SOPAC Water Resources Unit

OFFSET WENNER RESISTIVITY SURVEY GUIDELINES

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PRINCIPLES

Surface resistivity methods are based on the concept that the apparent resistivity of the ground can be measured by inducing an electrical current at the ground surface using an array of electrodes (two current and two potential electrodes). Resistivity soundings involve measurements of apparent resistivity over a range of spacings to obtain an indication of how resistivity changes with depth. Interpretation of these soundings can establish the depths to a sequence of different layers with different electrical resistivity.

Figure 1 provides a schematic view of the basic components involved in making resistivity measurements. A battery is used to generate a measured current (I) between two current electrodes (C1 and C2). The resulting voltage difference (ΔV) between two potential electrodes (P1 and P2) is then measured to provide a measure of resistance. The relationship between that measured resistance and apparent ground resistivity depends on the configuration of the electrode array

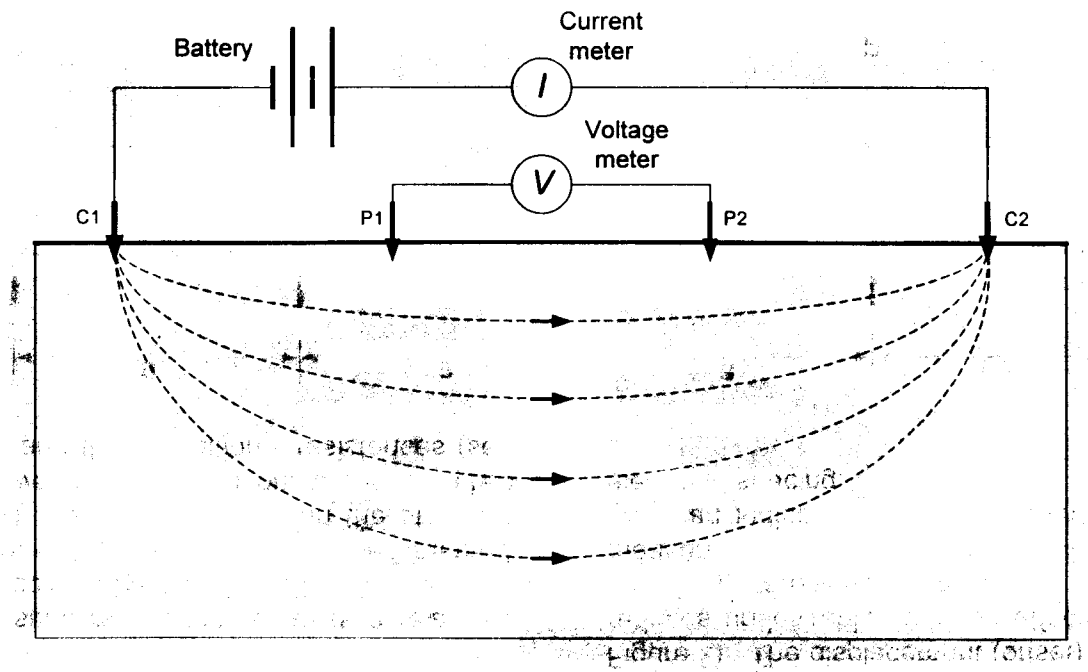


Figure 1 Schematic diagram of resistivity measurement

The Schlumberger and Wenner arrays are the most commonly used for surface resistivity surveys; the former uses a relatively small potential electrode spacing whereas the latter uses equally spaced electrodes (as in Figure 1). The "Offset Wenner" method developed by Barker (1981) is an improvement on the standard Wenner array and involves five electrode positions to measure two (offset) Wenner resistances and three additional resistances (see Figure 2). The displacement (offset) of each of the Wenner arrays reduces undesirable spurious effects due to lateral underground resistivity variations. In addition, three additional resistance measurements allow calculation of the observation error, which gives an indication of the reliability of the measurements for all electrode spacing.

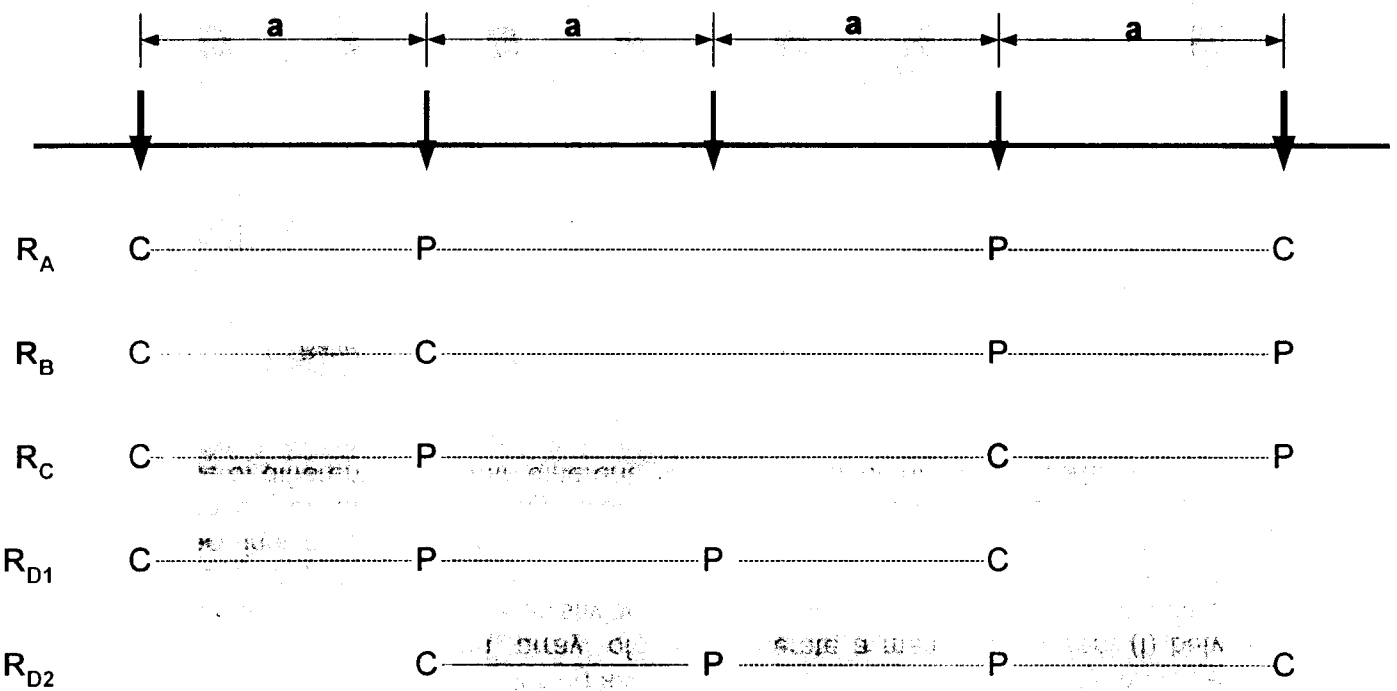


Figure 2 Electrode configurations used in the Offset Wenner array

C indicates that the electrode is used as a current electrode

P indicates that the electrode is used as a potential electrode

For the standard Wenner array the apparent resistivity (ρ_a) may be determined from the expression:

$$\rho_a = 2\pi aR$$

where a is the electrode spacing and R is the measured resistance.

For the Offset Wenner array this is instead calculated as the mean of the two Offset resistances (R_{D1} and R_{D2}):

$$\rho_a = 2\pi a(R_{D1} + R_{D2})$$

The offset error (e_o) is a function of the difference between the two offset resistances:

$$e_o = \frac{2(R_{D1} - R_{D2})}{R_{D1} + R_{D2}} \times 100\%$$

and the observation error (e_{obs}) is determined from a tri-potential check as follows:

$$e_{obs} = \frac{R_A - [R_B + R_C]}{R_A} \times 100\%$$

This observation error should normally fall within the range -5% to 5%. Values outside this range could indicate instrument malfunction, leakage of current from damaged cables or high electrode contact resistances. The Offset Wenner method includes a procedure to extrapolate the measured sounding curve allowing a Wenner resistivity at 256 m spacing to be computed from resistances measured with an electrode spacing of 128 m. However, as demonstrated by White and Scott (1988), these extrapolated points can be unreliable and should be used with considerable caution.

PROCEDURES

Resistivity methods perform better and give more reliable results in a horizontal layered situation. For surveys intended to detect coastal saline water the resistivity soundings should be oriented, as far as possible, parallel to the coastline. The maximum electrode spacing employed with the Offset Wenner method is 128 m (involving a total cable spread of 512 m and 21 electrodes) and it is desirable to use that complete spread wherever possible. Following the placing and connection of all electrodes, resistance measurements should be made beginning with the smallest spacings and progressing outward. This approach allows reliable detection of problems such as a failure to connect an electrode (the ABEM SAS error codes and their significance are tabulated in Appendix 1). Observations should be recorded on the Offset Wenner Sounding Data Form (Appendix 2) and the observation error calculated (see above equation) and checked at each setting to ensure that any faults are detected and corrected. In addition, it is desirable for the apparent resistivity to be calculated and plotted in the field to obtain an initial indication of the sounding results.

INTERPRETATION

Field observations can be processed using the Excel spreadsheet (Offset.xls) to calculate apparent resistivities and to produce plots (Appendix 3). The derived resistivity data can be interpreted using a computer program such as RINVERT (© C Vision). RINVERT is designed for interpreting resistivity sounding data acquired by either Wenner or Schlumberger electrode arrays. The assumed earth model consists of multiple horizontal layers, each of which is described by a thickness and resistivity value. This is often a reasonable approximation to the real earth, especially in shallow environments, as a result of the mechanisms of sedimentation and weathering. Further details are provided in Appendix 4.

FIELD PROCEDURES

Preparation

Preparation for the field survey should include a check that all necessary equipment is available and in working order.

The LIST OF EQUIPMENT is as follows (tick boxes to check):

- 1 SAS300 Terrameter ☐
- 1 Switch Box ☐
- 2 Reels with cables ☐
- 18 Electrodes with Clips ☐
- 1 Compass ☐
- 1 Calculator ☐
- 1 ABEM Instruction Manual ☐
- Standard Data Sheets ☐
- 2 Pens/Pencils ☐

The BATTERY VOLTAGE must be checked and must not be less than 11.5 volts, and should be above 12.5 volts. ☐

Location

The site must be CAREFULLY CHOSEN.

This must take into consideration some, if not all of the following points:-

- location of proposed borehole/s
- the cable line requires a reasonably straight site
- the cable line should avoid large obstacles or metallic objects
- if the location is less than 500 metres from the shoreline make the cable line run approximately parallel to the shore.
- avoid cables running onto slopes and over hills
- avoid running the cable along formed roads
- if cable lines cross roadways, either stop traffic or raise the cable to allow traffic to pass.

Weather conditions must be taken into consideration.

- Do not make measurements in the rain
- avoid in particular thunderstorms and lightning

Setting Up

When setting up the survey select a centre point, close to a proposed borehole if one is to be drilled. Run out the cables in a straight line from the centre point, and connect the electrodes (steel pegs with clips) to the cable. Connect the cable wires to the switch box. N.B. Note the bearing of the D1 connection.

Cable connections

- P1 and P2 on the SAS300 to P1 and P2 on the switch box ☐
- C1 and C2 on the SAS300 to C1 and C2 on the switch box ☐
- Centre cable from yellow connector on the switch box to the central electrode. ☐

Taking Measurements

Measurements must be carried out with care.

1. Fill out the Site Details on the standard data sheet. ☐
2. Check the Battery to ensure it is still charged, (above 11.5 volts), using the battery check on the SAS300 ☐
3. Set PC switch towards the BGS label. ☐

(Start with a current setting of 20mA. Always use maximum current obtainable and decrease as required.)

4. Set the Resistivity Range either to 1 ohm or 100 ohms ☐
5. Take Measurements from A,C,D1,D2,and B at settings 1 to 9. ☐

If an error code is displayed refer to the error code sheet copies of which will be held in the field.
As an example error message "1" indicates that a current electrode is disconnected

6. Write down the resistance measured, making sure consistent readings are obtained and noting carefully the units recorded e.g. mohms, ohms or kohms. ☐

Use the standard data sheet.

Measure the direction of the cable line using a compass, and record on the data sheet.

Field Calculations

Field calculation of the Apparent Wenner Resistivity (AWR) should be carried out using the field sheet.

Calculations involve finding the average of measurements RD1 and RD2 and multiplying by the appropriate K value

1. Plot the values obtained on the log-log graph sheet.
2. Draw a curve to fit the points plotted.

APPENDIX 1: ABEM TERRAMETER SAS SYSTEM

Error Code	Causes	Remedies
1+	Transmitter cables or groundings have too high resistance for selected current (can also be caused by bad connections).	Reduce current step by step until beeper stops sounding. In certain circumstances error code 2 will replace error code 1. If this occurs, proceed as instructed below. Wait for reading to appear. If beeper does not stop, check transmitter circuits.
2+	Operator has selected a resistivity range that is too low.	Increase resistivity range step by step until beeper stops sounding. Wait for reading to appear.
3+	Operator has selected a voltage range that is too low.	Increase voltage range step by step until beeper stops sounding. Wait for reading to appear.
4	Current selector setting has been changed during measurement.	Repeat measurement.
5++	Measurements stopped due to persistent transmitter current drop. Or The SAS 2000 Booster, if connected, has overheated or has too low a battery voltage	Reduce transmitter current one step and try again. If error code appears again check transmitter cable and groundings or check booster. Let booster cool down if overheated. Charge booster battery if voltage is below 10.5v.
6++	Measurements stopped due to persistent overloading (signal plus excessive noise).	Reduce transmitter current one step and try again. If beeper continues, return to original current setting and increase the RANGE selector (resistance) setting one step at a time.
7	Operator trying to transmit more than 20 mA without booster.	Reduce current to 20 mA or lower or use booster.
8 & 9	Not used.	
10 & 11	Special diagnostic code.	Contact ABEM.

REFERENCES

Barker, R.D. (1981) The offset system of electrical resistivity sounding and its use with a multicore cable. *Geophysical Prospecting* **29**, 128-143.

White P.A. and D.M. Scott (1984) Resistivity Handbook. Unpublished Report No. H53, Geology Division, Minystry of Natural Resources, Honiara, Solomon Islands.

White P.A. and D.M. Scott (1988) Examination of sounding curve extrapolation used by the Offset Wenner system. *Geophysical Prospecting* **36**, 194-200.

Error Code	Causes	Remedies
12	Battery voltage too low.	Charge battery and check voltage.
13	Non-standard power supply that provides too high a voltage is being used.	Use standard battery pack or adjust power supply to right voltage.
14	Cycles selector is between two positions or is faulty.	Check selector position and performance.
15	RANGE selector is between two positions or is faulty.	Check selector position and performance.
16	CURRENT selector is between two positions or is faulty.	Check selector position and performance.
17	Special diagnostic code.	Contact ABEM.
18	Cycle time jumper is not correctly set.	Read instructions in section 3.1.5 and check jumper.
19	Not used.	
20	Fault in input amplifier or transmitter.	See section 7.3.1.
21	Component fault in input amplifier unit No. 9136 3100 21.	See section 7.3.1.
22	Component fault in transmitter circuit.	See section 7.3.1.
Irregular beeps occur. Diplay of results is delayed. No error code is displayed	Transmitter current drops, occasionally below selected value, Receiver is occasionally overloaded by signal and excessive noise combined, or Measurement proceeds with delay: Only undisturbed cycles are accepted.	Reduce transmitter current one step and try again. If irregular beeps continue, return to original current setting. Then increase RANGE selector (resistance) setting one step and try again.

\+ Indicates that repeated beeping accompanies the error code in question

++ Indicates that the error code will be replaced after one second by the latest calculated result (if calculated result is available).

ABEM TERRAMETER SAS SYSTEM

Relationship between cycling, current setting and resistance reading

Resistance Reading

Current Setting	>2KΩ	2KΩ	1KΩ	500Ω	200Ω	100Ω	50Ω	2Ω	1Ω	0.5Ω	< 0.5Ω
20 mA	A			B			C			D	
10 mA											
5 mA											

Recommended Cycling Conditions

A No cycling required

B Repeat measurement twice. If the two numbers are within 5% then record the average as the resistance. If not then cycle 4 times and record that value.

C Cycle 4 times twice. If these two numbers are within 5% then record the average of the two as the resistance. If not then cycle 16 times. If the resistance changes markedly, i.e. the first or second digit, towards the end of the 16 cycles then the reading is unstable and the 16 cycle measurement should be repeated and the average of the two recorded.

D Cycle 16 times twice. If these numbers are within 5% of each other then write down the average of the two. If the two are very different then record both measurements. Measurements of resistance near this low level are at the machine limit. When calculating resistivity ignore the resistance if the two 16 cycle measurements are significantly different.

From White and Scott (1984)

APPENDIX 2: OFFSET WENNER DATA FORM

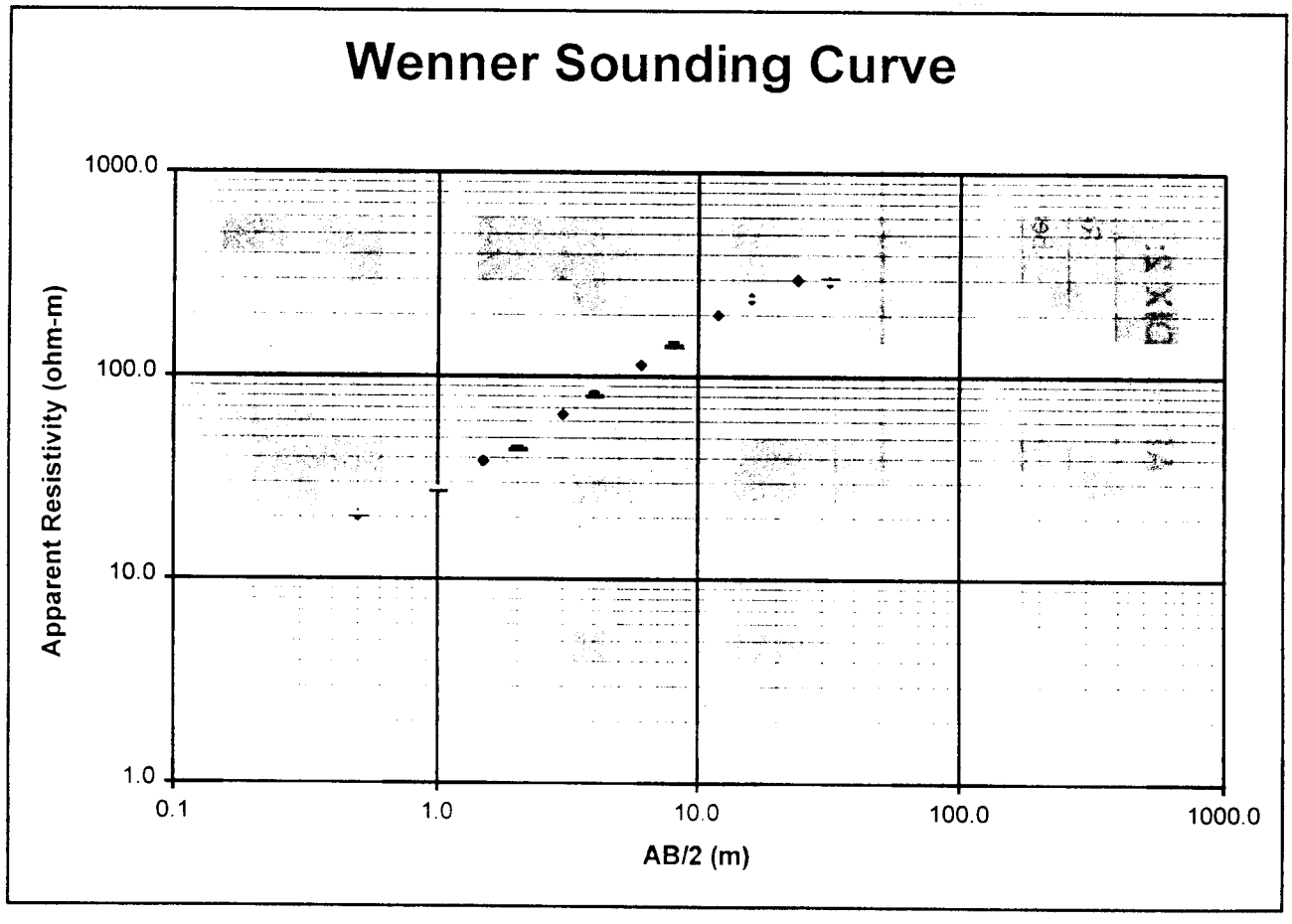
Site:	Ref No:	Weather:	
Observers:	Bearing:	Topography:	
Date:	Soil:	Geology:	

SETTING (n)	OBSERVED MEASUREMENTS RA	RC	RD1	RD2	RB	ERRORS OBS	OFFSET	LATERAL	SPACING (metres)	WENNER RESISTIVITY
1									0.5	
2									1.0	
									1.5	
3									2.0	
									3.0	
4									4.0	
									6.0	
5									8.0	
									12.0	
6									16.0	
									24.0	
7									32.0	
									48.0	
8									64.0	
									96.0	
9									128.0	
					RMS Error:				*192.0*	
									256.0	

APPENDIX 3 – SAMPLE RESULTS

Site:	Port Vila school playing field	Ref No:	Test	Weather:	
Observers:	Chris, Morris, David et al.	Bearing:		Topography:	
Date:	21/08/98	Soil:		Geology:	

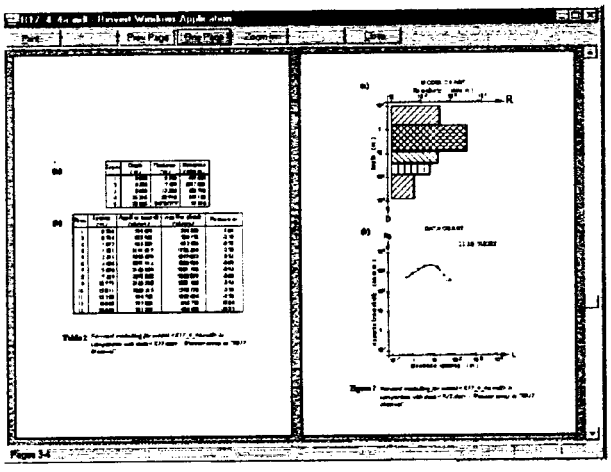
SETTING	OBSERVED MEASUREMENTS					ERRORS			SPACING	WENNER
(n)	RA	RC	RD1	RD2	RB	OBS	OFFSET	LATERAL	(metres)	RESISTIVITY
1	9.28	8.89	6.52	6.62	0.43	-0.43	-1.52		0.5	20.64
2	6.33	6.05	4.33	4.52	0.463	-2.85	-4.29	-3.99	1.0	27.80
									1.5	38.07
3	5.46	5.04	3.49	3.71	0.459	-0.71	-6.11	14.51	2.0	45.24
									3.0	65.28
4	4.98	4.69	3.19	3.46	0.332	-0.84	-8.12	14.46	4.0	83.57
									6.0	113.22
5	4.45	4.14	2.82	3.05	0.32	-0.22	-7.84	8.33	8.0	147.53
									12.0	200.67
6	3.27	3.1	2.42	2.4	0.384	-6.34	0.83	0.39	16.0	242.28
									24.0	300.15
7	2.02	1.832	1.48	1.453	0.286	-4.74	1.84	19.29	32.0	294.86
									48.0	
8						N/A	N/A	N/A	64.0	
									96.0	
9						N/A	N/A	N/A	128.0	
					RMS Error:	3.21	5.20	11.20	*192.0*	
									256.0	



RESISTIVITY MODELLING PACKAGE

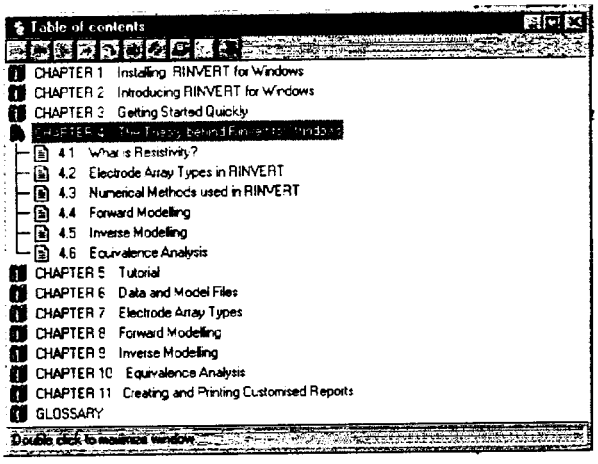
Intuitive Point and Click Interface

Easy aspect of the interface has been designed to make RINVERT for Windows easy to use. You can access all menu options and dialog boxes via the mouse or keyboard, so that you can use the interface that you feel comfortable with. RINVERT for Windows makes your first chart displayed by simply selecting a data file and clicking on OK. It's easy! Intelligent default settings allow you to analyse complex data sets without having to go through menu after menu. If you have used Microsoft Windows then you are familiar with a lot of the commands used in RINVERT for Windows. If not, now is the time to discover the power of Microsoft Windows together with RINVERT for Windows.



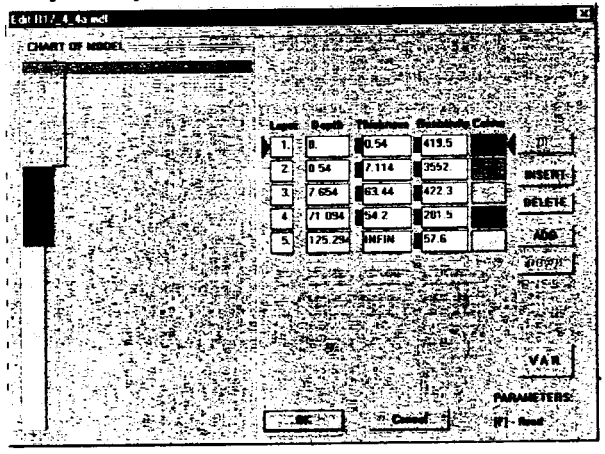
Report Generator

The user has the opportunity to complete an on-screen form of sounding, location, project and illustration details, as well as free-form comments. This information may be printed out with tables and graphics, for field data, forward modelling, inverse modelling and equivalence analysis - in report ready format. The report may be checked by a print preview facility and then sent to any Windows-supported output device in full colour or black and white. Intelligent default settings combined with intuitive on-screen editing make customising your reports a snap. Creating publication quality reports has never been easier.

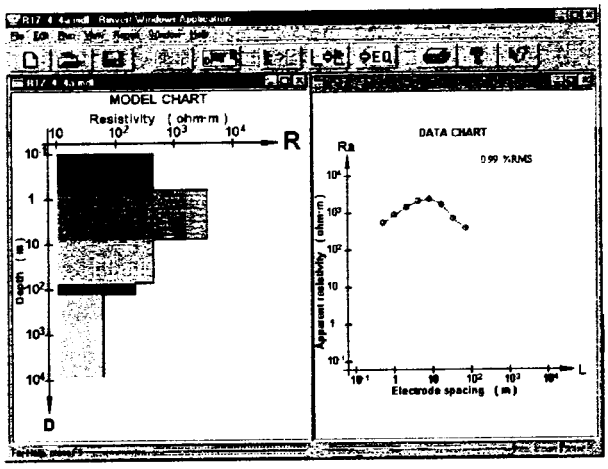


Comprehensive and Context Sensitive Help System

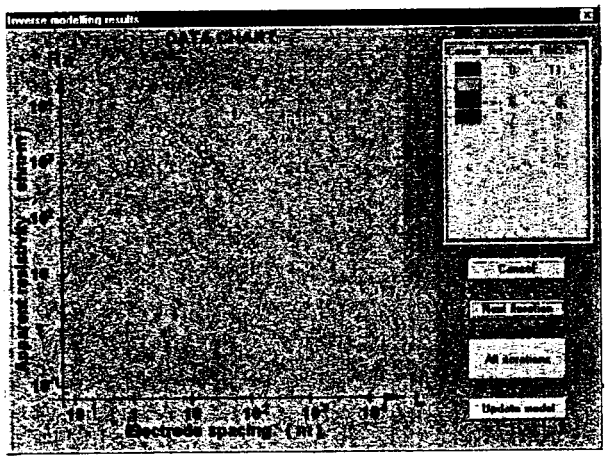
RINVERT for Windows comes together with a Windows help system, providing you with fully comprehensive, context sensitive help on every menu item or dialog box. With RINVERT's sophisticated help system, your search is only a keystroke away.



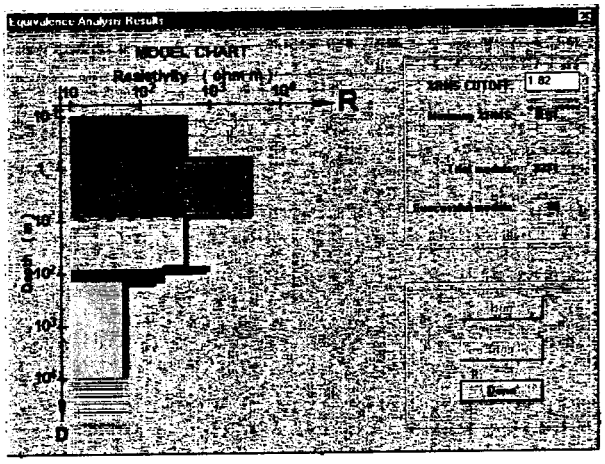
Forward Modelling (Simulation)
Selecting FORWARD allows RINVERT for Windows to generate the sounding curve for your earth model. RINVERT for Windows also allows the user to change the model repeatedly until the sounding curve matches visually with the field data.



Inverse Modelling (Automatic Interpretation)
Selecting INVERSE allows RINVERT for Windows to find the best models which fits your sounding data. RINVERT for Windows automatically modifies an initial estimate of a layered earth model until the simulated and observed sounding data agree closely. RINVERT for Windows also displays the sounding curve and goodness-of-fit for each iteration.



Equivalence Analysis
RINVERT for Windows provides a unique facility for equivalence analysis which permits the user to control the range of equivalence by nominating the accuracy of the field data. The degree of equivalence is indicated by meaningful descriptors: "unique", "minor", "severe", "extreme". RINVERT for Windows also provides an impressive 3D visual display of equivalent models.



RINVERT for Windows - A Proven Solution
RINVERT for Windows supersedes RINVERT for DOS, adding even more features at an unbelievable price. It is a natural evolution of an algorithm which has been applied successfully to thousands of resistivity soundings worldwide over the last 20 years. Can you afford to be without it? Save time and increase productivity - RINVERT for Windows provides fast, accurate 'user friendly' interpretation and dynamic on-screen model display.

Price:(Australian Dollar)
Single User - AUD$695 plus freight & handling. Academic and Multiple user licence available at reduced cost.