RES1D ver. 1.0

for Windows 95/98/Me/2000/NT

1-D Resistivity, IP & SIP
Inversion and forward modeling

Wenner and Schlumberger arrays

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1 Introduction

RES1D is a free computer program for the Microsoft Windows 95/98/Me/2000/NT operating system that will carry out both forward modeling and inversion for electrical sounding surveys. The computer hardware requirements are quite minimal. If your computer has sufficient RAM (usually about 32 to 128MB RAM) for Windows to function properly, it should be able to run this program.

Besides normal resistivity surveys, it also supports IP (induced polarisation) and SIP (Spectral Induced Polarisation or Complex Resistivity) models. The linear filter method (Koefoed 1979) is used for the forward modeling calculations, while the least-squares optimization method (Lines and Treitel 1984) is used in the data inversion. This program is intended for teaching purposes only.

In the present version, the IP values are assumed to be chargeability values (Summer 1976). The SIP values are assumed to be frequency domain measurements at different frequencies, and the SIP model is the Cole-Cole model (Pelton *et al.* 1978). The Cole-Cole SIP model is defined by the following equation

$$\rho(\omega) = \rho_0 \left[1 - m \left(1 - \frac{1}{1 + (i\omega\tau)^c} \right) \right] \qquad (1)$$

where ρ_0 is the DC resistivity, m is the chargeability, ω is the angular frequency ($2\pi f$), τ is a time constant and c is the exponent or relaxation constant.

Figure 1 shows the subsurface model used in the 1-D sounding method. The layers are horizontal layers that have two parameters, the layer resistivity ρ and thickness h (except for the last layer that is assumed to extend infinitely downwards). In an IP model each layer has an additional parameter, the chargeability m. In a SIP model there are two further parameters for each layer, the time constant τ and the exponent factor c.

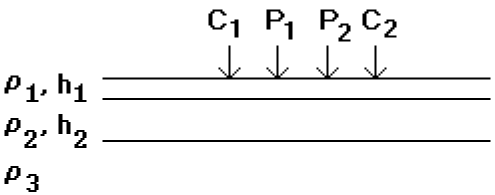
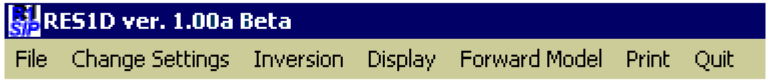


Figure 1. A typical 1-D resistivity model.

2. Installing and starting the program

The RES1D package comes in a single compress installation file SETUP.EXE that is a Windows based installation program. To install the program, click Start, and then Settings followed by the Control Panel, and then Add/Remove Programs.

On starting the program, the following screen will be displayed.



The program starts up in the inversion mode, i.e. it will a data set with the measured apparent resistivity values and carry out an inversion. To calculate the apparent resistivity values for a given model, you will need to select the "Forward Model" menu option. In the following section, the various menu options associated with the data inversion mode will be described. This is then followed by a description of the forward modeling option.

3. Data inversion options

The typical steps involved in inverting a data set is to first read in a data file with the apparent resistivity values, modify the inversion parameters if necessary, and then carry out the inversion. The data collected from a 1-D resistivity sounding survey consists of the electrode spacings used and the corresponding apparent resistivity values. The apparent resistivity values are commonly plotted on a log-log graph (Figure 2).

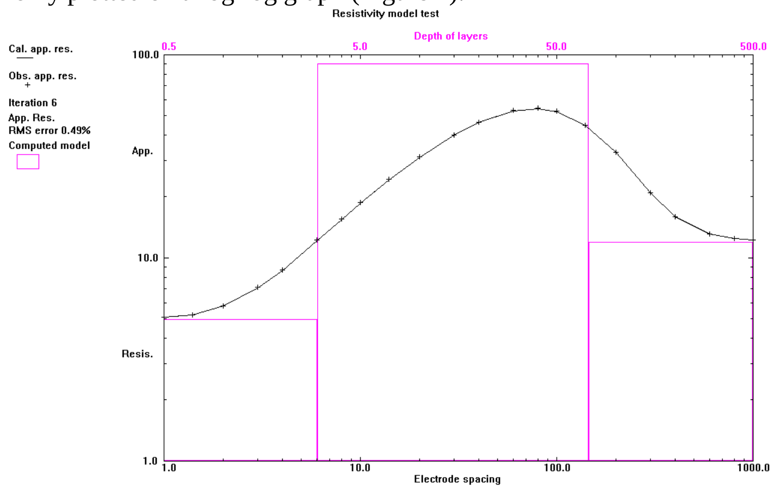


Figure 2. A typical 1-D model used in the interpretation of resistivity sounding data for the Wenner array.

The purpose the inversion subroutine is to determine the thickness and resistivity of the layers of a 1-D model that will produce a model response that matches the measured values. The method used in this program is the least-squares optimisation method (Lines and Treitel 1984). In this method, an initial model must be given, and the optimisation subroutine modifies the thickness and resistivity of the layers so as to reduce the difference between the calculated and measured apparent resistivity values. For a model where the number of layers is much smaller (less than half) than the number of data points, the damped least-sqaures method is used. The equation used by this method is given by

$$\left(\mathbf{J}^{\mathrm{T}}\mathbf{J} + \lambda\mathbf{I}\right)\Delta\mathbf{q}_{\mathbf{k}} = \mathbf{J}^{\mathrm{T}}\mathbf{g} \qquad (2)$$

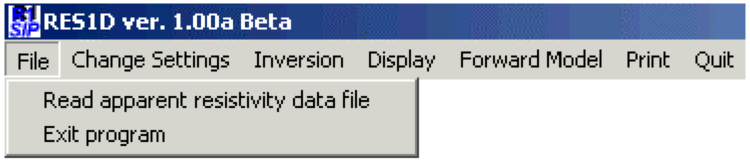
q is the model parameter vector that consists of the logarithm of the resistivity and thickness of the layers. **g** is the discrepancy vector that consists of the difference between the logarithms of the calculated and measured apparent resistivity values. **Δq** is the model parameter change vector, and **J** is the Jacobian matrix of partial derivatives. The elements of the Jacobian matrix are given by

$$J_{ij} = \frac{\partial f_i}{\partial q_j} \qquad (3)$$

It is the change in the *i*th model response f_i due to a change in the *j*th model parameter q_j. **I** is the identity matrix. The factor λ is known as the Marquardt or damping factor, and this method is also known as the ridge regression method (Inman 1975). The damping factor effectively constrains the range of values that the components of parameter change vector can **Δq** take. The damped least-squares method attempts to minimize a combination of the magnitude of the discrepancy vector and the parameter change vector.

3.1 Data file format

To read in a data file, click the “File” option on the main menu bar. This will then bring up the following menu list.



To read a data file, just click the “Read apparent resistivity data file” option. You will then see the standard Windows dialog box for reading a file. Using the WENNER3.DAT data file as an example, a description of the data format is as follows. This file contains apparent resistivity sounding data for the Wenner array.

WENNER3.DAT file	Comments
Three layer model	Title
Array Type (Wenner or Schlumbeger)	Array type header
Wenner	Type of array (Wenner or Schlumbreger)
Number of data points	Number of data points header
15	The number of data points
Data Type (Resistivity,IP,SIP)	Data type header
Resistivity	Data type (Resistivity or IP or SIP)
Error in measurements included (Yes,No)	Header
No	No for now
Data section (spacing,app. res.)	Header for data section
1.000,94.424	spacing,app. resis. for 1st data point
2.154,69.782	spacing,app. resis. for 2nd data point
…..	Other data points
…..	
215.443,147.054	Last two
316.227,164.987	data points
User Starting Model Available (Yes/No)	Header
Yes	Yes or No, if No put 0 below
Fix Parameters (Yes/No)	Header
No	No for now
Number of model layers	Header
3	The number of model layers
Model Parameters (Res.,thickness)	Header
120,1.5	The resistivity and thickness of 1st layer
15,10	The resistivity and thickness of 2nd layer
180	Resistivity of last layer
0	Put a few 0’s at the end

For the Wenner array, the “**a**” spacing between adjacent electrodes is used as the “electrode spacing” in the data file. For the Schlumberger array, two spacing parameters are involved. They are the half-length of the array (given as “**a**” in Figure 3b) and the spacing between the two central potential electrodes (“**b**” in Figure 3b).

Figure 3. The spacing parameters for the Wenner and Schlumberger arrays.

The contents of the SCHLUM4.DAT file is listed below with the format description for a Schlumbreger array data file.

SCHLUM4.DAT file	Comments
Schlumberger test	Tiitle
Array Type (Wenner or Schlumbeger)	Header
Schlumberger	Type of array (Wenner or Schlumbreger)
Number of data points	Header
14	No. of data points
Data Type (Resistivity,IP,SIP)	Header
Resistivity	The data type
Error in measurements included (Yes,No)	Header
No	No for now
Data section	Header
15.0 1.0 4500.000	"**a**" spacing, "**b**" spacing, app. resis.
20.0 1.0 4000.000	
…..	Same for the other data points
…..	
100.0 3.0 210.570	
150.0 10.0 129.304	Last data point
User Starting Model Available (Yes/No)	Header
Yes	Yes if available
Fix Parameters (Yes/No)	Header
No	No for now
Number of model layers	Header
4	Four layers in this example
Model Parameters	Header
4000,10.	Resis. and thickness of layer 1
1000,15	Same for the rest
100,20	
1000	Resistivity of last layer
0	Put a few zero's
0	at the end of the file
0	

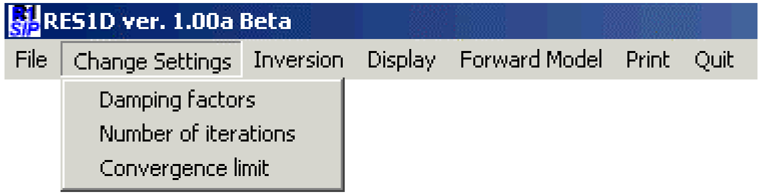
The format for an IP data set is similar to the resistivity data set, except the IP values are added after the apparent resistivity data for each data point, and some extra information about the IP measurements is added near the beginning of the file. The contents of the IPTESTM.DAT example data file with a description of the format is as follows.

IPTESTM.DAT file	Comments
Two layer IP model	Title
Array Type (Wenner or Schlumbeger)	Header
Wenner	Array type
Number of data points	Header
18	Number of data points
Data Type (Resistivity,IP,SIP)	Header
IP	Type of data
Chargeability	Type of IP measurement
Msec	IP unit
0.1,1.0	Starting and ending integration time
Error in measurements inluded (Yes,No)	Header
No	No for now
Data section	Header
1.00 9.99 0.20	Spacing,app. resis, app. IP
1.40 9.99 0.20	
…..	Same for the other data points
…..	
200.00 1.00 0.50	Last two
300.00 1.00 0.50	data points
User Starting Model Available (Yes/No)	Header
Yes	Yes if starting model specified
Fix Parameters (Yes/No)	Header
No	No for now
Number of model layers	Header
2	Two layers in this case
Model Parameters	Header
9,0.25,6	Resis., Chargeability, Thickness
1.5,0.45	Resistivity, Chargeability
Convergence limit	Header
0.1	Convergence limit in percent
0	Zeros at the end

After reading in a data file, you can carry out the inversion by using the "Inversion" option on the Main Menu bar. However, in some cases, you might like to modify the inversion settings.

3.2 Changing the program settings

On clicking the “Change settings” menu option, the follow list of sub-options will be displayed.



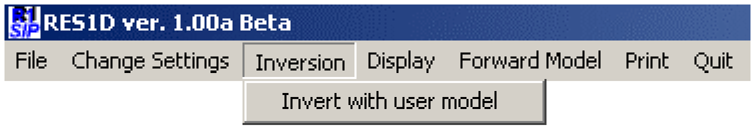
Damping factors - In this option, you can set the initial value for the damping factor λ in equation (2), as well as the minimum damping factor. If the data set is very noisy, you should use a relatively larger damping factor (for example 0.3). If the data set is less noisy, use a smaller initial damping factor (for example 0.1). The inversion subroutine will generally reduce the damping factor in equation (2) after each iteration. However, a minimum limit for the damping factor must be set to stabilise the inversion process. The minimum value should usually be set to about one-fifth the value of the initial damping factor.

Number of iterations - This allows the user to set the maximum number of iterations for the inversion routine. By default the maximum number of iterations is set to 8. For most data sets, this is probably sufficient. When the inversion routine reaches this maximum limit, it will ask the user for the number of additional iterations if you wish to continue with the inversion process. It is usually not necessary to use more than 10 iterations.

Convergence limit – The program will stop the inversion process if the RMS error falls below the limit set. Normally, a convergence limit of 2% for the RMS error is used.

3.3 Carrying out the inversion

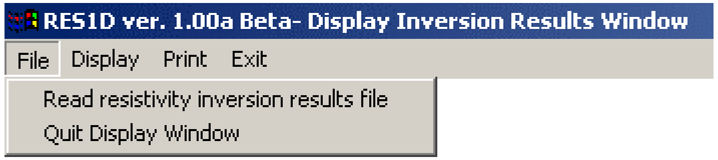
To carry out the inversion of the data set, click the “Inversion” menu option. The following menu will then be displayed.



On selecting the “Invert with user model” choice, the program will then carry out an inversion of the data set. The inversion will then start, and it should not take more then a couple of seconds to complete.

3.4 Displaying the results

To view the inversion results, click the “Display” menu choice on the main menu bar. This will then display the flowing window with options to read the file containing the inversion results, display the inversion model, as well to make screen dumps of the results.



The various menu choices in this window are as follows.

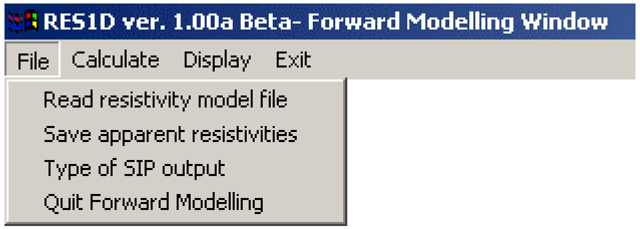
File – Select this option to read in the data file, with an INV extension, containing the inversion results. As a test, select the WENNER3.INV file when the dialog box to read the inversion file is shown.

Display – after reading in the INV file, click this option to display the inversion model, together with the measured and calculated apparent resistivity curves. Press the PgUp or PgDn key to view the results from the different iterations.

Print – After displaying the results on the screen, the “Print” option allows you to make a screen dump of the model displayed on the screen.

4 Forward modeling

This option allows you to calculate the apparent resistivity sounding curve for a user defined model where the resistivity and thickness of the layers are specified. Click “Forward Model” on the Main Menu to enter the window for the forward modeling.



File options

The “File” option on the menu bar has the following sub-options.

Read resistivity model file – Select this option to read in a file that contains the model parameters.

The file RES1D2L.MOD is an example resistivity model file. The contents of this file with the format description are given below.

RES1D2L.MOD file	Comments
Resistivity 2 layer model	Title
Number of layers	Header
2	The number of layers
Type of model	Header
Resistivity	Indicates this model has resistivity only
Model parameters (thickness,resistivity)	Header
5.0,10	The thickness and resistivity of the 1st layer
100.0	The resistivity of the last layer
Number of spacings	Header
20	Number of electrode spacings
Spacing values	Header
1.0	First spacing
3.0	Second spacing
…..	
….	
37.0	Last two
39.0	spacings
Array Type (Wenner or Schlumberger)	Header
Schlumberger	Indicates Schlumberger
0	Put a few zero's
0	at the end

For the Schlumberger array, the spacing is the half-length of the array (Figure 4). The program assumes it is the ideal Schlumberger array where the spacing between the potential electrodes is much smaller than the spacing between the current electrodes.

The file IP1D3L.MOD gives an example of an IP model. The contents of the file is listed below to illustrate the new parameters needed compared to the resistivity model.

IP1D3L.MOD file	Comments
IP model with 3 layers	Title
Number of layers	Header
3	The number of layers
Type of model	Header
IP	Indicates this is IP model
Model parameters (thickness,resistivity,chargeability)	Header
10.0,100,0.050	Thickness, resistivity, IP of 1st layer
33,1000.0,0.010	Thickness, resistivity, IP of 2nd layer
10,0.040	Resistivity, IP of last layer
Number of spacings	Header
19	Number of electrode spacings
Spacing values	Header
1.0	First electrode spacing
1.5	Second electrode spacing
….	
….	
400.0	Last electrode spacing
Array Type (Wenner or Schlumbeger)	Header
Wenner	Indicates this is Wenner
0	
0	

Note that the program assumes the chargeability value is in V/V if it is less than 1.0, and in mV/V if it is more than 1.0.

Finally, an example Spectral IP (SIP) model is given in the file SIP1D2.MOD. Spectral IP sounding surveys are unlikely to be of practical use, but this feature is provided as an initial step to study the SIP response of non-homogenous models, with the 1-D as the simplest. The Cole-Cole model is used, so there are two additional parameters for each layer, the time constant τ and the exponent c. It is assumed that the survey is a frequency domain survey with measurements at different frequencies.

SIP1D2.MOD file	Comments
SIP model example	Title
Number of layers	Header
2	Indicates model has 2 layers
Type of model(Resistivity,IP,SIP)	Header
SIP	Shows it is SIP model
Model parameters (thickness,resistivity,chargeability,tau,c)	Header
10.0,10,0.2,1.0,0.2	h,ρ,m,τ,c for layer 1
1.0,0.4,0.1,0.4	ρ,m,τ,c for layer 2
Number of spacings	Header
18	18 spacings
Spacing values	Header
1.0	First spacing
1.4	Second spacing

….	
300.0	Last spacing
Number of Frequency values	Header
5	Five frequency values
Frequency values	Header
0.01	First frequency
0.1	
1.0	
10.0	
100.0	Last frequency
Array Type (Wenner or Schlumbeger)	Header
Wenner	Wenner array
0	
0	

Note that the SIP model also has a section that contains the frequency values used.

Save apparent resistivities – This option saves the apparent resistivity values into the format used by the inversion part of RES1D.

Type of SIP output – The SIP measurements can be given in the form of the in-phase and out-phase apparent resistivity values, or in the form of amplitude and phase (milliradians) values.

Calculate
This option starts the calculation of the apparent resistivity values.

Display
This displays the apparent resistivity values, together with the model.

References

Inman, J.R., 1975. Resistivity inversion with ridge regression. Geophysics, **40**, 798-817.

Koefoed O.,1979. Geosounding Principles 1 : Resistivity sounding measurements. Elsevier Science Publishing Company, Amsterdam.

Lines L.R. and Treitel S. 1984. Tutorial : A review of least-squares inversion and its application to geophysical problems. Geophysical Prospecting, **32**, 159-186.

Pelton, W.H., Ward, S.H., Hallof, P.G., Sill, W.R. and Nelson, P.H., 1978. Mineral discrimination and the removal of inductive coupling with multifrequency IP. Geophysics, **43**, 588-609.

Summer, J.S., 1976, Principles of induced polarization for geophysical exploration. Elsevier Scientific Publishing Company.

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