



GRENDL

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1 Program Description

Introduction

This documentation describes the GRENDL program module that can be used in conjunction with EM Vision. Time domain electromagnetic (TEM) modelling is best approached by applying relatively simple techniques and then refining the approach to gain more insight. It is important to initially understand the basic earth properties of resistivity and conductivity in the area being analysed. Following this, some idea of the target model that is consistent with known or expected geology should be formulated. With this knowledge forward models followed by more rigorous inversion modelling may be required.

EM Vision makes use of a number of modelling algorithms to accommodate different EM datasets and survey situations. Each algorithm can be purchased individually or collectively. The documentation available to describe and operate each module is presented individually and this manual relates only to the GRENDL modelling program.

Modelling within EM Vision can take one of two forms depending on the complexity of the modelling requirement, the simplicity of the algorithms available and the model types. Increasing model complexity usually results in increased computation times. This means that two modes of operation are necessary.

- Some algorithms can be implemented to operate interactively. Computed responses from these modelling algorithms is fast enough that a model can be created, response calculated and displayed in a few seconds or minutes. Examples of these programs include PLASI, OZPLTE and SPASYM.
- Where computation times are longer (typically some minutes or even hours), the modelling algorithms are implemented to operate remotely from EM Vision. Control and user feedback is provided to EM Vision while the program runs but the user can continue with other operations while the modelling executes in the background. Examples of these programs are GRENDL and LAYER.

Program GREN DL

Description

The GREN DL program was written in the early 1980's within CSIRO and sponsored by a group of companies under the Australian Mineral's Industry Research Association (AMIRA). The authors of GREN DL are Kim McAllister and Art Raiche. Refer to Raiche et al (1985) for additional information.

GREN DL is a program designed to operate on a single TEM sounding using either a forward or inversion approach. The program computes the voltage (db/dt) response on the surface of a horizontally layered half-space using a rectangular transmitter loop excited by a bi-polar square waveform with exponential rise-time and ramp turnoff.

A second operational mode within GREN DL is to use the forward solution from a user-supplied 'seed' model, to compare the theoretical responses with observed data. Variations to layer thickness and resistivity are applied and the response recomputed to minimise errors using the Jupp and Vozoff (1975) inversion technique. This inversion process is repeated until a maximum number of iterations are reached or the errors fall below a definable threshold.

The original GREN DL program had 4 operational modes. Two of the four are available in the current implementation. These options include:

- Inversion on coincident and in-loop TEM voltages.
- Compute apparent resistivities from the TEM voltages.
- Invert on DC apparent resistivities or voltages.
- Joint resistivity-coincident loop TEM inversion.

Only the computation of apparent resistivities and the inversion/forward modelling of TEM voltages have been implemented. The joint inversion within GREN DL will be enabled in a future release of EM Vision and GREN DL.

GREN DL DC Option

The purpose of the GREN DL DC option is to invert data from a DC resistivity survey using any arbitrary 4 electrode arrays. The inversion can be done on either voltages or apparent resistivities. There is an option included to calculate the forward problem only which can be used for modelling or experimental design.

The method used in the inversion and parameter sensitivity analysis is based on the singular value decomposition of the Jacobian (see Jupp and Vozoff, 1975).

GREN DL TEM Option

The TEM option can be made to invert data from either a coincident loop TEM survey or from an in-loop survey where the receiver is assumed to be in the loop centre. The inversion is based on the voltages (microvolts/amp) recorded by the receiver dipole. GREN DL can also be configured to calculate the forward model that gives apparent resistivities as well as voltages.

The method used for the forward model uses the Gaver-Stehfest method of inverse Laplace transformation to convert the frequency domain expression for an isotropic, horizontally-layered earth into the time domain. The source is modelled using a circular loop of the same area as the source. The inverse Hankel transform is calculated using digital filter coefficients obtained from Walt Anderson (see Knight and Raiche, 1982).

The step function response is calculated at a density of ten points per decade over a delay time span until the response drops below a set resolution voltage. Step response curves are produced by dividing the above response into offtime and ontime pulse lengths and appropriately combining them. The offtime pulse is integrated over the ramp turnoff. The effect of exponential risetime is simulated to an accuracy of better than 0.01 percent by integrating the turnon step response over a ramp of twice the risetime constant. The resulting offtime and ontime responses are combined and integrated over receiver window widths.

The inversion method is that of Jupp and Vozoff (1975) as described in the DC option.

GREN DL Joint Option

The GREN DL joint inversion of DC resistivity and coincident loop (or inloop) TEM data is for isotropic layers to be combined and the two inversion operations treated as described above. The method used is for the DC and TEM data to be combined into one dataset and then the forward and inverse computations to be performed.

GRENDL Apparent Resistivity

This option calculates apparent resistivities from either coincident loop or in-loop microvolts/amp data. These apparent resistivities are useful for making an initial estimate for either the DC or TEM models where ramp function current turnoff is assumed.

The method used is the series inversion of Spies and Raiche (1980) to calculate the coincident loop apparent resistivity for a step function. This is the first estimate for an iterative procedure to obtain the ramp function apparent resistivity.

Limitations of GRENDL

A number of limitations apply to the general operation of GRENDL. These are:

- The program is compute intensive and therefore can be slow to resolve a complex sounding with a large number of layers. GRENDL has been implemented using the Generic Model Interface to enable other operations to be undertaken while modelling continues.
- No complex earth (Cole-Cole) parameters can be derived from GRENDL.
- GRENDL assumes a one dimensional earth and examines only the response of a single sounding at a time. In situations with rapidly changing lateral layering, GRENDL can be unreliable or inaccurate in its solutions.
- GRENDL can only be used with coincident or in-loop survey configurations.
- Only the vertical component (Z) can be computed.

MCF Considerations

As described, different MCF control files are required for the correct operation of GRENDL under different operating systems. Refer to *MCF Files* for the purpose and usage of MCF control files.

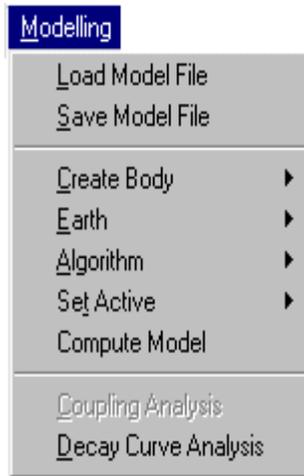
Windows[®] 95 (and NT) Operation

GRENDL will operate under EM Vision control in the Windows[®] 95, Windows[®] 98 and Windows NT[™] multi-tasking environments,. An example of an appropriate MCF file is shown below:

```
[Interface]
Algorithm    = Grendl
Description  = Grendl: Forward Multi-Layer Modelling
ModelClass   = Forward
DataType     = TEM
Executable   = c:\encom\emvision\grendl32.exe
ExeType      = WIN32
StatusPoll   = 0.5
StatusAbort  = 1200
```

Note that the Executable entry refers directly to the executable file.

Operation of GRENDL



As for all modelling in EM Vision, a number of preparatory steps must be initially taken before a model response can be computed. These steps are sequentially listed in the Modelling menu. Initially, a modelling operation requires a display for the response and a profile (or station) for the reading locations, a representation of the earth structure and model, plus the assignment of channels and stations to compute response.

Initially data can be loaded from a saved model file (Load Model File menu item) or, after creation, a model can be saved by using the Save Model File menu item.

Within EM Vision, access to GRENDL is through the Generic Model Interface. Refer to the section describing the *Generic Model Interface* for additional

information and operation of batch operated modelling programs such as GRENDL.

Earth Option

The Earth option of the EM Vision Modelling menu is used to define the Earth structure and assign its properties. Various Earth types are required to satisfy the many host environments that can be modelled. In some instances, discrete body types, such as plates can be contained in a homogeneous host, while in other instances, a layered Earth can be simulated. The methodology of defining an Earth Type and then the Properties of the earth force a logical model definition on the user. For GRENDL, only a layered earth model type can be applied.

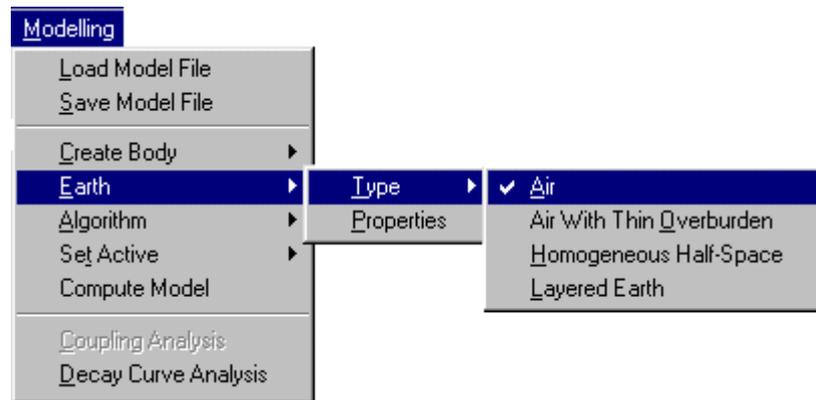
Note

Unless the correct information is specified in terms of model type, Earth host and defining parameters, GRENDL is not accessible and appears 'greyed' out in the Model/Algorithm menu option.

When selected, the Earth option provides two alternatives - Type and Properties. Initially, Type should be selected to define the specific Earth host type to be modelled.

Earth Type

Options available from the Earth Type option are as shown below:



Only two Earth types can be used with GRENDL. These are the homogeneous (single layer) half-space and the layered earth.

Homogeneous Half-Space

This Earth type assumes a single, conductive earth volume lying beneath the survey area. The earth host has a definable resistivity. No complex resistivity parameters are available for use with GRENDL. The extent of the half-space is assumed infinite horizontally as well as vertically (depth) and the top of the half-space lies at the surface of the earth.

Layered Earth

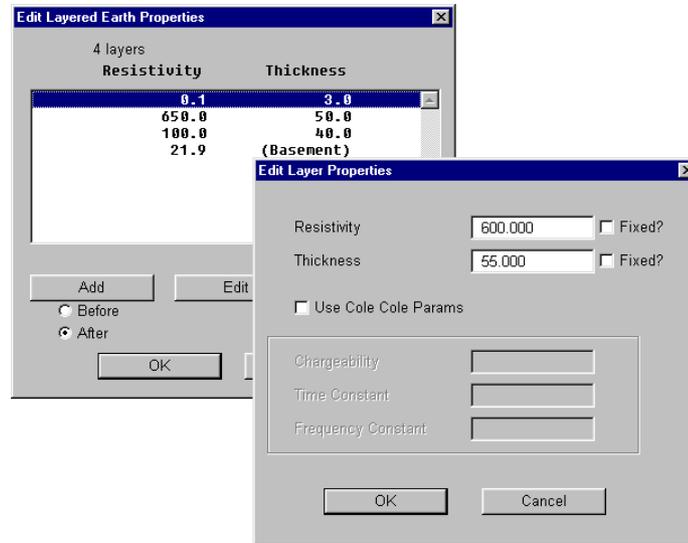
A Layered Earth model is comprised of a series of horizontal, stratified layers each of definable thickness and electrical property. The layered earth model can simulate a homogeneous half-space if only one layer is specified but usually more than one is defined. The extent of the layers is infinite laterally and defined by the thickness parameter vertically. The bottom layer is assumed to represent basement and so has resistivity properties but no thickness definition.

Any number of layers can be defined in EM Vision although the number is limited for GRENDL applications to 16. Individual layers can be defined by thickness (which cumulatively represents depths to the top and bottom surfaces) and resistivity.

Earth Properties

The Properties option is available from the Earth item of the Modelling main menu. This feature is used to define the properties used by the various Earth Types (see *Earth Type*). The dialog to control the various parameters of a layered earth will be displayed after selecting the Properties item.

For defining a **Layered Earth** model, a dialog controls the entry, editing and properties of the individual layers. The layers are presented within a scroll list as shown.



Editing the Layered Earth model

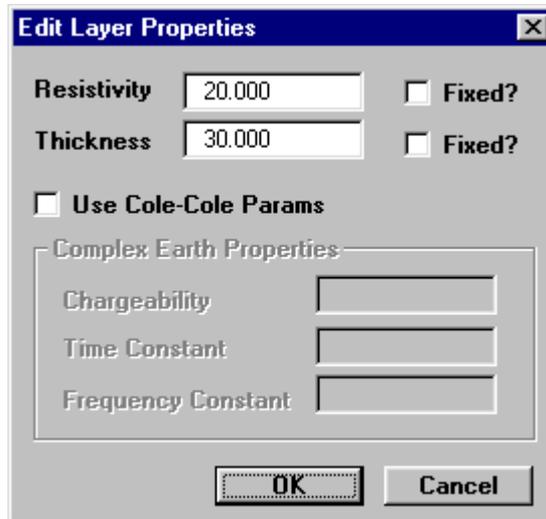
When the dialog is initially displayed, EM Vision will create a single layer which it refers to as basement. Note that no Thickness property is assigned to the bottom, basement layer of the list.

At the base of the dialog are three buttons that control the creation, deletion and editing of layers. Associated with the **Add** push button are two options for **Before** and **After**. These options enable creation of a new layer before (shallower) or after (deeper) than the layer highlighted.

Note

It is not possible to create a layer after or below the basement layer.

Any layer that is highlighted can be edited by selecting the **Edit** push button while the required layer is highlighted. An alternative means of directly selecting and editing a layer, is to position the cursor over the layer and double click with the left mouse button. By this method or by using the **Edit** push button, an editing dialog for the selected layer is presented.



Editing dialog for layers

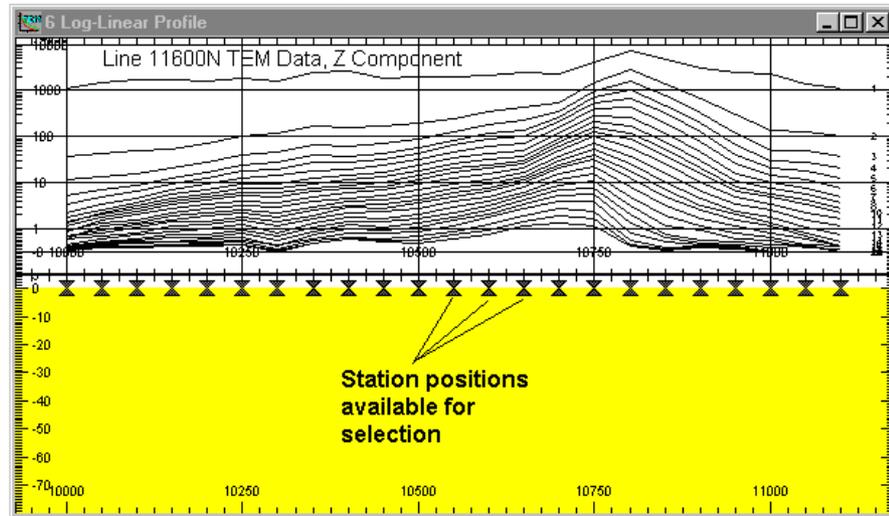
The resistivity and thickness can be edited on this dialog. Some modelling algorithms used for inversion can force parameters to remain unchanged (set the **Fixed** option) while the inversion process is being undertaken. This situation arises where for example, drilling evidence or resistivity soundings indicate a particular layer thickness or resistivity.

The dialog also provides the necessary control information for complex resistivity calculations. GRENDL however is not capable of computing complex resistivities.

Setting Individual Station Properties

In many layered earth modelling programs it is possible to set the properties of each station independently. Consequently, when the cross-section is displayed beneath a profile, the locations of the reading positions is displayed as an 'X' marker symbol. The purpose of this is to enable individual graphical selection of readings so their associated properties can be defined.

To set individual reading properties, display the profile and cross-section (see *Cross-Section Displays*). An example of this is shown below:



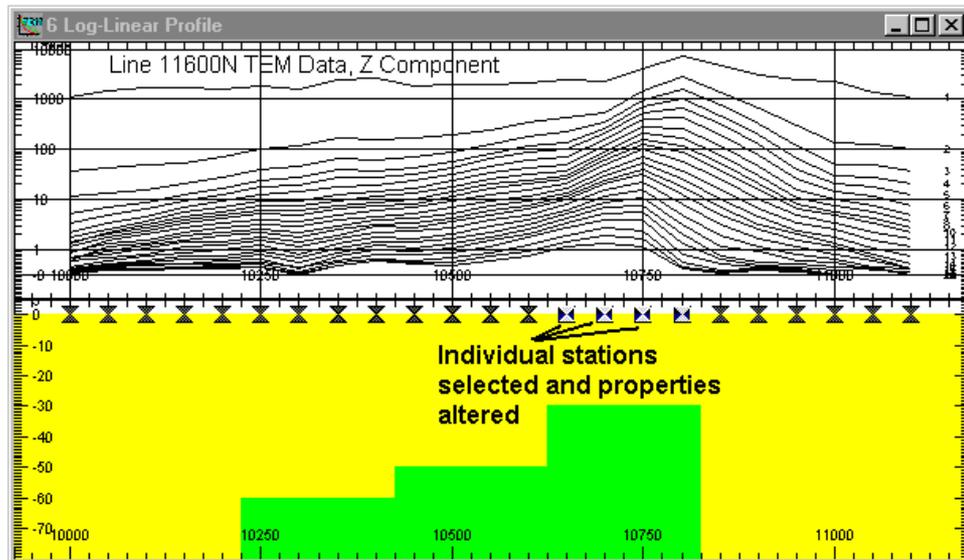
Example cross-section initial layered earth model

Select individual readings by positioning the cursor over the marker symbol and clicking the left mouse button. If more than one reading location is to be selected, press the SHIFT key while positioning and selecting. Refer to the section *Individual Station Symbols* to control and reconfigure the station markers. To define the earth properties of the selected layers, select the **Properties** button on the Tools toolbar or position the cursor over the layer and double click the left mouse button. When this is done, the Edit Layer Properties dialog is displayed (as described above).

Note

If difficulties are experienced in selecting the marker symbols, press CTRL key and the left mouse button to locate the symbol. The CTRL key can also be used with the SHIFT key for multiple selections.

You may also need to increase the height in the track of the symbols. To increase the height above the symbols by setting the vertical axis distance (Max) in the Drawing Configuration dialog (while ensuring the Earth Section is displayed in the Drawing list).



Cross-section with modified individual reading properties

Edit the layer properties as required for the various stations. When this is completed, modelling of programs (such as GRENDL) treats each station computation independently and therefore use the individual station properties to compute the theoretical response. Refer to *Setting Individual Station Properties* for additional information.

Note

If modelling a reading taken at only one station location, it is not possible to display a profile of the data. The response can be viewed in a Decay display format if required. The initial creation of a layered earth model is done by creating the layers within the Earth Properties option without a display of the earth cross-section.

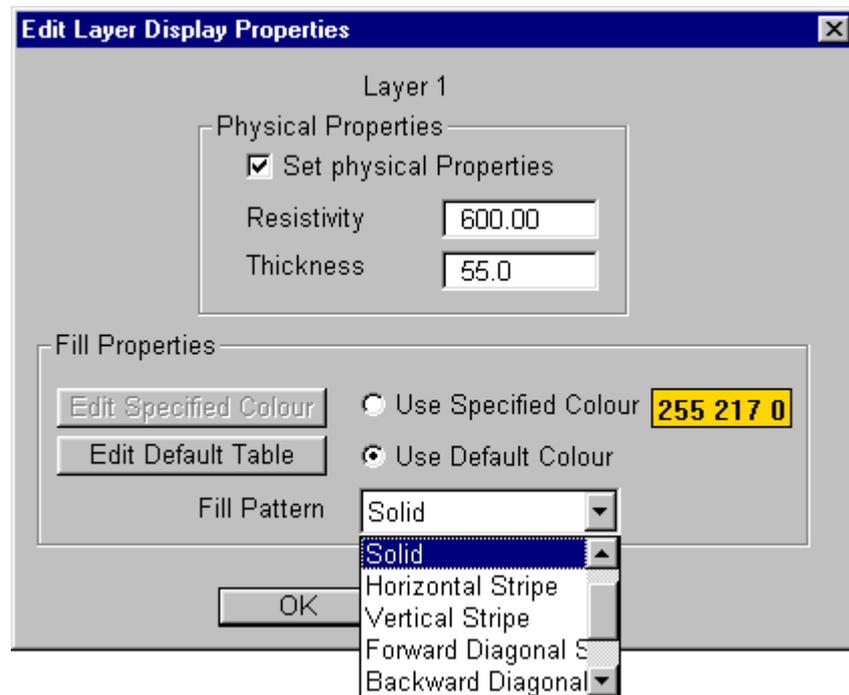
Controlling the Presentation of Layers

The section on *Earth Properties* and *Setting Individual Station Properties* describes the method of specifying a layer's thickness and resistivity properties. The appearance of layers, both on the screen and in hardcopy can also be controlled by allocating colours to specific resistivities.

To graphically alter the properties or colour of a layer, move the cursor over the desired layer and while positioned there, double click the left mouse button. A

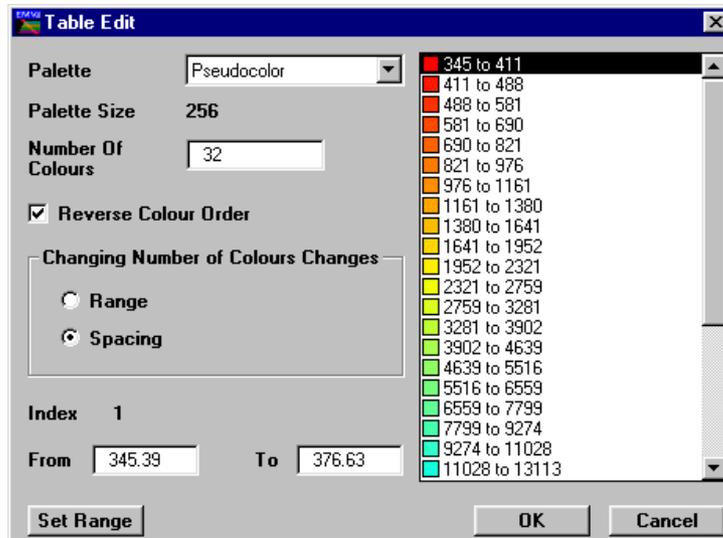
dialog indicating the layer colour and the properties is displayed. The properties can be altered by editing the values displayed.

The colour of a layer is indicated in the central indication box of the dialog and within this are Red:Green:Blue colour values indicating the mix of primary colours used to display the layer. This Default Colour can be altered by selecting the **Use Specified Colour** button. When activated, this button causes the **Edit Specified Colour** push button to be available. Selecting this button provides a dialog enabling you to modify the layer colour as required.



Editing the property or display attributes of layers

Control of the palette and the range of resistivities that can be presented is made available by the **Edit Default Palette** push button. This button is activated by selecting the **Use Default Colour** option. When the activated palette button is pressed a dialog that enables the mapping of resistivities to various colours is displayed:

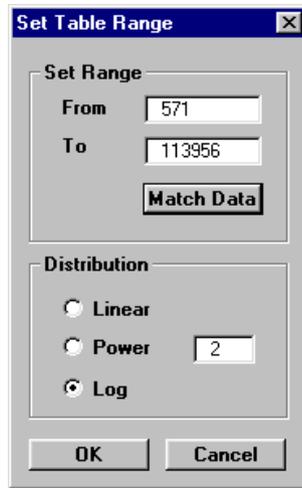


Editing layer resistivity colour mappings

This dialog allows standard colour palettes to be used to map the presentation colours of various layer resistivities. The Palette option specifies the standard palette files stored in the directory specified by the LUTDir parameter of the EMVIS.INI file (see *The EMVIS.INI Defaults File*). Note that these palettes are identical to the format used by ER Mapper (refer to *the ER Mapper Reference Manual* for details on look-up table specifications).

Palette sizes are typically composed of 16 or 256 colours. The number of colours derived from the palette is definable. The actual mapping of colours from the palette is seen on the right of the dialog in a scrollable list with the associated resistivity ranges. The list is made up of ‘from and to’ resistivity pairs that can be controlled specifically in the ‘**From**’ and ‘**To**’ entry fields. To modify a resistivity range for a specific colour mapping, position the cursor over the required colour entry and highlight it with a left mouse button click. The ‘From’ and ‘To’ resistivity values can then be altered in the entry fields.

If you wish to re-map the entire resistivity range to comply with a specific resistivities, select the **Set Range** button.



Dialog to control the range and look-up table for colour mappings

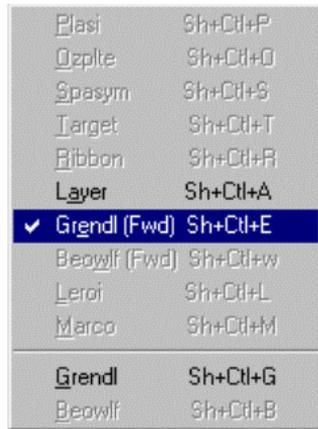
The upper and lower resistivity range can be defined and the distribution method of mapping the resistivity range across the colour mappings can use one of three methods:

- Linear provides a smooth distribution from highest to lowest resistivity.
- Power distribution of nth power.
- Logarithmic distribution.

The **Match To Data** button will force the From and To data values to match the minimum and maximum of the data contained in the dataset.

Algorithm Option

The Algorithm option in the Modelling menu is used to select GRENDL in either a forward or inversion mode. The two occurrences of GRENDL in the Algorithm menu item appear as shown. The upper GRENDL entry is for forward modelling as indicated.



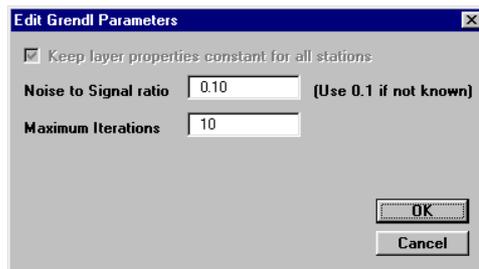
All implemented modelling programs are contained in the displayed menu list but not all algorithms will have been made accessible. When a program is not available or is not correctly configured, its entry on the Algorithm menu list will not be highlighted.

Even if a program is installed, access may be denied by EM Vision if an incorrect survey configuration or instrument combination has been set. For example, if fixed loop (Turam) survey data is imported, both forward and GRENDL options is not available since it is unable to operate on fixed loop data. Similarly, a layered earth model disables access to PLASI and OZPLTE.

Note

In the event that **NO** algorithm option, or the algorithm required is **not** available for selection when you think it should be, refer to *Non- Accessible Programs*.

Once the GRENDL algorithm is chosen, a dialog confirms its selection. In the case of GRENDL Forward operation, a message dialog will appear. In the case of GRENDL Inversion, an additional dialog will be presented.



Dialog to control GRENDL parameters

Options available enable the user to define the noise to signal ratio and the maximum number of iterations for each sounding. The noise to signal ratio is used within GRENDL to control the relative eigenvalue threshold used in the critical ‘ridge’ regression of the inversion. The ratio supplied is the minimum allowed value for this threshold. If a larger noise to signal ratio is specified, faster but less accurate solutions to the inversion will be derived. For precise results where a solution can be reached, use a smaller noise to signal ratio.

The number of iterations determines the upper number of iterative steps that GRENDL will perform in determining an inversion solution. Usually about 10 iterations is satisfactory, but up to 20 may be specified.

It is also possible to keep the layer properties static for all stations being inverted and this is the default setting. It is however possible to set a different ‘seed’ model for each sounding. Refer to *Setting Individual Station Properties* for further information.

Set Active Option

The modelling process involves creation of a model, data and survey definition and selection of an algorithm. The only remaining step prior to initiating GRENDL is to define which delay channels and readings are to be modelling. This is done by the Set Active option of the Modelling menu.

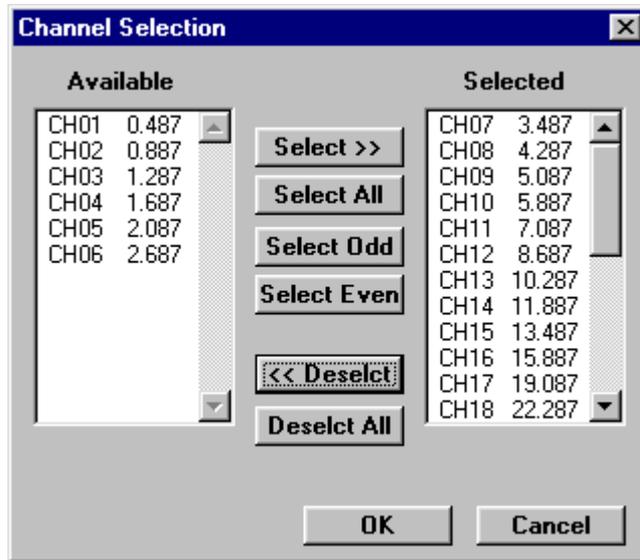
Modelling computations can be restricted to user defined delay channels and data readings. Channels and readings available for modelling are referred to as active.

Note

By default, EM Vision makes all data initially active.

Setting Channel Activity

The Set Active option for channels presents the Channel Selection dialog as below. Nominate the channels to be modelled by taking into account any early time noise or response behaviour which is uncharacteristic of expected decays. Similarly, late time noise can be derived from instrumentation, geological and cultural sources.

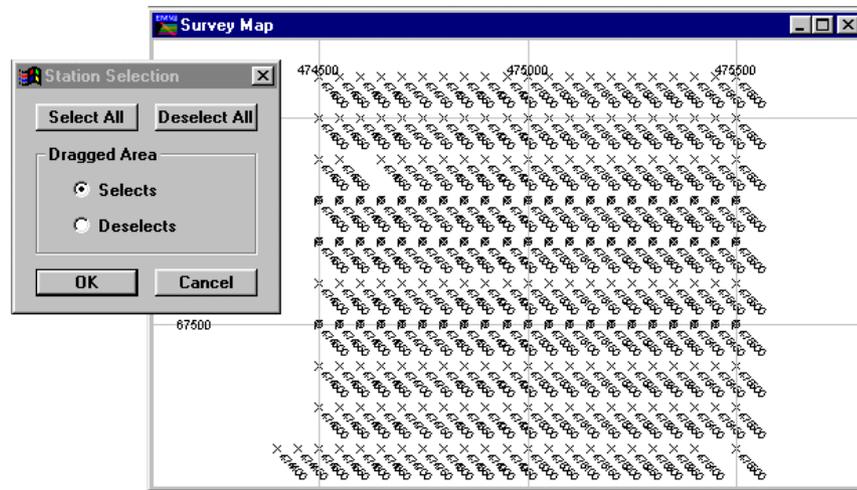


Channel selection dialog

The channels on the right scroll list is regarded as active for the applied modelling.

Setting Station Activity

Defining which data readings are to be modelled is controlled by the **Set Active>Stations** option. When selected a dialog accompanied by a survey map of the available station locations will be displayed. Initially all readings will be highlighted indicating their active state. Within the dialog you can **Select All** or **Deselect All** readings. Also, within the dialog you can choose to use the cursor to **Select** or **Deselect** stations. To use this method, choose one of the two options and then move the cursor to the survey map. When the left mouse button is pressed and the cursor moved a dashed rectangle is drawn.



Station selection for modelling

When the mouse button is released, all the readings enclosed within the rectangle alters their activity state to match that set in the dialog.

To reverse the activity of individual stations, despite the **Dragged Area** selection, you can position the cursor over a reading and then click the left mouse button. This technique toggles the activity state of the station.

Compute Model

Once the data, survey, algorithm and model have been defined and the desired channels and data readings made active, GRENDL can be initiated. EM Vision can execute the program by selecting the Compute Model option of the Modelling menu, or by pressing the **Compute** button on the Tools toolbar.

GRENDL uses the Generic Modelling Interface to operate and so is executed externally from EM Vision. In these cases, an icon will appear in the Windows status bar that indicates that EM Vision has initiated the program in an external portion of memory. This icon should not be selected while the program is running. For additional information on the icon settings and its operation, refer to *Controlling Algorithm Access*.

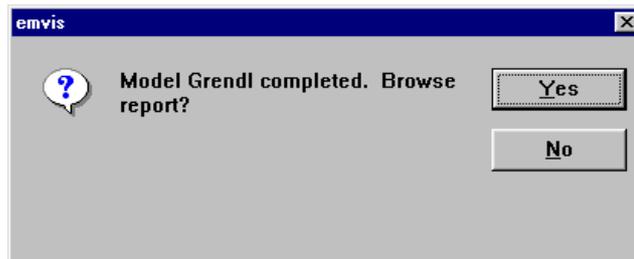
Progress of modelling is indicated by a slider bar with a percentage of completion. In cases where GRENDL is to be halted during execution, the progress bar has a **Cancel** push button. If you select this button, the program will abort. After the program has been aborted, status files and results to that point

will be available for examination. These files along with control and model files will reside in the project directory as defined by the import data.

Once a program has been halted, modifications to the model, channel and station activity can be made and the program re-initiated. Halting and re-executing the program can be undertaken any number of times.

Running GRENDL in Forward Mode

If the algorithm selected (see *Algorithm Option*) is GRENDL (FWD - Forward), the progress bar moves as computation of the response is calculated. As GRENDL operates, it creates text result files which, can be viewed when execution is completed. At completion, a dialog enabling access to the text results is presented as shown. If you select **Yes** to browse the report, the text editor as specified in the EM Vision defaults file (see *The EMVIS.INI Defaults File*) will be initiated and it automatically loads and displays the GRENDL results.



Message displayed at the conclusion of GRENDL

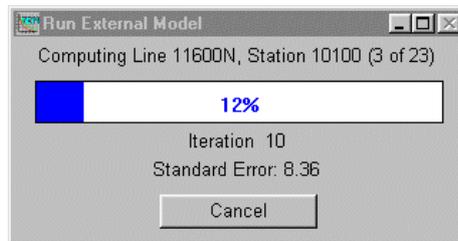
After browsing the results, or after selecting **No** in the dialog above, EM Vision displays the modelled responses in any displayed profile window that has the Model Display option enabled (refer to *Profile Selection*).

Running GRENDL in Inversion Mode

The inversion operation of GRENDL is markedly different from the forward operation since user feedback and display of inversion convergence are important aspects of the operation.

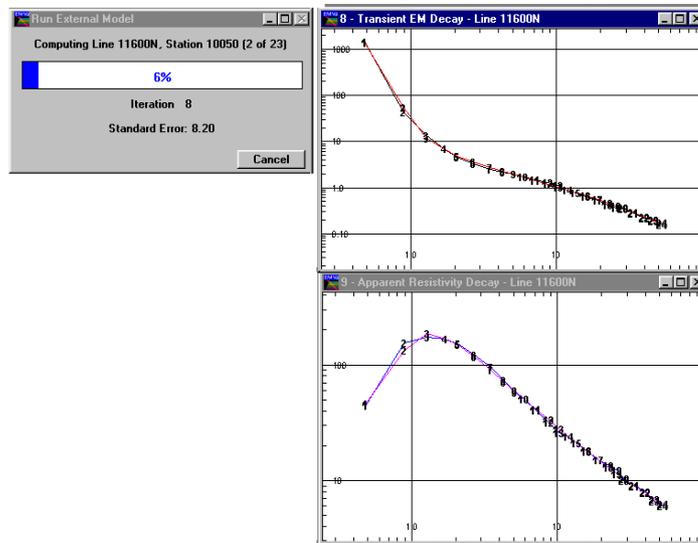
After definition of the data, model, reading and channel activity, initiation of GRENDL Inversion results in four new objects appearing on the screen. These objects include:

1. An icon in the Windows status bar. This icon indicates the execution of GRENDL externally to EM Vision under Generic Model Interface control.
2. A progress bar which contains not only an indication of computation progress, but also a **Cancel** button and an indication of the standard error between the computed and observed results for the station being modelled. The iteration number of the processing for each station is also displayed along with the station number and location (easting/northing).



3. Comparative decay results between observed and computed TEM voltages. These displayed results give an indication of the accuracy of the initial 'seed' model between the computed and observed responses. If the results are widely separated, you may wish to halt the inversion, modify the layered earth properties, and then recompute the response.
4. Comparative results between observed and computed apparent resistivities. Note that these results will not initially be displayed for the first iteration (labelled as Iteration 0 in the progress window) since results at that point have not been returned to EM Vision from GRENDL.

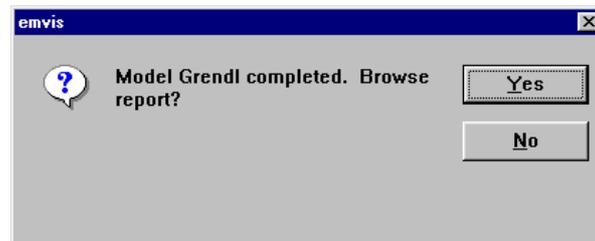
As for the displayed voltage comparisons, these results enable an assessment to be made of the original 'seed' model. The apparent resistivities will have a greater numeric range of values and may not vary in a decaying manner. Changes of curve slope and shape will also provide much higher sensitivity to the 'goodness-of-fit' between the computed and observed results of apparent resistivities. An example of the compared response and apparent resistivity display follows.



Response and apparent resistivity decay comparisons during a GREN DL iteration

As GREN DL progresses across a displayed profile it also displays the modelled response and resultant layered earth model in addition to the observed profile data. Refer to the *GREN DL Tutorial* for further explanation.

As GREN DL operates, it creates text result files that, when completed can be viewed. At completion, a dialog enabling access to the text results is presented as shown. If you select **Yes** to browse the report, the text editor specified in the EM Vision defaults file (see *The EMVIS.INI Defaults File*) is initiated and automatically loads and displays the GREN DL results.



For an example of the text file results and an analysis of the file contents, refer to the *GREN DL Tutorial*.

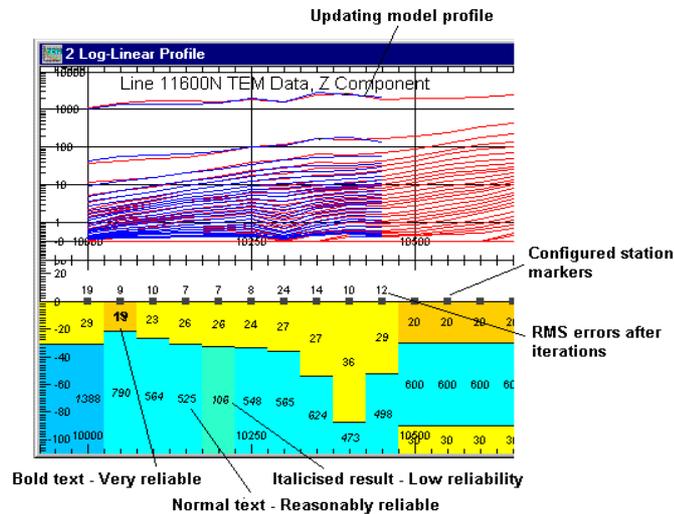
After browsing the results, or after selecting **No** in the dialog above, EM Vision will display the modelled results in any displayed profile window that has the Model Display option enabled (refer to *Profile Selection*).

Display of Errors from Inversion

At the conclusion of some inversion modelling programs (e.g. GRENDL), a report is produced. The errors reported in the GRENDL output report are useful, (see *GRENDL Operating Manual*) but a more graphical method of examining errors and inversion accuracy can be gained by displaying the computed errors of a GRENDL inversion in conjunction with the model and profile results. Note in the Layer Configuration dialog (see below) that a Data Channel called STDERR is present.



If the Data Channel (STDERR) option is enabled and the channel selected, it is possible to display the earth section with RMS errors (as percentages) for each station.



Plotting of errors along the top of a GRENDL inversion section.

A second indication of the errors associated with results for an inversion relate to the text used for the posted resistivity values in the model section. Three levels of importance are assigned to these:

- Bold text** = Low error, high reliability
- Normal text = Reasonable result, moderate error
- Italicised text* = Poor result, high error and risk.

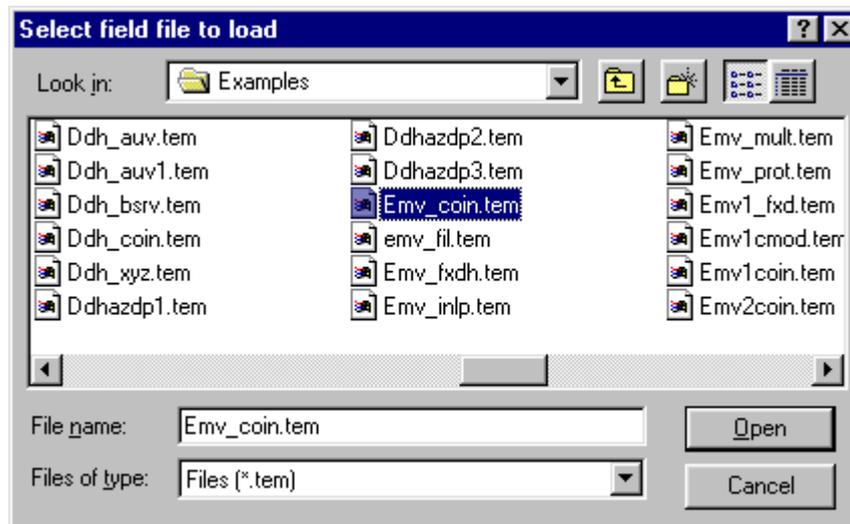
If there is insufficient space between the base of the data track and the top of the model, you can adjust the size of this space by allowing a greater distance (depth) above the model. Use the Min/Max vertical axis settings of the Drawing Configuration dialog to do this. Ensure the Earth Section track is the selected entry in the Drawings list at the top of the dialog before altering the depth values.

2 GRENDL Tutorial

The following section is a brief tutorial to explain the normal methods of operating GRENDL. The dataset to be used for this exercise is supplied with EM Vision and is called EMV1COIN.TEM. The file will be read into the EXAMPLES subdirectory during installation of EM Vision. The tutorial is presented as a number of critical steps. Within each step where applicable, some additional information will be provided to assist you in understanding alternative analysis or display options.

Step 1 - Import the data

Import the EMV1COIN.TEM data file using the **Data>Open Field Data** option (or the TEM import icon) as shown below:



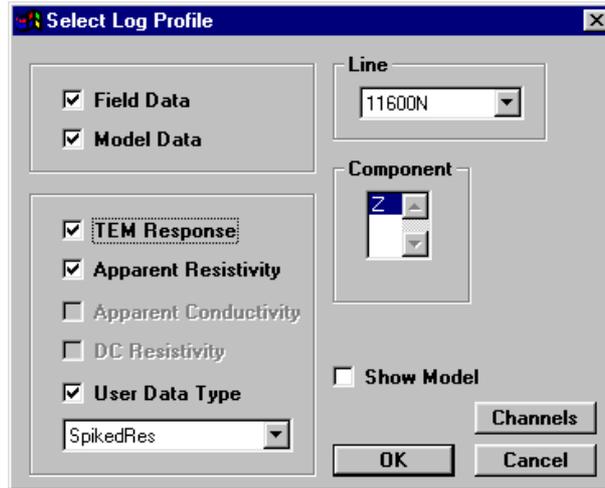
File selection dialog for tutorial data file.

The data is read (indicated by a progress bar) and then an explanatory dialog describing the data is presented. The data file has been acquired using standard time channels on a SiroteM Mk3 with a 100 x 100 metre square coincident loop survey configuration. Only a single line of data is contained in the file.

Step 2 - Examine the data by profile display

The data needs to be displayed as a profile to create layers for modelling with GRENDL. Select the **Display>Profile>Linear-Linear** or Log-Linear option.

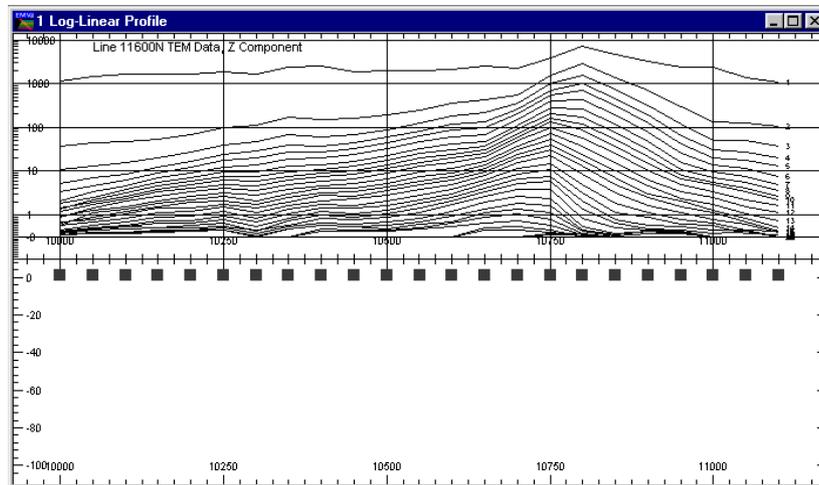
Note that to present the profile with a section area beneath, the **Show Model Section** check box needs to be enabled.



Selection dialog for the required profile.

It is also advisable to enable the **Model Data** check box, as GRENDL then displays the theoretical responses automatically as it executes.

Once these items have been selected and **OK** pressed, the display is presented.



Display of profile with earth section beneath.

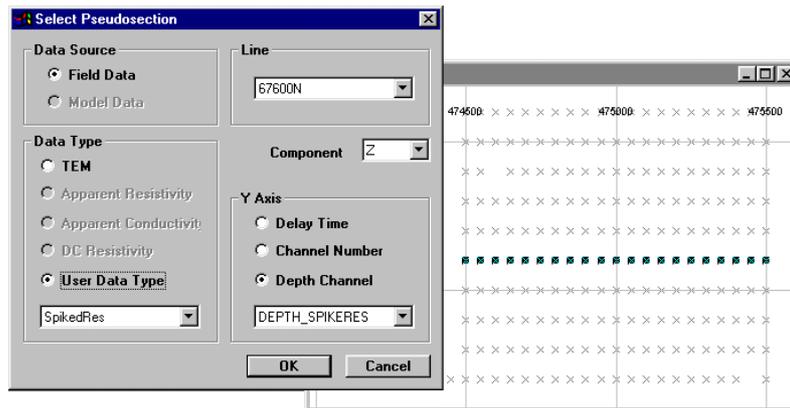
In the above display, an empty section beneath the data is provided, but at the top of this, small marker symbols appear at the site of each data reading. In this display, a log-linear profile has been used, but linear-linear, multi-track or predefined style could also be used.

Step 3 - Obtain an estimate of the resistivity section

In some circumstances, you will have some idea of the earth resistivity and how many layers will adequately represent the electric section. This information may be known from IP studies, DC soundings or a general knowledge of the regional resistivity. Often these ideas are satisfactory to develop a suitable initial 'seed' model.

If you do not have an understanding of the electric section, a good guide can be derived from the resistivity computation operations provided in the Operations option of the Data menu item. Select this, and choose the Apparent Resistivity item. Either the Raiche/Spies (asymptotic formula) or the Spiker algorithm can be used. A benefit of the Spiker formula is that an indication of depth is also computed.

One of the best graphical methods to display the apparent resistivity computed results is by using a text presented Pseudosection, Multi-Track display or Point Section. To present the apparent resistivities in this way, select the **Display>Pseudosection** option and nominate the Spiked Resistivity data to be displayed with a vertical (Y axis) scale of Depth Channel as shown below (assuming the Spiker algorithm was used).



When you select the **OK** button, the Pseudosection (or Point Section) display but is by default, be presented with a colour or shaded image of the apparent resistivities. By positioning the cursor in the window and pressing the right

mouse button, the Pseudosection configuration dialog is presented. On this, enable the Style to be **Text** only. If when you redisplay the pseudosection, (by selecting **OK**), the numbers are too small or overpost each other, again display the configuration dialog and reduce the vertical depth range of the section to expand the resistivity values. For this dataset, a good setting is with a depth range between 0 and 300 metres.

From the displayed values, note that the shallow values are typically of low resistivity (approximately 1-2 ohm.metres), the central values increase to 200-2500 ohm.metres and then at deeper levels they again decrease, in some instances to 70-150 ohm.metres. The earth resistivity structure is therefore conductive near surface, resistive, and then underlain by a conductive basement.

This has therefore provided an initial guide to the resistivity structure along the profile. A three layer model should be used and with similar resistivities to those described above.

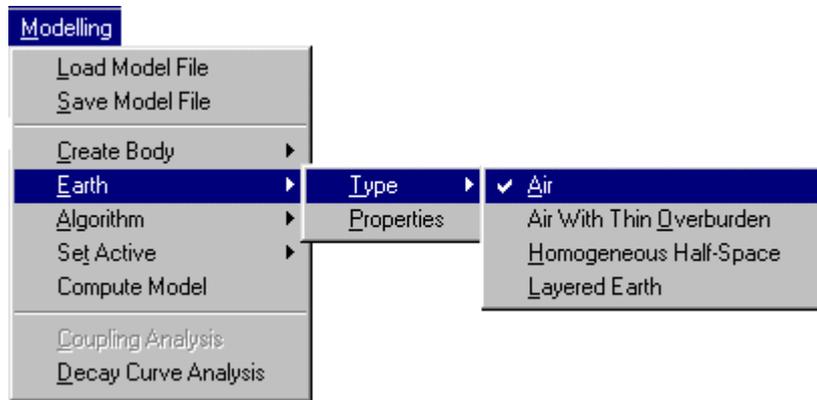
Step 4 - Define the Earth Type

The Earth option of the Modelling menu is used to define the Earth Type and assign its properties. Various Earth types are available to satisfy the many host environments that can be modelled but in the case of GRENDL, the only Earth Type available is the Layered Earth.

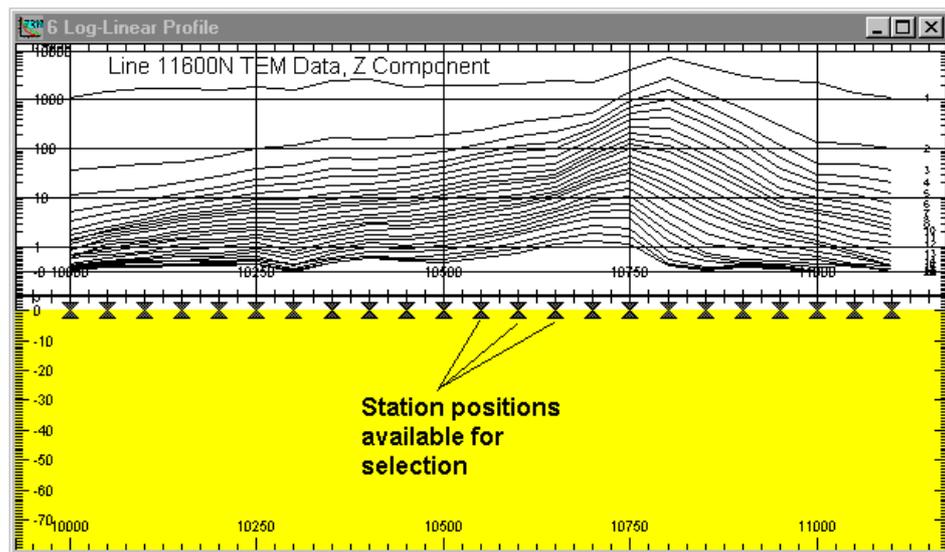
Note

Unless the correct information is specified in terms of model type, Earth host and defining parameters, the GRENDL algorithm will not be accessible and will appear 'greyed' out in the Model/Algorithm menu option.

When selected, the Earth option provides two alternatives - Type and Properties. Type should be set to Layered Earth for GRENDL.



When the Layered Earth option is initially selected, if a profile with cross-section is displayed, the station locations and a single basement 'half-space' layer is drawn.



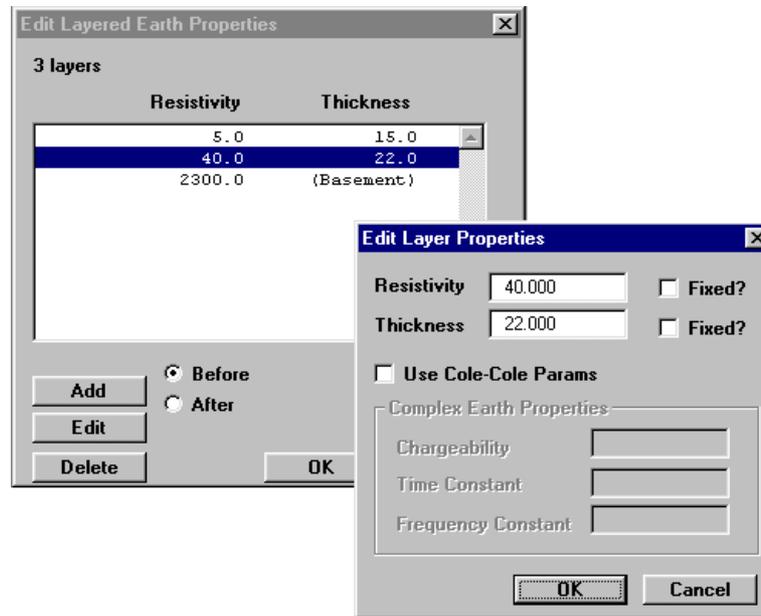
Profile with basement layer and reading locations (marker symbols)

On the surface of the basement layer are a number of station marker symbols. These locations mark the position of each individual reading for this profile.

Step 5 - Defining the Layer Properties

As shown above, a single basement 'half-space' for the displayed profile has been presented. Additional layers and with individual resistivity properties can be

added by selecting the **Modelling>Earth>Properties** menu option. When this is done, a dialog is presented which describes the existing layer properties of Thickness and Resistivity (initially for only the Basement layer).



Adding and editing Layered Earth properties

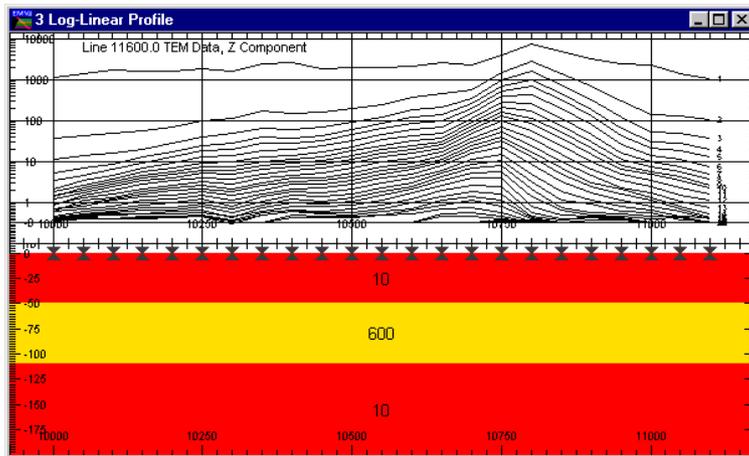
To add layers, select the **Add** button and enter new resistivity and thickness properties. When adding a layer, it is added either before or after the highlighted layer depending on the **Before** or **After** button selected.

After a layer has been created, it can be edited by either highlighting it in the Edit Layered Earth Properties dialog and selecting the **Edit** push button, or, alternatively, positioning the cursor over the desired layer and double clicking with the left mouse button.

A layer can be removed by highlighting it and then pressing the **Delete** push button. For the model and data being simulated here, we have determined a three layer case is applicable. As an initial 'seed' model, use a 1 or 2 ohm.metre resistivity of 5-10 metres thickness over a 550-600 ohm.metre layer of 80-100 metres thickness. A conductive basement of 80-100 ohm.metres should complete a suitable initial model.

Step 6 - Modifying Layer Properties and Colour

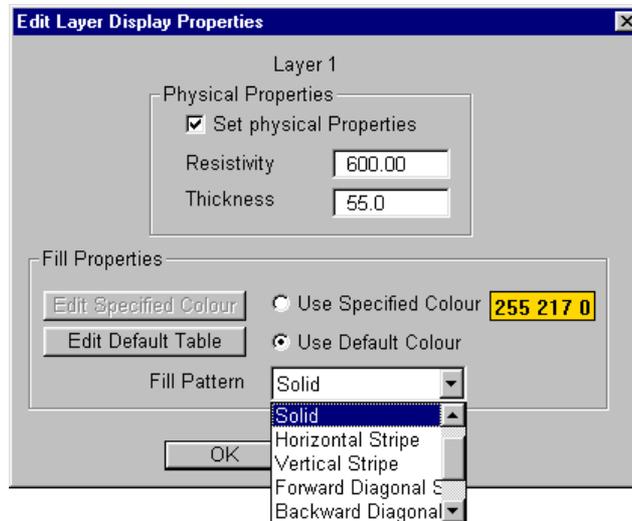
After defining the layers, the properties and appearance of each layer can be altered graphically. In the diagram below, three layers with different resistivity and thickness properties are shown. Note that the bottom layer represents the basement and so has infinite thickness.



Three layers of different resistivity and thickness properties

To graphically alter the properties or colour of a layer, move the cursor over the desired layer and while positioned there, double click the left mouse button. A dialog indicating the layer colour and the properties is displayed. The properties can be altered by editing the values displayed.

The colour of a layer is indicated in the central indication box of the dialog and within this are Red:Green:Blue colours indicating the mix of primary colours used to display the layer. This Default Colour can be altered by selecting the **Use Specified Colour** button. When activated, this button causes the **Edit Specified Colour** push button to be available. Selecting this button will provide a dialog enabling you to modify the layer colour as required.



Dialog for graphically editing a layer's properties

Additional modifications to colour settings of layers can be obtained by selecting the **Use Default Colour** option. Refer to *Controlling the Presentation of Layers* for further information.

Step 7 - Controlling Layers of Individual Stations

GRENDL operates on single TEM soundings and computes or inverts their response before moving to the next active reading. This means that EM Vision can supply GRENDL with individual station models. The individual sounding models will act as different layered earths in a GRENDL forward modelling operation but will serve as different 'seed' models in the case of an inversion GRENDL run.

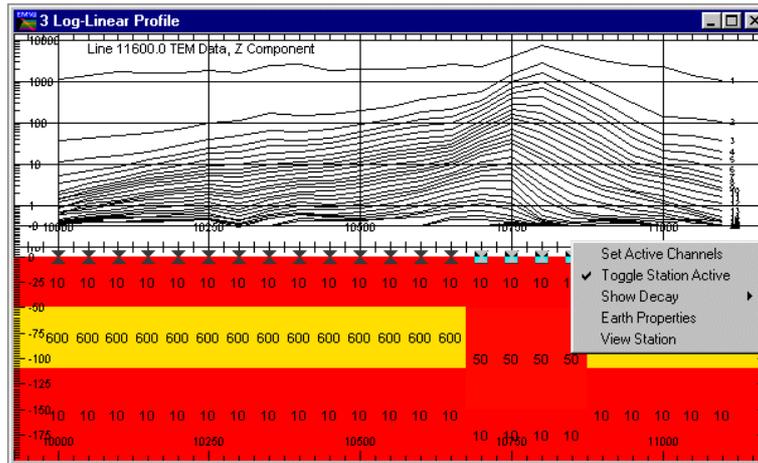
To set the properties of a single sounding independently of surrounding stations, the 'X' marker symbols which appear along the top surface of the uppermost layer are used. The marker symbols can be configured to be any size or symbol type (refer to *Setting Properties of Individual Stations*). Position the cursor over the symbol for the required station and click the left mouse button. The symbol will be highlighted when selected. If difficulty is experienced in selecting the symbol, press the CTRL key at the same time as the left mouse click.

Once selected, the standard Earth Properties dialog can be displayed by either positioning the cursor over the selected station symbol and double clicking the left mouse button, or pressing the **Properties** push button on the Toolbar.

Note

If a grouping of stations are to be modelled with different layer properties from other readings, these station marker symbols can be grouped by positioning the cursor above the first reading required and then, with the SHIFT key held down, select the other required stations in the group. Using this technique, it is not necessary that adjacent readings are selected. They can be selected from any location on the profile. As before, if difficulty is experienced in selecting individual station marker symbols, use the CTRL key as well as the SHIFT key.

Further assistance in selecting marker symbols can be achieved by providing greater space in the track above the symbols. To control this, reduce the minimum Earth Section setting (see *Profile Window Configuration*).



Cross-section with modified individual reading properties

WARNING

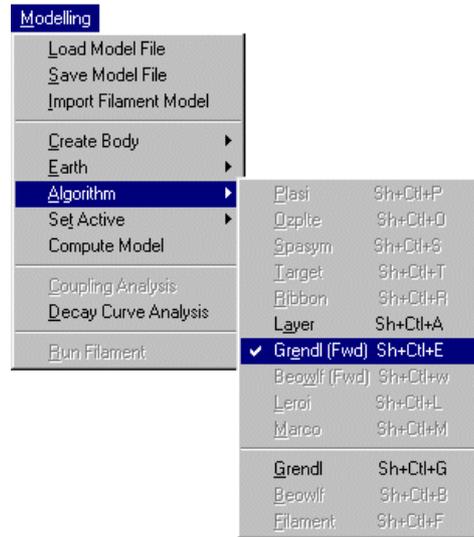
When a group of readings are selected for individual layer property control, do not double click to display the Earth Properties dialog as this will reset your station selections. To set the properties, use the **Properties** push button located on the Toolbar.

Note

When only a single TEM sounding is available, it is not possible to display the data in profile form. In this case you can display the data as a single station decay and then create a layer model from the menu option of **Modelling>Earth>Properties**.

Step 8 - Define the Algorithm

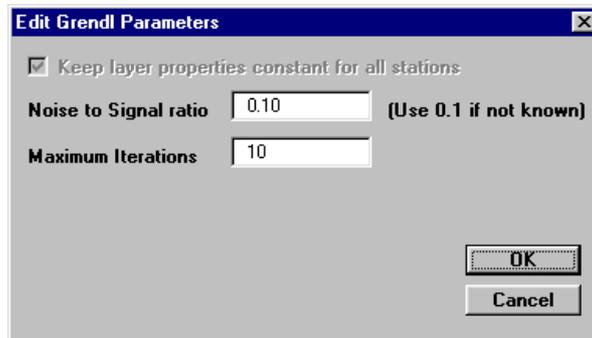
Once the earth model is defined (see Steps 5-7), you must decide whether to model using GRENDL in either forward or inverse mode. To set the algorithm, select from the menu **Modelling>Algorithm**. The menu appears as shown below.



A horizontal line in the Algorithm menu list separates the available forward programs from the inversion programs. Note that many algorithm names are not available for selection. If the algorithm you require is not available, refer to the section on *Controlling Algorithm Access* and the *Algorithm Option* of the main EM Vision Manual. Some typical causes of an algorithm not being available include:

- Algorithm option not purchased or licensed.
- Inappropriate survey configuration for algorithm required. For example, GRENDL will not operate with Fixed Loop survey configurations.
- Incorrect settings of the Generic Model Interface. For details of this refer to the *Generic Model Interface*.

Select GRENDL to operate in either the forward or inversion mode. If forward mode is requested, EM Vision will display a dialog to report that this mode has been selected. If GRENDL inversion mode is chosen a dialog to control the number of iterations and noise-to-signal ratio is displayed.



GRENDL inversion control parameters

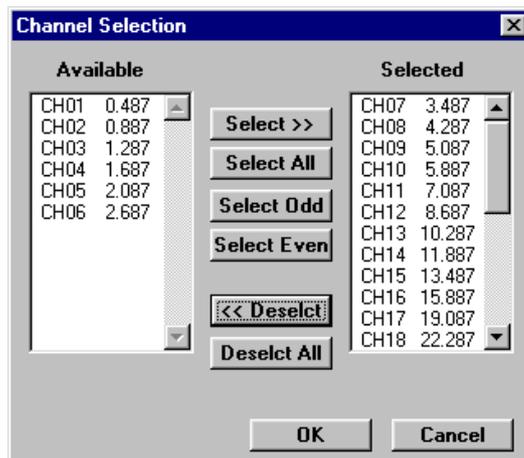
For most TEM datasets the maximum number of iterations should be approximately 10-15. For rapid (but inaccurate) results, a model can be derived with 3-4 iterations.

Initially set the Algorithm to GRENDL FORWARD (see *Step 11*) and then set the Algorithm option to GRENDL Inversion (see *Step 12*).

Step 9 - Controlling Which Channels to Model

By default, GRENDL will model all data channels available. If early or late time noise is present in the data being modelled it is often a good idea not to model the noisy channels. Using the **Modelling>Set Active >Channels** option it is possible to 'turn off' certain channels which are not to be computed by GRENDL.

When the option is selected the standard channel selection dialog as shown below is presented.

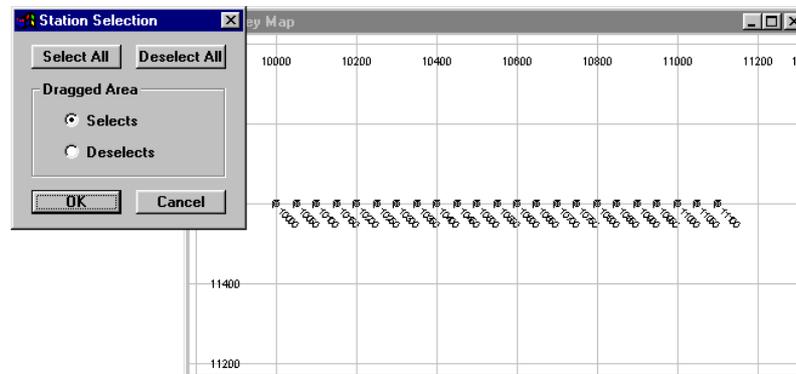


Channel selection dialog for channel activity

Refer to the section on *Standard Operations* for details on selecting and deselecting channels.

Step 10 - Controlling Which Stations to Model

The GRENDL program models station responses individually. This means that you can control on which stations you wish GRENDL to calculate responses. This control is provided by the **Modelling>Set Active>Stations** option. When selected the option presents a dialog accompanied by a survey map of the data loaded as shown below. Using the dialog options, individual or groups of stations can be selected as being 'active'. Stations that are highlighted are deemed to be active.



Setting stations to be active for modelling

It is possible to drag a rectangle over one or more stations and select them as active or inactive, depending on the setting of the dialog. To do this, position the cursor where appropriate and then press the left mouse button while moving the mouse. A rectangle will be created and all stations contained in this will be selected.

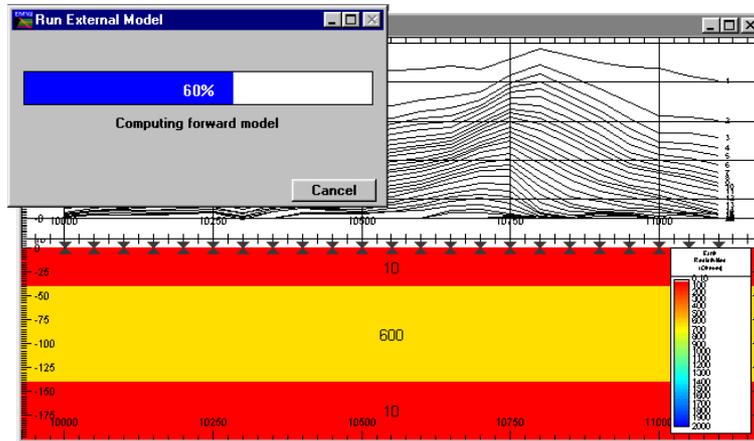
Step 11 - Computing a Forward GRENDL Model

After creating a model and setting the activity and algorithm appropriately, you can initiate a forward GRENDL model in one of two ways:

- Press the **Compute** push button on the Toolbar.
- Select the **Modelling>Compute Model** option from the menu.

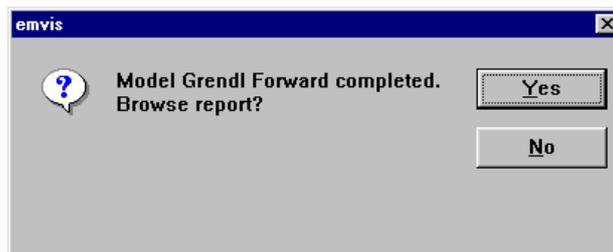
When GRENDL is initiated a progress bar is displayed as the program computes the individual station responses. The program examines stations ahead of the current one being computed and will only compute those with different layer properties. This in-built feature ensures that the forward computation operates efficiently and repeat computations are not performed.

As responses are derived, the progress bar will be updated but also the model response will be displayed (assuming the Model Response option was enabled during the profile display).



Forward model with modelled and observed responses

The program will continue executing until all stations and channels are completed. If you require, you can terminate a program run early by selecting the **Cancel** button. On normal termination of the program, a file will be written which contains computed results for each station. A dialog appears that enables you to examine this results file (see below).



Dialog used to examine results text file

The text editor used to examine result files is specified in the EMVIS.INI defaults file (see *The EMVIS.INI Defaults File*). The Windows program NOTEPAD or WORDPAD are usually used to examine the file. If you examine the text file, the content provides information on:

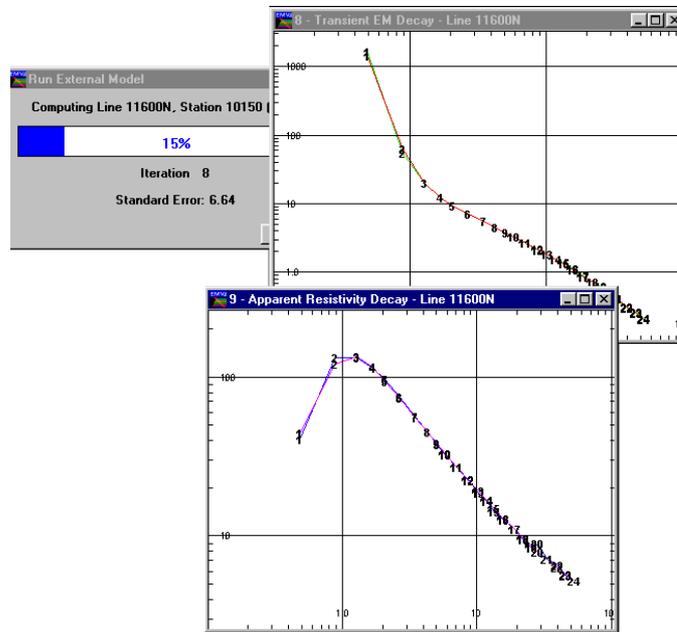
- The initial model (for each station).
- The control parameters for ramp, delay times, etc.
- The computed and observed responses and computed apparent resistivities.

Step 12 - Computing an Inversion GRENDL Run

When a GRENDL inversion is initiated (using the **Modelling> Compute Model** option or Toolbar **Compute** push button is used), operation is different to that of forward operation. As inversion is an iterative operation, it is useful for the user to see results and model parameters change as the inversion progresses. Consequently, after GRENDL is initiated, three new display windows are presented. These are:

- A progress bar that displays not only the station number, iteration and incremental progress, but also the Root Mean Square error between the computed and observed responses.
- A decay display (for the computed station) comparing the measured and computed model TEM voltage responses.
- A decay display (for the computed station) comparing the calculated and computed model apparent resistivities. This display is especially diagnostic in determining if the initial ‘seed’ model is appropriate for the data being modelled.

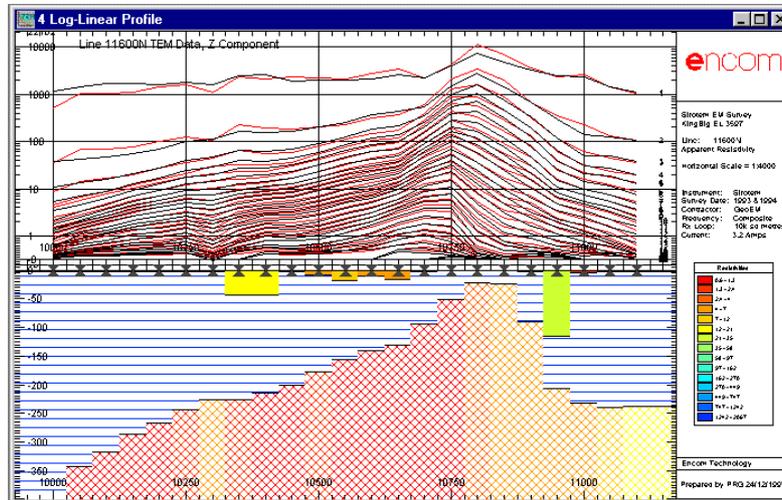
An example of these three displays follows.



Progress bar, and decay comparisons of voltage and apparent resistivities

The comparison of the decay curves is a critical indicator as to the quality of the initial ‘seed’ model. In the case above, the apparent resistivity display indicates that the earth structure is going from conductive to resistive and returning to a conductive basement. This is much less obvious from the Voltage display window although the change in decay between channels 5 and 10 is diagnostic.

As the inversion progresses across the active stations, a model response curve can be made to display with the observed response. In addition, the modified ‘seed’ models will reflect the re-modelled layer properties derived from the GRENDL inversions. A final model after the inversion has completed is shown on the following page.



Completed GRENDL inversion with modified layers and model response curves

Similar to a forward GRENDL program run, when an inversion is terminated, a report file is generated. The report will contain the initial and final model details, control parameters plus response and apparent resistivity results.

Note in this display that the layered results are shown with patterns rather than solid colours. This presentation style is often preferred over a solid layer representation when a colour printer is used for final hardcopy output.

Step 13 - Analysing the GRENDL Results File

To graphically assess the errors derived from a GRENDL inversion, see *Display of Errors from Inversion*.

In addition to the basic results described above, a number of diagnostic analyses on the inversion are also provided. In the examples provided below, a three layer model has been used for the GRENDL model (therefore three resistivities and two layer thicknesses are analysed). An eigenvalue and a correlation matrix analysis is performed for each station inverted. These analyses provide excellent assessment of the results obtained for inversions using GRENDL.

Eigenparameter Matrix Analysis (EP)

You can judge the performance of inversions from a combination of the damping factors, the \mathbf{V} matrix (the Eigenparameter matrix) and the calculated error bounds. An example of this analysis is provided below for a model with three layers as detailed in Hohmann and Raiche (1987). This model used a 100

ohm.metre overburden, conductive intermediate layer (0.25 ohm.metres) and resistive basement (1000 ohm.metres).

The columns of the \mathbf{V} matrix correspond to the eigenparameters (EP) and the rows to the logarithms of the physical parameters resistivity and thickness. A damping factor above 0.9 indicates that the associated eigenparameter is well resolved. Damping factors less than 0.8 imply that the resolution of the eigenparameter is less well resolved. Damping factors less than 0.1 imply that the eigenparameter is completely unresolved.

```
*****
* LAYER THICKNESS PARAMETER SENSITIVITY ANALYSIS *
*****

THE NUMBER OF EFFECTIVE PARAMETERS IS 2.001
PARAMETER SPACE EIGENVECTORS (VMATRIX)

          EP1      EP2      EP3      EP4      EP5
LOG(RES1) 0.026  -0.023   0.091  -0.121  -0.988
LOG(RES2) 0.678   0.015  -0.727  -0.101  -0.037
LOG(RES3) 0.008   0.006   0.136  -0.982   0.133
LOG(THK1) 0.118  -0.989   0.086   0.011   0.032
LOG(THK2) -0.725 -0.148  -0.661  -0.107  -0.063
Damping Factors 1.0  1.0    0.96   0.094   0.028
```

As shown in the example above, clearly EP1, EP2 and EP3 are well resolved. EP4 is poorly resolved and EP5 is unresolved. Since each of these eigenparameters is a linear combination of logarithms of physical parameters, we can estimate the resolution of different aspects of the final model.

For example, EP1 and EP3 consist of the second layer resistivity-thickness quotient and product respectively, so the resistivity and thickness of the second layer are each well resolved. EP2 shows that the depth to the conductive layer is well resolved. EP4 and EP5 have very low damping factors. Consequently basement and overburden resistivity are not at all resolved. These assessments are also supported by the statistics provided in the 95 percent confidence intervals as shown below:

```
Error bounds for TEM inversion
      Bound(1)      Bound(2)
Layer resistivities - 95 percent confidence interval
(undamped)
```

RES1	22.270	0.0024	206086.2100
RES2	0.186	0.0911	0.3812
RES3	240.800	2.9151	19889.0500

Layer thicknesses - 95 percent confidence interval
(undamped)

H1	34.3540	25.1844	46.863
H2	7.3392	3.1302	17.208

Correlation Matrix Analysis

The correlation matrix analysis is also a useful component of assessing the confidence of solutions and interactivity of parameters. The matrix has vertical columns in the same order as the eigenparameter \mathbf{V} matrix.

CORRELATION MATRIX

1	1.000	.482	.305	.985	-.946
2	.482	1.000	.692	.619	-.696
3	.305	.692	1.000	.394	-.513
4	.985	.619	.394	1.000	-.977
5	-.946	-.696	-.513	-.977	1.000

The correlation matrix analysis provides estimates of the confidence that can be placed on the results of various layer parameters derived from the inversion. The matrix is displayed with the three resistivities and two thickness correlations listed as 1-5 vertically against five vertical columns. Each of the columns reflects the same parameters horizontally. Note that the central value of 1.00 indicates that the parameter correlates on a 1:1 basis with itself. Alternatively, in the above example, the first layer resistivity result correlates with a factor of 0.985 with the first layer thickness. This indicates that a variation of either first layer thickness or first layer resistivity would result in an equivalent change in the other property for this layer. Conversely, there is only a small correlation in effect between the first layer and the third layer resistivity (0.305). Other similar conclusions can be drawn between the various parameters.

Analysis using the APRE Parameter

One of the most useful statistics in finding a model consistent with the data is the average predicted residual error (APRE). Consider the problem of fitting a model to N data points. Suppose one data point is removed and a model is fitted to the remaining $N-1$ points. We use this model to calculate a value for the eliminated point. The difference between the calculated point and the original point is the predicted residual error. If each of the N points is deleted in turn and a model is

fitted to the remaining N-1 points, APRE is the root-mean-square predicted residual error.

In practice, APRE exhibits a sharp minimum for the best model derived from the data. It has been found that an appropriate model fit to good data will yield a value of APRE slightly larger than the standard error. Inappropriate models or bad data will result in a value of APRE much larger than the standard error.

Step 14 - Saving (or Loading) a Computed Model

Prior to, or after running GRENDL, it is a wise policy to save the created model. Use the **Modelling>Save Model File** (or Load Model File) option to write or retrieve a model file. By default, EM Vision model files have the file extension .MOD. Once saved, these ASCII files become a valuable resource.

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