medium sand	352	107.32	11.28
Gy. F. sand + sand stone	360	109.76	2.44
Gy. M. sand + sand stone	368	112.20	2.44
Clay	370	112.80	0.60

State Tube Well No. 24 **Village: Salempur Rajputana**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface clay	10	3.05	3.05
Brown fine sand	52	15.85	12.80
Clay	58	17.68	1.83
Grey fine sand	64	19.51	1.83
Clay + kankar	68	20.73	1.22
Grey fine sand	74	22.56	1.83
Clay	95	28.96	6.40
Brown fine sand	114	34.76	5.79
Clay	131	39.94	5.18
Grey fine sand	138	42.07	2.13
Clay	146	44.51	2.44
Grey M. F. sand	155	47.26	2.74
Grey fine sand	212	64.63	17.38
Clay + kankar	222	67.68	3.05
Brown fine sand	255	77.74	10.06
Gy. M. sand + sand stone	265	80.79	3.05
Brown fine sand	287	87.50	6.71

State Tube Well No. 25 **Village: Matlabpur**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface clay	7	2.13	2.13
Brown fine sand	17	5.18	3.05
Clay	107	32.62	27.44
Fine sand	150	45.73	13.11
Fine to medium sand	160	48.78	3.05
Clay	212	64.63	15.85
Medium sand + bolder	223	67.99	3.35
Clay	234	71.34	3.35
Fine to medium sand	269	82.01	10.67
Hard clay + kankar	291	88.72	6.71
Clay	306	93.29	4.57
Medium sand	312	95.12	1.83
Clay	340	103.66	8.54

State Tube Well No. 26 **Village: Saliyar**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Brown fine sand	21	6.40	6.40
Hard clay	43	13.11	6.71
Grey fine sand	55	16.77	3.66
Clay	78	23.78	7.01
Grey fine sand	90	27.44	3.66
Clay	116	35.37	7.93
Grey M. F. sand	136	41.46	6.10
Hard clay	166	50.61	9.15
Brown fine sand	172	52.44	1.83
Hard clay	243	74.09	21.65
Gy. F.sand+sand stone	288	87.80	13.72
Hard clay	310	94.51	6.71
Fine sand &clay	319	97.26	2.74
Clay	360	109.76	12.50
Clay +kankar	364	110.98	1.22
Brown fine sand	376	114.63	3.66
Clay	390	118.90	4.27

State Tube Well No. 27 **Village: Madhavpur**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Clay	40	12.20	12.20
Sticky Clay	52	15.85	3.66
Fine sand	60	18.29	2.44
Fine medium sand	75	22.87	4.57
Sticky Clay	106	32.32	9.45
Fine sand	110	33.54	1.22
Clay	170	51.83	18.29
Fine sand	175	53.35	1.52
Brown fine sand	187	57.01	3.66
Clay	226	68.90	11.89
Sticky clay	237	72.26	3.35
Fine sand	270	82.32	10.06
Clay	320	97.56	15.24
Hard sticky clay	337	102.74	5.18
Fine medium sand	368	112.20	9.45
Brown medium sand	380	115.85	3.66
Clay	395	120.43	4.57

State Tube Well No. 28 **Village: Nanhera Anantpur**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface clay	9	2.74	2.74
Clay	14	4.27	1.52
Grey fine sand	18	5.49	1.22
Clay	48	14.63	9.15
Brown fine sand	79	24.09	9.45
Gy.fine medium sand	93	28.35	4.27
Clay	98	29.88	1.52
Gy. F.sand + sand stone	105	32.01	2.13
Clay	117	35.67	3.66
Gy. F.sand + sand stone	138	42.07	6.40
Clay	272	82.93	40.85
Brown fine sand	298	90.85	7.93
Clay	336	102.44	11.59
Fine sand	347	105.79	3.35
Clay	362	110.37	4.57
B. F. sand + sand stone	378	115.24	4.88
Clay	390	118.90	3.66

State Tube Well No. 29 **Village: Karoundhi**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface sandy clay	6	1.83	1.83
Brown fine sand	17	5.18	3.35
Clay	98	29.88	24.70
Gy. fine medium sand	117	35.67	5.79
Clay	120	36.59	0.91
Grey medium sand	136	41.46	4.88
Kankar + sand stone	142	43.29	1.83
Clay	210	64.02	20.73
Brown fine sand	213	64.94	0.91
Hard clay	216	65.85	0.91
Clay	225	68.60	2.74
Kankar + sand stone	226	68.90	0.30
Clay	235	71.65	2.74
Grey fine sand + pebble	246	75.00	3.35
Clay	264	80.49	5.49
Grey fine sand	302	92.07	11.59
Sandy clay	307	93.60	1.52
Clay	340	103.66	10.06

State Tube Well No. 35 **Village: Manak Adampur**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface sandy clay	16	4.88	4.88
Clay	22	6.71	1.83
Very fine sand	28	8.54	1.83
Fine medium sand	38	11.59	3.05
Clay	43	13.11	1.52
Brown fine sand	49	14.94	1.83
Clay	54	16.46	1.52
Medium sand + sand stone	66	20.12	3.66
Clay	70	21.34	1.22
Grey M.f. sand + sand stone	92	28.05	6.71
Clay + kankar	135	41.16	13.11
Grey M.f. sand	166	50.61	9.45
Clay	171	52.13	1.52
Medium sand	185	56.40	4.27
Clay	215	65.55	9.15
Medium sand	262	79.88	14.33
Clay	286	87.20	7.32
Very fine sand	294	89.63	2.44
Clay	319	97.26	7.62

State Tube Well No. 36 **Village: Manak Adampur**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface sand	19	5.79	5.79
Brown fine sand	35	10.67	4.88
Clay	50	15.24	4.57
Grey Fine sand	65	19.82	4.57
Clay	88	26.83	7.01
Brown fine sand	98	29.88	3.05
Brown fine sand + kankar	110	33.54	3.66
Clay +kankar	125	38.11	4.57
Brown fine sand	150	45.73	7.62
Clay	158	48.17	2.44
Medium sand	180	54.88	6.71
Gy. M.sand + sand stone	185	56.40	1.52
Sand stone	204	62.20	5.79
Clay	212	64.63	2.44
Medium sand	226	68.90	4.27
Clay	250	76.22	7.32

State Tube Well No. 37 **Village: Hosangpur**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Brown medium sand	10	3.05	3.05
Hard clay	25	7.62	4.57
Fine sand	35	10.67	3.05
Hard clay	43	13.11	2.44
Grey medium sand	58	17.68	4.57
Clay	64	19.51	1.83
Medium sand	73	22.26	2.74
Hard clay	77	23.48	1.22
Clay + kankar	93	28.35	4.88
M. sand + sand stone	112	34.15	5.79
Hard clay	123	37.50	3.35
Medium sand	128	39.02	1.52
M. sand + sand stone	154	46.95	7.93
Clay	200	60.98	14.02
M. sand + sand stone	253	77.13	16.16
Clay	263	80.18	3.05

State Tube Well No. 38 **Village: Jabarhera**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Brown fine sand	5	1.52	1.52
Clay	40	12.20	10.67
Fine grey sand	98	29.88	17.68
Clay + kankar	103	31.40	1.52
Medium sand	113	34.45	3.05
Clay	123	37.50	3.05
Clay +kankar	143	43.60	6.10
Clay	155	47.26	3.66
Brown fine sand	175	53.35	6.10
Clay	188	57.32	3.96
Br. fine sand + kankar	200	60.98	3.66
Brown fine sand	220	67.07	6.10
Br. fine sand + kankar	245	74.70	7.62
Gy. M.sand+ sand stone	265	80.79	6.10
Medium sand + bajri	270	82.32	1.52
Clay	300	91.46	9.15

State Tube Well No. 39 **Village: Lodhipur**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface sandy clay	16	4.88	4.88
Clay	26	7.93	3.05
Fine medium sand	76	23.17	15.24
Clay	88	26.83	3.66
Fine grey sand	96	29.27	2.44
Medium grey sand	114	34.76	5.49
Clay	134	40.85	6.10
Fine grey sand	150	45.73	4.88
Clay	210	64.02	18.29
Brown fine sand	213	64.94	0.91
Fine medium sand	240	73.17	8.23
Medium sand	250	76.22	3.05
G M.F.sand + sand stone	280	85.37	9.15
Clay + kankar	300	91.46	6.10

State Tube Well No. 40 **Village: Padli Gujar**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface brown fine sand	20	6.10	6.10
Fine sand	30	9.15	3.05
Hard Clay + kankar	62	18.90	9.76
Fine sand	85	25.91	7.01
Clay	108	32.93	7.01
Fine sand + sand stone	140	42.68	9.76
Fine medium sand	159	48.48	5.79
Sticky Clay	185	56.40	7.93
Brown fine sand	205	62.50	6.10
Very fine brown sand	225	68.60	6.10
Fine medium sand	266	81.10	12.50
Hard sand stone	270	82.32	1.22
Medium sand	284	86.59	4.27
Clay + kankar	295	89.94	3.35

State Tube Well No. 41 **Village: Tanshipur**

Layer type:	Depth from G.L. (feet)	Depth from G.L. (m)	Thickness of layer (m)
Surface clay	10	3.05	3.05
Brown fine medium sand	35	10.67	7.62
Clay	54	16.46	5.79
Grey fine sand	71	21.65	5.18
Clay	95	28.96	7.32
Grey F. sand + sand stone	157	47.87	18.90
Clay	183	55.79	7.93
Grey fine sand	213	64.94	9.15
Brown fine sand	217	66.16	1.22
Grey brown fine sand	244	74.39	8.23
Clay	246	75.00	0.61
Grey medium sand	255	77.74	2.74
Grey medium fine sand	262	79.88	2.13
G M.F sand + sand stone	284	86.59	6.71
Grey M. sand + pebbles	293	89.33	2.74
Clay + kankar	300	91.46	2.13

State Tube Well No. 42 **Village: Salahpur**

Layer type:	Depth from G.L. (feet)	Depth from G.L. (m)	Thickness of layer (m)
Surface brown sand	28	8.54	8.54
Medium sand	38	11.59	3.05
Grey medium sand	44	13.41	1.83
Clay	46	14.02	0.61
Fine medium sand	55	16.77	2.74
Clay	64	19.51	2.74
M. sand + sand stone	80	24.39	4.88
Clay	106	32.32	7.93
Fine medium sand	120	36.59	4.27
Fine sand	135	41.16	4.57
Very hard clay	150	45.73	4.57
Medium brown sand	163	49.70	3.96
Medium brown fine sand	186	56.71	7.01
Grey fine medium sand	222	67.68	10.98
Sand stone + pebbles	236	71.95	4.27
Grey medium sand	265	80.79	8.84
Sand + sand stone	270	82.32	1.52

State Tube Well No.44 **Village: Ikbalpur Nanhera**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Clay	25	7.62	7.62
Fine sand	30	9.15	1.52
Clay	40	12.20	3.05
Fine sand	45	13.72	1.52
Hard clay	70	21.34	7.62
Fine sand	95	28.96	7.62
Clay	105	32.01	3.05
Medium coarse sand	120	36.59	4.57
Clay	160	48.78	12.20
Fine sand	170	51.83	3.05
Clay	220	67.07	15.24
Brown fine sand	230	70.12	3.05
Clay	238	72.56	2.44
Medium sand	260	79.27	6.71
Hard clay	337	102.74	23.48
Medium sand	386	117.68	14.94
Clay	393	119.82	2.13
Medium sand	400	121.95	2.13
Medium sand + bajri	425	129.57	7.62
Medium sand	450	137.20	7.62
Fine sand	460	140.24	3.05

State Tube Well No.52 **Village: Delna**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface clay	10	3.05	3.05
Sandy Clay	30	9.15	6.10
Hard clay	36	10.98	1.83
Fine sand	40	12.20	1.22
Hard clay	50	15.24	3.05
Grey medium sand	70	21.34	6.10
Hard clay	95	28.96	7.62
Medium sand	120	36.59	7.62
Hard clay	140	42.68	6.10
Fine to medium sand	155	47.26	4.57
Hard clay	200	60.98	13.72
Fine to medium sand	214	65.24	4.27
Hard clay	220	67.07	1.83
Medium sand	250	76.22	9.15
Hard clay	268	81.71	5.49
Medium sand	290	88.41	6.71
Hard clay	310	94.51	6.10

State Tube Well No.53 **Village: Harchandpur**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface clay	10	3.05	3.05
Fine sand	20	6.10	3.05
Clay	40	12.20	6.10
Fine sand + kankar	70	21.34	9.15
Fine to medium sand	80	24.39	3.05
Clay + kankar	85	25.91	1.52
Medium sand	117	35.67	9.76
Hard clay	140	42.68	7.01
Medium sand	160	48.78	6.10
B.Medium sand+sand stone	175	53.35	4.57
Hard clay	190	57.93	4.57
Brown medium sand	202	61.59	3.66
Hard caving clay	235	71.65	10.06
Medium sand + sand stone	261	79.57	7.93
Caving clay	325	99.09	19.51
Medium sand + sand stone	370	112.80	13.72
Fine sand	375	114.33	1.52
Hard clay	390	118.90	4.57

State Tube Well No.54 **Village: Balailpur Paniala**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface clay	10	3.05	3.05
Sandy Clay	50	15.24	12.20
Fine sand	60	18.29	3.05
Sandy Clay	70	21.34	3.05
Fine to medium sand	80	24.39	3.05
Hard clay	95	28.96	4.57
Fine sand	110	33.54	4.57
Hard clay +kankar	138	42.07	8.54
Fine to medium sand	173	52.74	10.67
Caving clay	196	59.76	7.01
Fine to medium sand	224	68.29	8.54
Hard clay	235	71.65	3.35
Fine to medium sand	264	80.49	8.84
Caving clay	308	93.90	13.41
F M. sand + sand stone	344	104.88	10.98
Clay	370	112.80	7.93

State Tube Well No.55 **Village: Kharkhar Boyal**

Layer type:	Depth from G.L.		Thickness of layer
	(feet)	(m)	(m)
Surface clay	12	3.66	3.66
Fine sand	30	9.15	5.49
Hard clay	40	12.20	3.05
Fine to medium sand	104	31.71	19.51
Hard clay	128	39.02	7.32
Fine sand	160	48.78	9.76
Hard clay	170	51.83	3.05
Fine sand	184	56.10	4.27
Hard clay	194	59.15	3.05
Brown fine sand	210	64.02	4.88
Clay +kankar	217	66.16	2.13
Medium sand + sand stone	252	76.83	10.67
Sandy clay + kankar	268	81.71	4.88
Medium sand	290	88.41	6.71
Hard clay	300	91.46	3.05
Medium sand + sand stone	360	109.76	18.29