Gas Processing, LPG Recovery Plant and Allied Facilities at Nashpa Field

Surface Hydrology Using Climatological Data and Site Topography

(Report)

Geotechnical Investigation & Survey of Gas Processing, LPG Recovery Plant and Allied Facilities at NASHPA Oil Field

March 2016

Zealcon Engineering (Pvt) Ltd.

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SURFACE HYDROLOGY USING CLIMATOLOGICAL DATA AND SITE TOPOGRAPHY REPORT

ABSTRACT

Hydrological data using the site topography and other studies have been mentioned in detail for reference of high flood levels observed near to project area. The resistivity survey was carried out by using vertical electrical sounding (VES) techniques in the Nashpa area, Kohat (KPK). Wenner method is used to collect subsurface hydrological data and then processed in software IPI2win. Seven VES points have been studied in this site. Geologically the alternate cyclic deposit is present which are Shale/Clay and Sandstone.

Seven sounding points have been selected for study. Field resistivity data which is collected from the site based on wenner technique to study subsurface hydrological conditions of the project area.

It is concluded that there is no hydrological subsurface body up to studied depth 20m.

NASHPA GAS PROCESSING AND LPG RECOVERY PLANT

SURFACE HYDROLOGY USING CLIMATOLOGICAL DATA AND SITE TOPOGRAPHY REPORT

1.0 BACKGROUND AND PURPOSE

M/S HBP awarded the assignment of conducting study of Hydrology at NASHPA Gas Processing & LPG Recovery Plant to M/S ZEALCON ENGINEERING.

This report furnishes the hydrological studies and the results of electrical resistivity survey conducted at seven (7) sounding points in the presence of client and consultant's representatives by M/s ZEALCON ENGINEERING.

2.0 SURFACE HYDROLOGY STUDIES:-

2.1 Feasibility of the Project:-

The feasibility of the project comprises a number of factors. The main factor is that it must be treated at safe place against seismic and flood effects. If so then, the design is made for this project which can bear such impact upto its limit of safety. The designer will propose the project site free of both the above mentioned factors or otherwise will devise the design against the damaging phenomenon mentioned above. Herein, the seismic phenomenon is out of scope of this work whereas hydrology & morphology of the area are briefly discussed for the first hand knowledge of the designer.

2.2 Hydrology of the project area:-

The project site is located well away from high bank of Indus River at a distance of 15 km in District Karak, KPK. The affecting streams in the proximity of the project site are Indus river flood heights downstream of khushal khan khattak bridge. In addition to the Indus river, the main hill torrents prevail nearby the project site namely Kohat Toi river and Terri Toi River.

The Indus river in this area propagates in between two defined high bank with bolder bed configuration. The doubt of meandering phenomenon at the project site is ceased to exist. However, flood heights may affect the project site. The flood height should be known to the designer.

The ever highest flood level appeared at bridge on 27.07.1929 as R.L 802.32’(amsl) with bed level of the river as R.L 780’(amsl). The Positioning of the project can be compared w.r.t the river data information. Similarly, the main hill torrents propagate towards the right bank of the river viz. Kohat Toi and Terri Toi Rivers. The length of Kohat river is about 94 miles with its catchment area as 1276 sq. miles. The average slope of the river is as 86.9’/mile with its highest altitude 1647’.

Similarly, the length of Terri River is as 86 miles with an average slope as 22.4’/mile along with its catchment area as 671 sq. miles. The highest altitude of Terri Catchment area is as 2212’.

The project is to be treated keeping in view the above hydrological and morphological information.

3.0 SUB SURFACE HYDROLOGICAL STUDIES:-

For this study the results of ERS have been used. The purpose of soil resistivity measurements was to determine the electrical resistivity of the subsurface material upto the depth of 20 meters.

Electrical resistivity measurements would be required by using Wenner Electrodes Configuration in accordance with ASTM Designation G57. At each sounding point the resistivity readings were to be taken at electrode spacing of 1, 3, 5, 7, 10, 15 and 20 meters. The results of the survey would be presented in the form of apparent resistivity of the subsurface material. Such information was required in connection with the designing of "Earthing System" for the electrical installations at project site.

The electrical resistivity sounding points are designated as S-01 to S-07. The field resistivity data of all the sounding points along with their apparent resistivity (ohm-m) VS electrode spacing a (m) curves are given in Annexure-1 of the report. The field work for electrical resistivity survey has been done on March 3, 2016.

Figure 1: location of the survey area for the for the subsurface water study.

3.1 METHODOLOGY

3.1.1 Theory

Electrical Resistivity Imaging (ERI) is an active geophysical method which measures the electric potential differences at specific locations while injecting a controlled electric current at other locations [2]. The theory of the method holds that in an entirely homogeneous half-space, a resistivity value can be calculated for the subsurface by knowing the current injected, and measuring the resulting electric potential at specific locations. However, homogeneity within the subsurface is very rare and electric current, when introduced, will follow the path of least resistance, concentrating in areas of conductive material and avoiding areas of resistive material. Figure 2 illustrates the concept of subsurface electric current flow and how current flow is affected by subsurface heterogeneities.

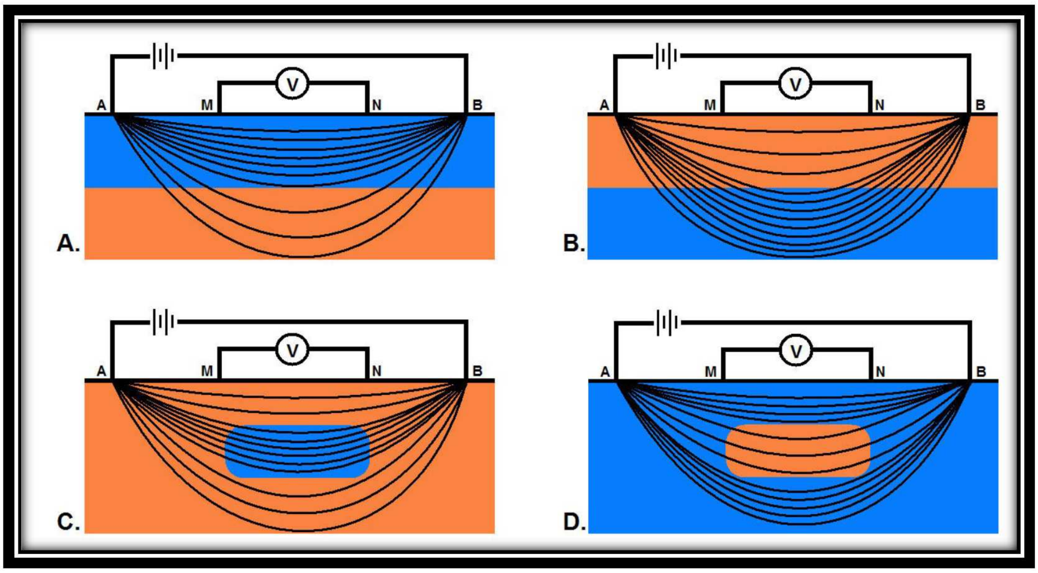

Figure 2: Variations in subsurface electric current density will occur with variations in earth resistivity.

Resistivity of the earth have changed with the change in densities of the subsurface. In all images the blue material is more conductive than the orange material. In image **A** the majority of the electrical current flows close to the surface, in the more conductive layer, leaving very little current flow to penetrate the resistive layer at depth. In image **B** the electrical current is drawn to the more conductive layer at depth. In image **C** the current flow lines merge to concentrate through the conductive anomaly at the center of the survey. In image **D** the current flow lines diverge away from the resistive anomaly at the center of the survey area.

Ohm's Law describes electric current flow through a resistive material (equation 1). The basic concept of the law relates electric current (I) flowing through a resistor to the voltage (V) applied across the resistor and the conductance of that resistor. The inverse quantity of electrical conductance is electrical resistance (R).

$$I = V/R \text{--} (1)$$

Electrical resistance is not a physical material property, but electrical resistivity is a physical material property. Electrical resistance defines the opposition to the flow of electric current through a defined volume of material. This is best explained by imagining electrical current flow through a wire. The *resistivity* of the wire would be a specific value determined by the wire's material composition (e.g. copper). However, the wire's *resistance* would change based on the length and thickness (gauge) of the wire. Figure 3 illustrates the difference between resistance and resistivity for a length of wire, and the mathematical relationship between the two concepts.

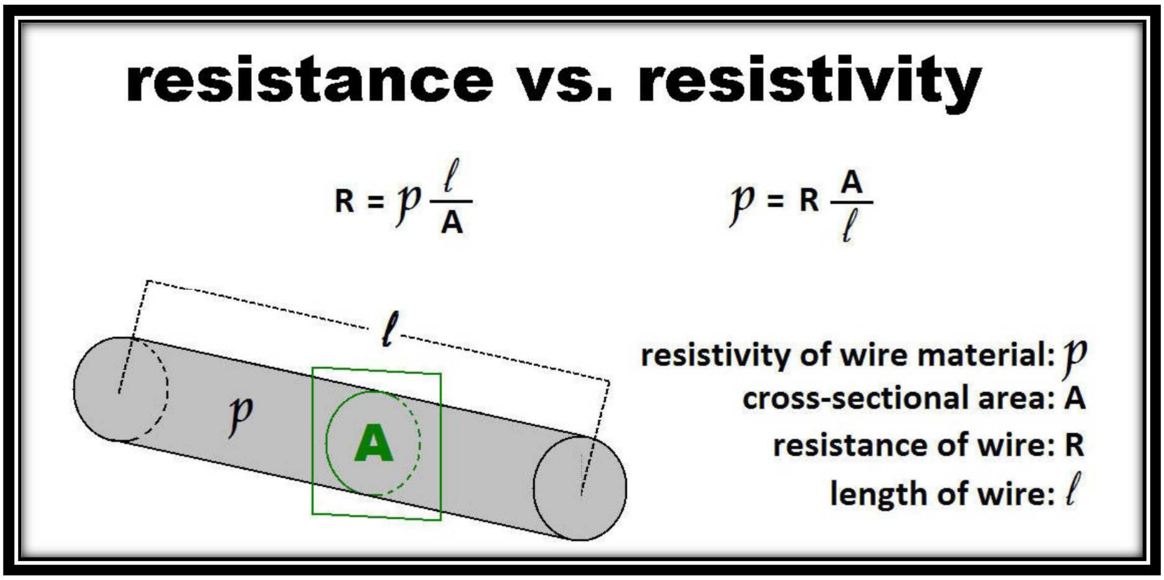

Figure 3: The relationship between resistance and resistivity.

By substituting resistivity (ρ) into the equation for resistance (R), Ohm's Law can be rewritten (equation 2) in a format that takes a material's volume into considerations by defining that volume's cross-sectional area (A) and length (l).

$$\rho = A/l \times V/I \text{--(2)}$$

ERI aims to model the electrical resistivity structure of some volume of the earth. From each ERI measurement, information is gained about the average electrical resistance of a certain volume in the subsurface [3]. Variations in electrical properties of subsurface materials make determination a true electrical resistivity model of those materials nearly impossible [3]. Instead, the immediate quantity calculated from an ERI survey is known as apparent resistivity (ρa). Apparent resistivity can be thought of as a weighted average of all the true material resistivities in the vicinity of the measurement. Apparent resistivity is calculated using both current injected and electric potential measured, but also includes a term that accounts for the relative positions of the current injection and potential measurement electrodes, known as the geometric factor (K). The geometric factor in ERI data processing can be compared conceptually to the wire's length and gauge in Figure 3 which relates resistance and resistivity in a three dimensional space. By adapting Ohm's law to account for the conditions specific to ERI surveys, the basic equation of apparent resistivity can be derived (equation 3).

$$\rho_a = K \times V/I \quad (3)$$

ERI surveys are sometimes called a four-pin resistivity survey. This is because a minimum of four electrodes are necessary for data acquisition. Two electrodes are used for current injection and two electrodes are used for measurement of electric potential. The four electrodes can be placed in a variety of configurations, or arrays. Each array has a specific geometric factor. Figure 4 illustrates the basic formula for determining the geometric factor of any array [3]. By convention, and throughout the rest of this TM, current injection electrodes will be referred to as "A" and "B" while potential measurement electrodes will be referred to as "M" and "N". Figure 4 illustrates an arbitrary electrode layout, or electrodes which are not placed in a standard ERI array. However, most ERI surveys are conducted using one of the conventionally defined electrode arrays. These arrays are typically linear, especially for two dimensional profiling surveys. The advantage of using consistent and defined arrays is that the calculation of geometric factor can be simplified. With a simplified and constant geometric factor, calculation of the apparent resistivity for each measurement in a large data set can be accomplished more efficiently.

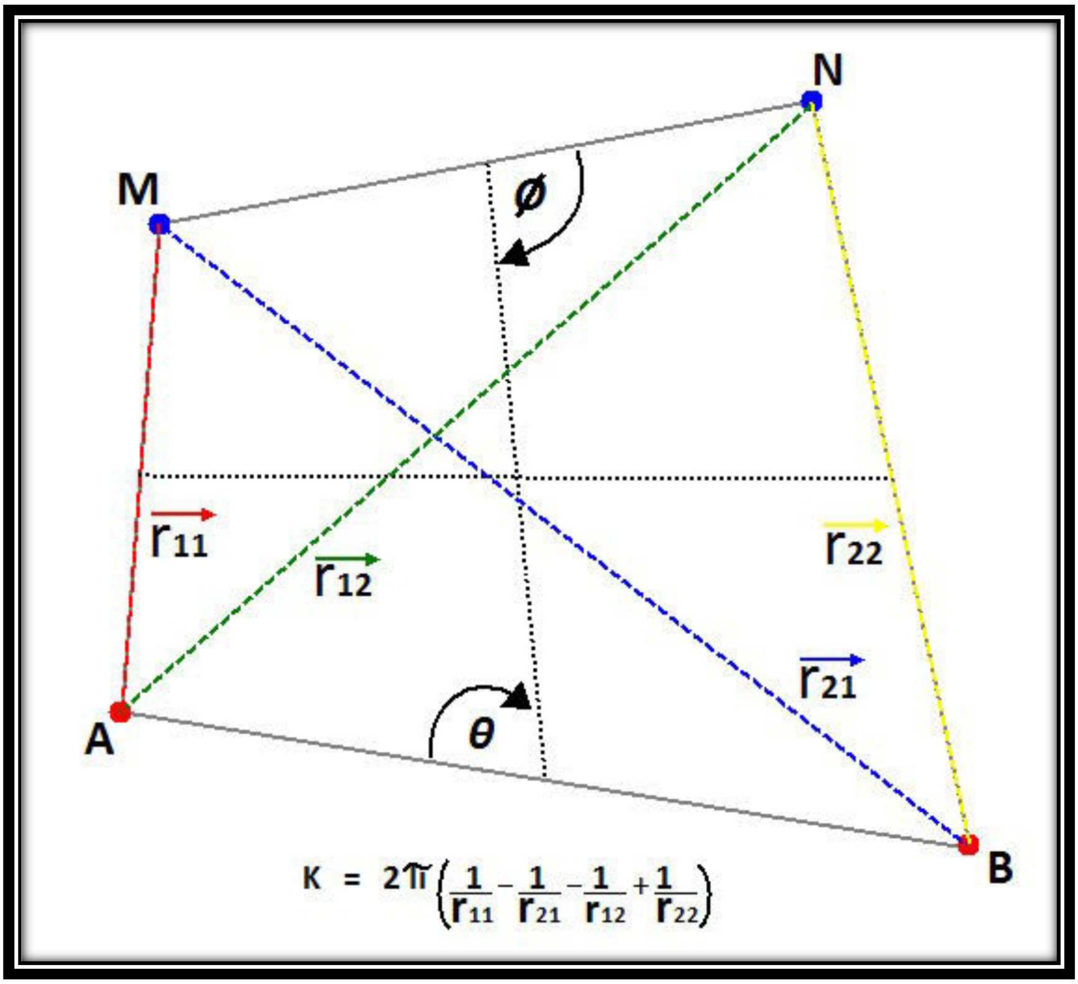

Figure 4: An illustration of the concept of the geometric factor (K) which is used to calculate apparent resistivity values from measurements of an ERI survey. The geometric factor can be determined for any possible ERI array, as long as the electrode locations are known. Here is an arbitrary layout of two current injection electrodes (red) and two potential measurement electrodes (blue).

3.1.2 Corrosion Potential Classification

Though corrosion of metal embedded in the soil generally not as rapid as in atmosphere or underwater, yet I present problems of sizeable magnitude. Factors governing corrosion by soil include its (i) Oxygen content (ii) moisture content (iii) hydrogen ion concentration (iv) electrical conduction (v) particle size (vi) drainage (vii) bacterial process activity etc.

In the case of pipeline corrosion, the concentration of electrolytic cells, formed due to localized difference in the physical and chemical characteristics of the soil coming in contact with the pipe, could lead to localized attack. Similarly soil water and groundwater attack metals to a degree, which depends upon the nature and concentration of various salts present in the water.

Soils are generally assigned one of the following classes of corrosivity.

- Soils with very low corrosivity for steel and iron generally include somewhat excessively drained coarse textured soils that have little clay, water and air move through these soils rapidly. Electrical resistivity of such soils at natural moisture content is above 100 ohm-meters.
- Soils with low corrosivity for steel and iron generally include well drained soils that have a coarse to medium texture. These soils are moderately permeable. The electrical resistivity of such soils is 50 to 100 ohm-meters.
- Soils with moderate corrosivity for the steel and iron generally include well drained soil that have medium to fine texture. Electrical resistivity of these soils varies between 20 to 50 ohm-meters.
- Soil with high corrosivity for steel and iron generally include moderately well drained fine textured soils. Very poorly drained soils are included when the water table fluctuates within 30 centimeters at some time during the year. Electrical resistivity of these soils at natural moisture equivalent is 10 to 20 ohm-meters.

Table 1. Resistivities of some common rocks, minerals and chemicals.

MATERIAL	Resistivity (Ω•m)	Conductivity (Siemen/m)
IGNEOUS & METAMORPHIC ROCKS		
Granite	$5x10^{3}$ - 10^{6}	10^{-6} - $2x10^{-4}$
Basalt	10^{3} - 10^{6}	10^{-6} - 10^{-3}
Slate	$6x10^{2}$ - $4x10^{7}$	$2.5x10^{-8}$ - $1.7x10^{-3}$
Marble	10^{2} - $2.5x10^{8}$	$4x10^{-9}$ - 10^{-2}
Quartzite	10^{2} - $2x10^{8}$	$5x10^{-9}$ - 10^{-2}
SEDIMENTARY ROCKS		
Sandstone	8 - $4x10^{3}$	$2.5x10^{-4}$ - 0.125
Shale	20 - $2x10^{3}$	$5x10^{-4}$ - 0.05
Limestone	50 - $4x10^{2}$	$2.5x10^{-3}$ - 0.02
SOILS AND WATERS		
Clay	1 - 100	0.01 - 1
Alluvium	10 - 800	$1.25 x10^{-3}$ - 0.1
Groundwater (fresh)	10 - 100	0.01 - 0.1
Sea water	0.2	5
CHEMICALS		
Iron	$9.074x10^{-8}$	$1.102x10^{7}$
0.01 M Potassium chloride	0.708	1.413
0.01 M Sodium chloride	0.843	1.185
0.01 M acetic acid	6.13	0.163
Xylene	$6.998x10^{16}$	$1.429x10^{-17}$

3.1.3 Data Acquisition

There are three geophysical techniques which are used to study subsurface hydrological condition of the area. In this study wenner method is used.

Figure 5 illustrates the Wenner array types and their respective geometric factors.

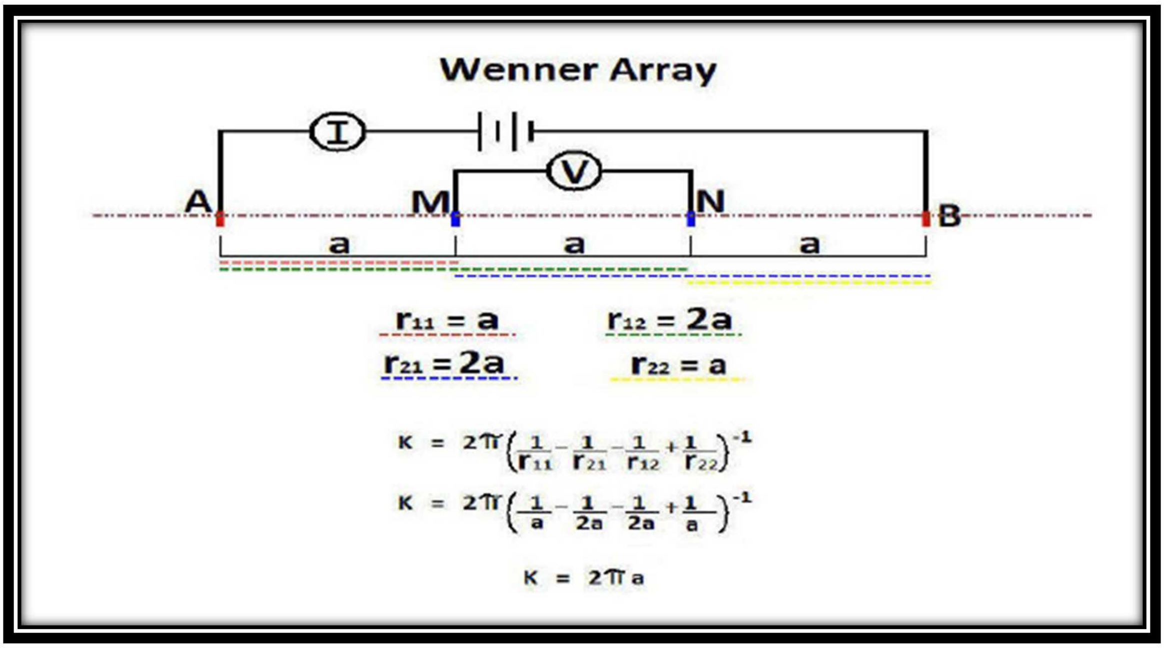

Figure 5: Illustration of the Wenner method of data acquisition.

The Wenner and Schlumberger arrays are generally known to have good signal strength, because the electric potential measurement electrodes are located between the current injection electrodes [4]. The time for data collection, as well as data processing is generally greater for ERI data collected with the Wenner array.

3.1.3.1 Field Procedure

Fully calibrated resistivity-measuring equipment was used to measure directly the resistance R at each electrode spacing using Wenner Configuration. In the case of Wenner array, all the four electrodes are placed at equal distance apart in a straight line symmetrically from the centre point C. The two outer electrodes A & B are used for passing current into the ground and the resulting potential difference is measured across the inner change by more than a factor of 10. This makes the resistivity and other electrical or electromagnetic based methods very versatile geophysical techniques.

3.2 DATA PROCESSING AND INTERPRETATION

There are two coupled techniques in geophysical data processing and interpretation known as inversion and forward modeling. In order to perform one process, the other process must also be performed. Therefore, the theoretical basis of the two techniques is best understood when presented concurrently.

Data processing for the Nashpa hydrological Study involved the technique of data inversion, and interpretation of the inversion results were aided by the use of forward modeling. Both techniques aim to create an accurate model of a physical property in the earth's subsurface. Inversion is a mathematical process very common in geophysics by which collected data of one parameter or more is used to formulate a model of the physical parameter of interest. The collected data and the model parameter must have some type of physical relation. In inverse and forward problems, there is a mathematical relationship that links the measured quantities (data) to the quantities of interest [5]. In the inversion process a generic model is generated, and through the forward modeling process a synthetic data set is calculated. The collected and calculated data sets are compared for equivalency. If the collected data and the calculated synthetic data sets do not agree, the model is altered and another forward model is performed. Each time a new synthetic data set is calculated and compared to a collected data set, it known as an iteration of the inversion. In the case of the ERI geophysical method, inversion of measured voltages creates a model of earth resistivity. An important factor for the inversion of this data was the manner in which the model was determined. These inversions used a finite element model, which involved dividing the subsurface into cells, or blocks, and determining the earth resistivity value of each cell [5].

The initial model for each file inversion consisted of a homogeneous media with a resistivity value equal to the average resistivity of all data points in the file. The initial models also begin with the correct surface topography defined. The resistivity value of each cell in the model was systematically adjusted until the model accurately reflected the collected data. Each time the resistivity values of cells in the model are altered and to the inversion of geophysical data is a computationally-intensive process, involving numerous iterations and subsequent model adjustments. The specifics of inversion theory are numerous and multi-faceted, and are discussed in detail in the research literature for this topic [5].

4.0 RESULTS AND INTERPRETATION

Seven sounding points have been studied by wenner method up to 20m depth. Resistivity values showed that top 5m layer is clay than we have sand stone. There is no evidence of water up to studied depth.

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Appendix A

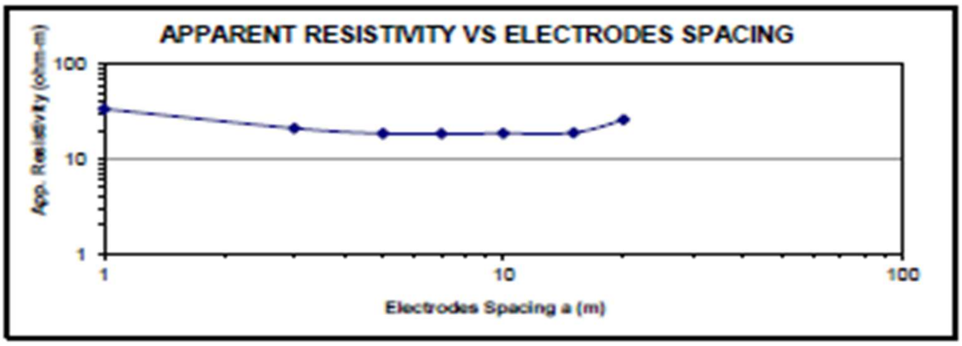
ERS Survey Data Inversion Results

This Appendix contains images of the processed ERI data inversions for the Santee Aquifer Basin Recharge Study. All data presented in this appendix was collected using a Wenner array, filtered and processed as detailed of this TM. The plots are titled and ordered according to data file numbers, please refer to the figure A1 for positional locations of data files. Figure A2 details important features of the plots in this appendix, with the description for figure A2 occurring on page A-3.**Sounding # S1**

IN-SITU ELECTRICAL RESISTIVITY MEASUREMENTS OF SOIL

Project: NASHPA Gas Processing & LPG Recovery Plant	Sounding #: S-1
Client: OGDCL	Date: 03-03-2016
Location: NASHPA	Coordinates: 714756 E, 3683041 N
Weather Conditions: Fair	
Soil Conditions: Dry	Configuration: Wenner

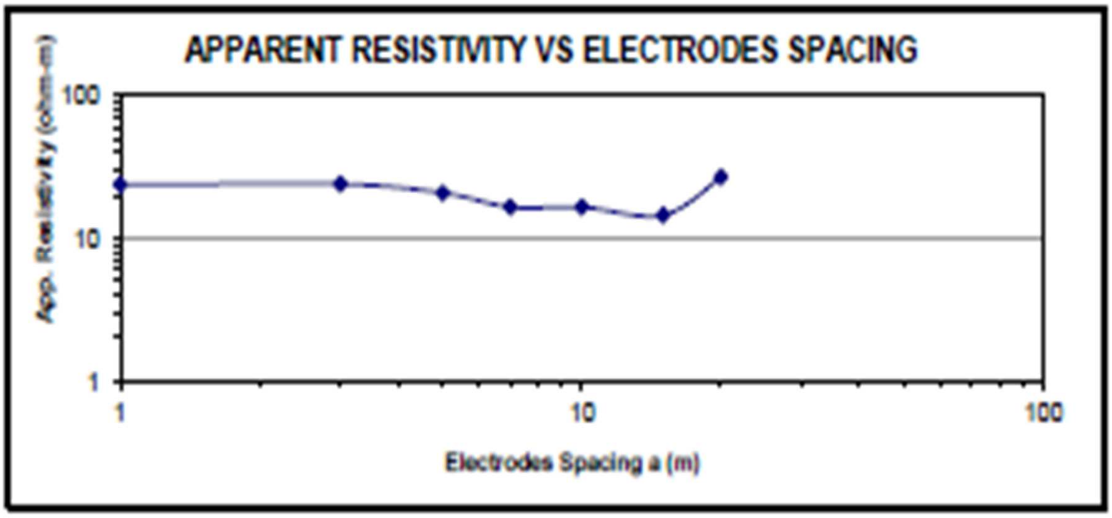
Sr. #	Space a(m)	Inside a/2 (m)	Outside 3a/2	K=2πa	P (mV)	C (mA)	R (Ω)	ρ (ohm-m)
1	1	0.50	1.50	6.28	45.96	8.56	5.37	33.72
2	3	1.50	4.50	18.84	12.52	11.22	1.12	21.02
3	5	2.50	7.50	31.40	9.10	15.47	0.59	18.48
4	7	3.50	10.50	43.96	4.47	10.69	0.42	18.40
5	10	5.00	15.00	62.80	2.46	8.30	0.30	18.58
6	15	7.50	22.50	94.20	1.54	7.66	0.20	18.89
7	20	10.00	30.00	125.60	1.70	8.24	0.21	25.89



IN-SITU ELECTRICAL RESISTIVITY MEASUREMENTS OF SOIL

Project: NASHPA Gas Processing & LPG Recovery Plant	Sounding #: S-2
Client: OGDCL	Date: 03-03-2016
Location: NASHPA	Coordinates: 714833 E, 3683055 N
Weather Conditions: Fair	
Soil Conditions: Dry	Configuration: Wenner

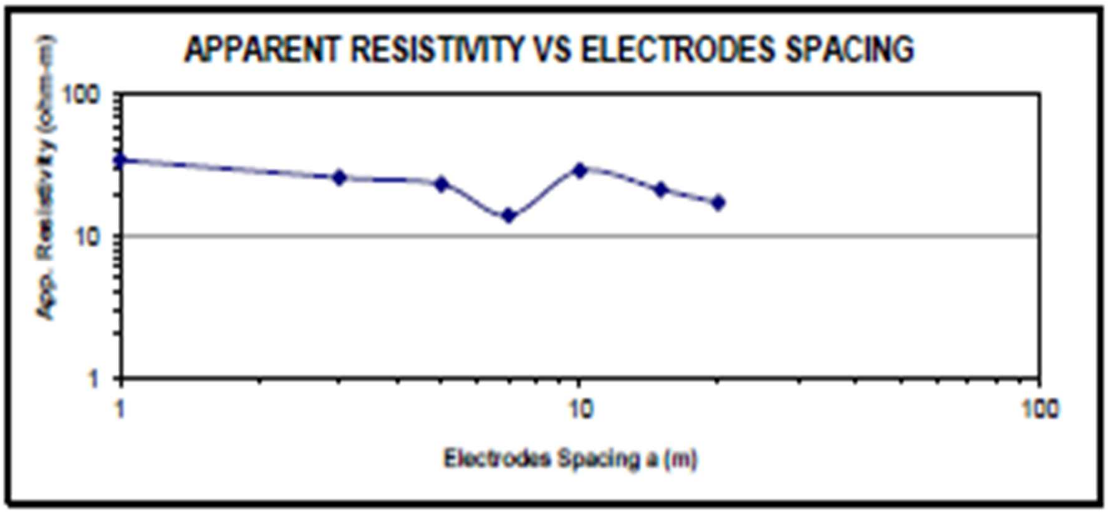
Sr. #	Space a(m)	Inside a/2 (m)	Outside 3a/2	K=2πa	P (mV)	C (mA)	R (Ω)	ρ (ohm-m)
1	1	0.50	1.50	6.28	31.87	8.44	3.78	23.71
2	3	1.50	4.50	18.84	23.90	18.80	1.27	23.95
3	5	2.50	7.50	31.40	7.43	11.22	0.66	20.78
4	7	3.50	10.50	43.96	3.87	10.29	0.38	16.53
5	10	5.00	15.00	62.80	2.94	11.21	0.26	16.49
6	15	7.50	22.50	94.20	1.69	10.98	0.15	14.51
7	20	10.00	30.00	125.60	1.69	7.96	0.21	26.74



IN-SITU ELECTRICAL RESISTIVITY MEASUREMENTS OF SOIL

Project: NASHPA Gas Processing & LPG Recovery Plant	Sounding #: S-3
Client: OGDCL	Date: 03-03-2016
Location: NASHPA	Coordinates: 714738 E, 3683094 N
Weather Conditions: Fair	
Soil Conditions: Dry	Configuration: Wenner

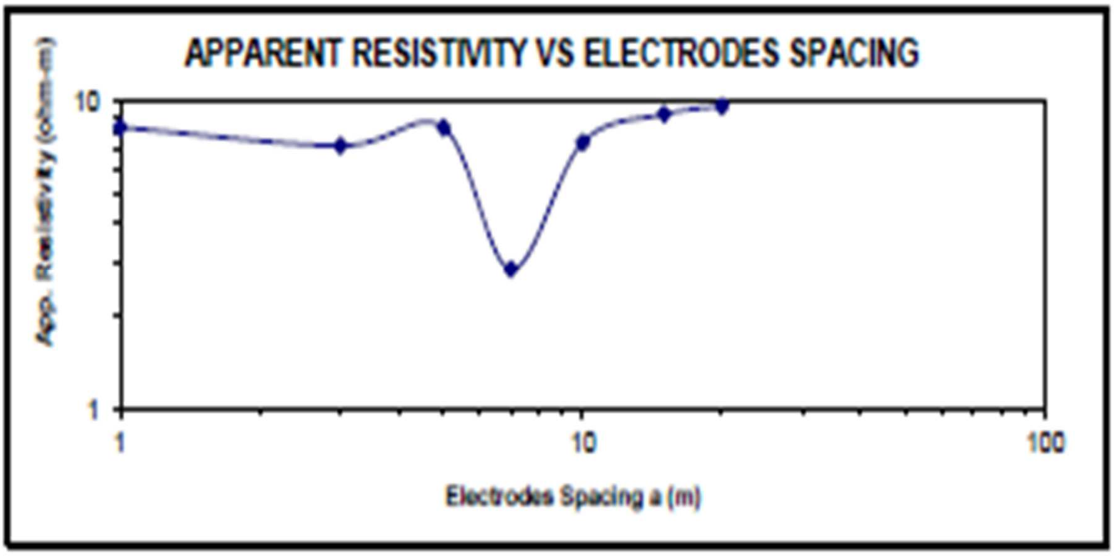
Sr. #	Space a(m)	Inside a/2 (m)	Outside 3a/2	K=2πa	P (mV)	C (mA)	R (Ω)	ρ (ohm-m)
1	1	0.50	1.50	6.28	61.79	11.28	5.48	34.40
2	3	1.50	4.50	18.84	13.95	10.15	1.37	25.90
3	5	2.50	7.50	31.40	8.68	11.76	0.74	23.18
4	7	3.50	10.50	43.96	2.77	8.72	0.32	13.96
5	10	5.00	15.00	62.80	4.22	9.14	0.46	28.99
6	15	7.50	22.50	94.20	2.33	10.31	0.23	21.26
7	20	10.00	30.00	125.60	1.80	13.16	0.14	17.18



IN-SITU ELECTRICAL RESISTIVITY MEASUREMENTS OF SOIL

Project: NASHPA Gas Processing & LPG Recovery Plant		Sounding #: S-4
Client: OGDCL		Date: 03-03-2016
Location: NASHPA	Coordinates: 714800 E, 3683231 N	
Weather Conditions: Fair		
Soil Conditions: Dry		Configuration: Wenner

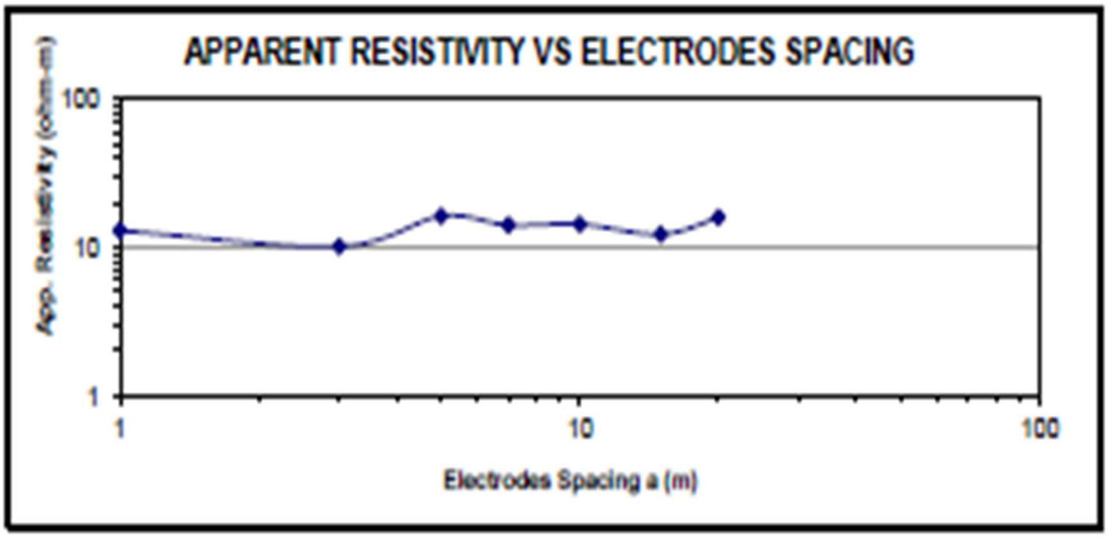
Sr. #	Space a(m)	Inside a/2 (m)	Outside 3a/2	K=2πa	P (mV)	C (mA)	R (Ω)	ρ (ohm-m)
1	1	0.50	1.50	6.28	205.63	11.28	18.23	8.26
2	3	1.50	4.50	18.84	319.52	10.15	31.48	7.19
3	5	2.50	7.50	31.40	274.13	11.76	23.31	8.24
4	7	3.50	10.50	43.96	144.93	8.72	16.62	2.83
5	10	5.00	15.00	62.80	253.36	9.14	27.72	7.38
6	15	7.50	22.50	94.20	82.27	10.31	7.98	9.12
7	20	10.00	30.00	125.60	137.65	13.16	10.46	9.68



IN-SITU ELECTRICAL RESISTIVITY MEASUREMENTS OF SOIL

Project: NASHPA Gas Processing & LPG Recovery Plant	Sounding #: S-5
Client: OGDCL	Date: 03-03-2016
Location: NASHPA	Coordinates: 714959 E, 3683385 N
Weather Conditions: Fair	
Soil Conditions: Dry	Configuration: Wenner

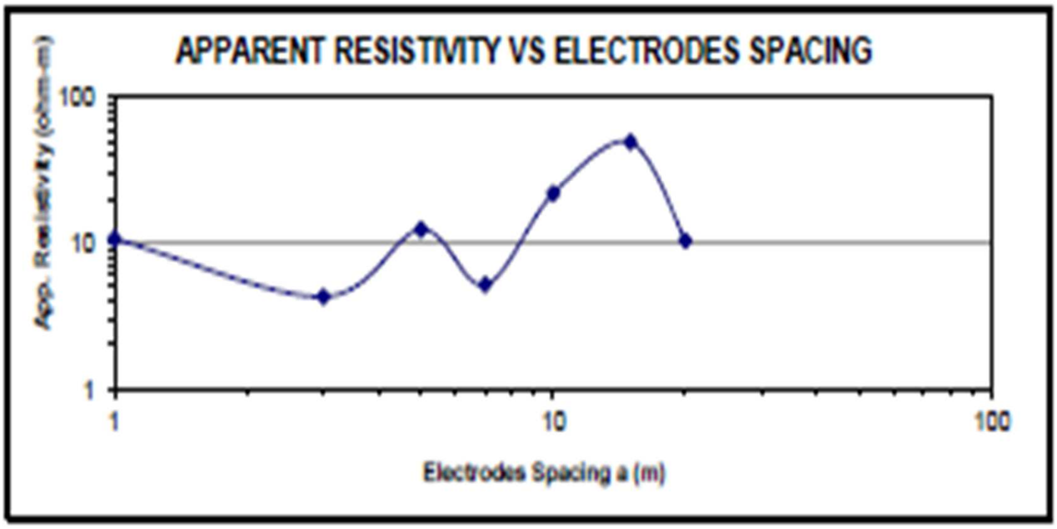
Sr. #	Space a(m)	Inside a/2 (m)	Outside 3a/2	K=2πa	P (mV)	C (mA)	R (Ω)	ρ (ohm-m)
1	1	0.50	1.50	6.28	215.34	11.28	19.09	12.92
2	3	1.50	4.50	18.84	61.10	10.15	6.02	10.11
3	5	2.50	7.50	31.40	214.62	11.76	18.25	16.21
4	7	3.50	10.50	43.96	370.08	8.72	42.44	14.10
5	10	5.00	15.00	62.80	93.32	9.14	10.21	14.29
6	15	7.50	22.50	94.20	156.40	10.31	15.17	12.21
7	20	10.00	30.00	125.60	68.43	13.16	5.20	15.91



IN-SITU ELECTRICAL RESISTIVITY MEASUREMENTS OF SOIL

Project: NASHPA Gas Processing & LPG Recovery Plant	Sounding #: S-6
Client: OGDCL	Date: 03-03-2016
Location: NASHPA	Coordinates: 714761 E, 3683543 N
Weather Conditions: Fair	
Soil Conditions: Dry	Configuration: Wenner

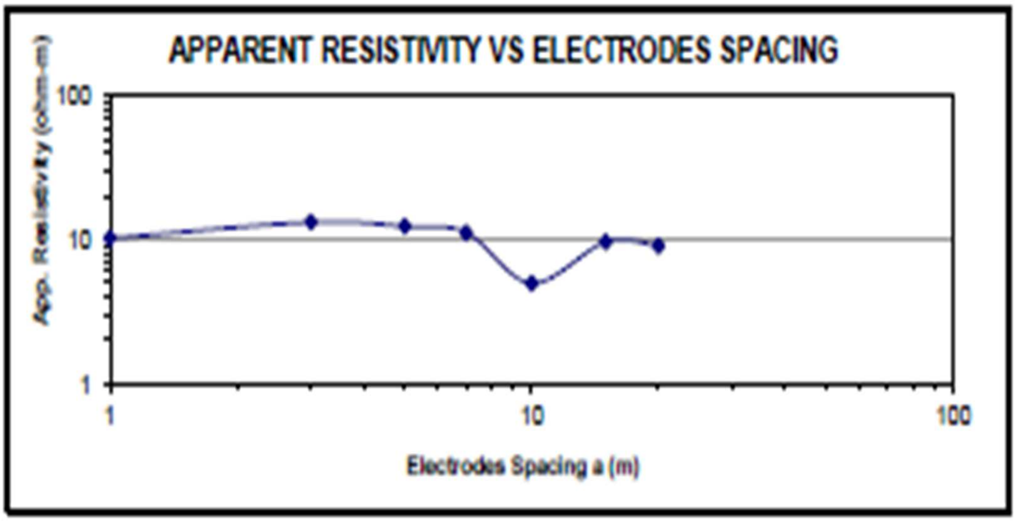
Sr. #	Space a(m)	Inside a/2 (m)	Outside 3a/2	K=2πa	P (mV)	C (mA)	R (Ω)	ρ (ohm-m)
1	1	0.50	1.50	6.28	32.63	19.35	1.69	10.59
2	3	1.50	4.50	18.84	2.77	12.28	0.23	4.25
3	5	2.50	7.50	31.40	4.94	12.66	0.39	12.25
4	7	3.50	10.50	43.96	0.61	5.23	0.12	5.12
5	10	5.00	15.00	62.80	0.51	1.47	0.34	21.65
6	15	7.50	22.50	94.20	0.59	1.14	0.52	49.00
7	20	10.00	30.00	125.60	0.22	2.69	0.08	10.28



IN-SITU ELECTRICAL RESISTIVITY MEASUREMENTS OF SOIL

Project: NASHPA Gas Processing & LPG Recovery Plant	Sounding #: S-7
Client: OGDCL	Date: 03-03-2016
Location: NASHPA	Coordinates: 715145 E, 3683479 N
Weather Conditions: Fair	
Soil Conditions: Dry	Configuration: Wenner

Sr. #	Space a(m)	Inside a/2 (m)	Outside 3a/2	K=2πa	P (mV)	C (mA)	R (Ω)	ρ (ohm-m)
1	1	0.50	1.50	6.28	15.62	9.69	1.61	10.12
2	3	1.50	4.50	18.84	3.09	4.44	0.70	13.11
3	5	2.50	7.50	31.40	3.43	8.79	0.39	12.26
4	7	3.50	10.50	43.96	2.64	10.49	0.25	11.07
5	10	5.00	15.00	62.80	0.18	2.28	0.08	4.93
6	15	7.50	22.50	94.20	0.37	3.69	0.10	9.56
7	20	10.00	30.00	125.60	0.54	7.51	0.07	8.95



Appendix B

Glossary of Selected Geophysical Terms

Apparent resistivity – The resistivity of homogenous, isotropic ground which would give the same voltage-current relationship as measured.

Array – In resistivity, an array is the arrangement of electrodes, also called configuration.

Competent (geologic) – A bed which retains its stratigraphic thickness under stress. It folds or breaks under stress, in comparison with adjacent incompetent beds which tend to flow.

Conductive material (electrical) – Any material which allows the passage of electric current through its volume.

Electric Current – Is a flow of electric charge through a medium. Types of electric circuits encountered in geophysics include conduction currents (flow of electrons), electrolytic conduction (flow of ions), and di-electric conduction (currents involved in capacitive storage of electric charge).

Electric Potential – The electric potential (a scalar quantity denoted by φ, φE or V and also called the electric field potential or the electrostatic potential) at a point is equal to the electric potential energy (measured in joules) of a charged particle at that location divided by the charge (measured in coulombs) of the particle. Electric potentials involved in geophysics include the zeta potential, liquid junction and shale potentials, electrolytic contact potential, electrokinetic potential, and polarization potentials.

Electrical Resistance – The opposition to the passage of an electric current through that element.

Electrical Resistivity – The electrical resistance per unit length of a unit cross-sectional area of a material. The unit of electrical resistivity is the ohm·metre (Ω·m).

Electrodes – A piece of metallic material that is used as an electric contact with a nonmetal. Can refer to a grounding contact, to metallic minerals in a rock, or to electric contacts in laboratory equipment.

Four-pin resistivity survey – Also known as the Wenner Method, involves placing 4 probes in the earth at equal spacing. The probes are connected with wires to the ground resistance test set. The test set passes a known amount of current through the outer two probes and measures the voltage drop between the inner two probes. Using ohms law it will output a resistance value, which can then be converted to a resistivity value.

Forward Model – The technique of determining what a given survey would measure in a given formation and environment by applying a set of theoretical equations for the survey response. B-2

Geometric factor (K) – A numerical factor used to multiply the voltage-to-current ratio from measurements between electrodes to give apparent resistivity. Geometric factor is dependent on the type of electrode array and spacing used.

Geophysical – Study of the Earth by quantitative physical methods.

Half-space – A mathematical model bounded only by one plane surface, i.e., the model is so large in other dimensions that only the one boundary affects the results. Properties within the model are usually assumed to be homogenous and isotropic, though other models are also used.

Heterogeneous – Lack of spatial uniformity.

Homogeneous – The same throughout; uniformity of a physical property throughout the material.

Inversion – Deriving from field data a model to describe the subsurface that is consistent with the data. Determining the cause from observation of effects.

Masked – The effect whereby a highly conductive layer near the surface dominates resistivity measurements so as to make undetectable the effects of deeper resistivity variations.

Noisy – Noise in electrical surveying can be due to interference from power lines, motor-generator or electric components, atmospheric electrical discharges (sferics), or low-frequency magnetotelluric phenomena. Even near surface elements such as vegetation, saturated sediments, underground utility pipes, etc. can create noise in electrical surveys.

Ohm's Law – The current (I) through a conductor between two points is directly proportional to the potential difference (V) across the two points, introducing the constant of proportionality, resistance (R).

Ohm-meter – A unit of resistivity, measuring the extent to which a substance offers resistance to passage of an electric current. The resistivity of a conductor in ohm meters is defined to be its resistance (in ohms) multiplied by its cross-sectional area (in square meters) divided by its length (in meters).

Physical material property – Any property that is measurable whose value describes a physical system's state. It is an intensive, often quantitative property of a material, usually with a unit that may be used as a metric of value to compare the benefits of one material versus another to aid in materials selection. The value of a physical property depends upon material type (rock, soil, etc), alteration or weathering, how different components are mixed, texture, grain size, porosity, connectivity of fluid pathways, types of interstitial fluids etc. Thus the physical property value is situation dependent. Ideally, geophysical surveys using samples or borehole techniques can be carried out to determine the relationship between the different components of the earth and the physical property value. It is often possible to use information in the literature or from previous case histories to estimate a likely range for a physical B-3.