



# 1 EMMA - Data and Model Analysis

EMMA (ElectroMagnetic Model Analysis) is a newly developed program for resistivity and electromagnetic data and model analysis, enabling the user to simulate measured data acquired with a definite instrument in a given measuring configuration over a known geological model. With an estimated data uncertainty, EMMA estimates also the model resolution.

A geophysical model is a translation of geological formation characteristics into geophysical parameters, as e.g. electrical resistivity. The geophysical model in EMMA is presumed to be one-dimensional (1-D) (Figure 1.1). Each model layer having an electrical resistivity and a thickness and is homogeneous and isotropic. Homogeneous means same electrical resistivity all over the formation, but not necessarily in all directions. Isotropic means same resistivity in all directions, but not all over the formation. Thus, a homogeneous and isotropic formation has the same resistivity all over and in all directions.

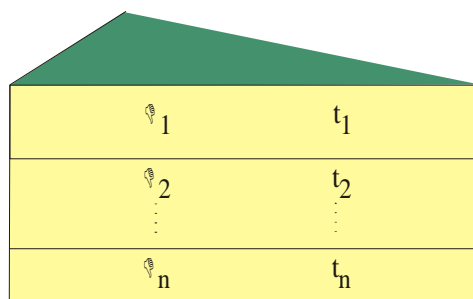


Figure 1.1 1-D earth model. The model has  $n$  layers, each with a resistivity  $\rho$  and a thickness  $t$ .

EMMA model analysis can be performed of different data types separately, or of several differ-

ent data types or data sets used simultaneously. The latter is called "joint analysis". Beyond model analyses with more than one data set, Emma also makes analyses coupling many one-dimensional models by lateral bands; in this way a pseudo two-dimensional model is achieved.

With EMMA even non-experts are able, by a few clicks of the mouse, to perform complicated analyses of e.g. hydrogeological problems. Thus, Emma is a tool to be used before an investigation is finally planned, but also to be used for obtaining an intuitive understanding of how electrogeophysical methods work and how they can resolve a certain geophysical model.

EMMA is a Windows based (preferably NT) graphical user interface for use on a fast computer. The program performing the actual calculations of model responses and model analyses is called `em1dinv` and was developed partly in the USA and partly in Denmark at DTU, the University of Aarhus and in the HydroGeophysical Group. It should be emphasized that use of Emma requires no knowledge of construction or use of `em1dinv`.

In our opinion, the algorithms used in `em1dinv`, accessible through Emma, are some of the most advanced existing. Some of them are based on mathematical solutions developed through the latest 30 years, whereas others are developed in connection with our research in the HydroGeophysics Group at the University of Aarhus.

EMMA is free-ware and can be used by anyone. If Emma, or parts of Emma, is included in other



applications, these applications must be offered as free-ware.

EMMA is still being developed, and the user may encounter features yet to be implemented.

EMMA is available from the homepage of the HydroGeophysics Group ([www.hgg.au.dk](http://www.hgg.au.dk) or [www.gfs.au.dk](http://www.gfs.au.dk) for Danish version).

### 1.1 EMMA Basic Structure

The following is a short description of the basic structure and organization of EMMA.

EMMA builds upon a Workspace containing 1) all parameters used to determine a specified measuring configuration and model, and 2) all response and model analysis calculations. The workspace is basically a database consisting of more than 20 related tables.

Access to data in the workspace takes place by guides leading you through the various necessary steps for the requested visualization and analysis.

You will also find model templates defining standard geophysical models together with the most commonly used measuring configurations. Any model run is based on one of these templates, and you are free to create new templates for your special requirements.

### EMMA Organization

The best description of the organization of EMMA is a short description of the menus and the principal windows. Some menu items are self-explanatory, others require some explanation.

Plots of model responses are available from the workspace through a guide, in which you define plot parameters (e.g. Rhoa as a function of time for TEM plot) and axes. This system is meant to be so flexible that plots of, principally, all parameter combinations is possible. In the plot windows, curves can be copied from one window to

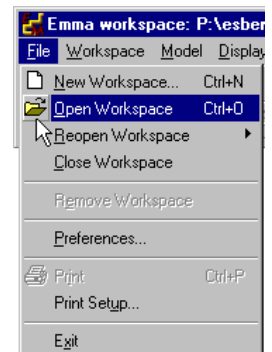
another, and it is possible e.g. to calculate the relative difference between two curves.



Display Wizard

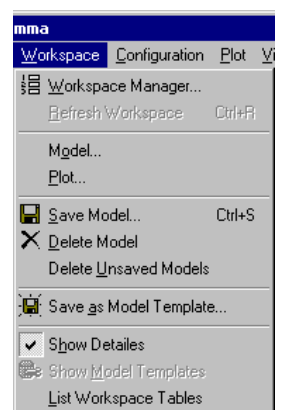
To use EMMA you must, in the "File" menu, choose "Open Workspace" or "Reopen Workspace" and then define a user name and specify a folder.

In the "File" menu, you find also "Close Workspace" and "Remove Workspace". In an open workspace you have access to all its menu items. This menu is for maintenance of and navigation in the workspace. Its most important items are "Workspace Manager" and "Save Model".



File menu

The "Workspace Manager" shows a list of the model responses and analysis calculations made so far. "Save Model" offers you the possibility of saving permanently a model in the workspace, i.e. otherwise calculations are "Unsaved" and auto-



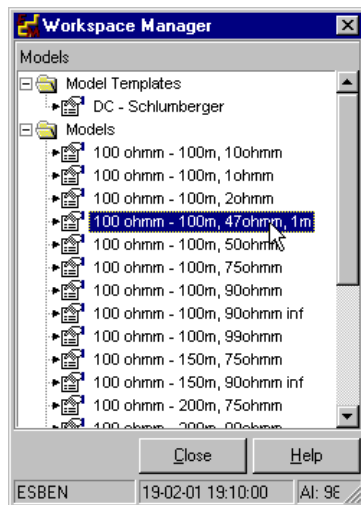
Workspace menu



matically deleted when the workspace is closed!

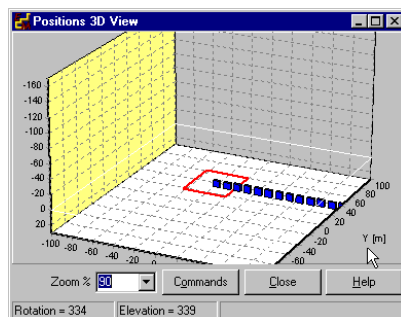
From the "Workspace Manager" you can make plots or define new model configurations. To make plots or analyses, select a model and choose "Workspace/Display Wizard".

If you choose "Workspace/Model Builder", the parameters used to define the chosen model in the list appears.



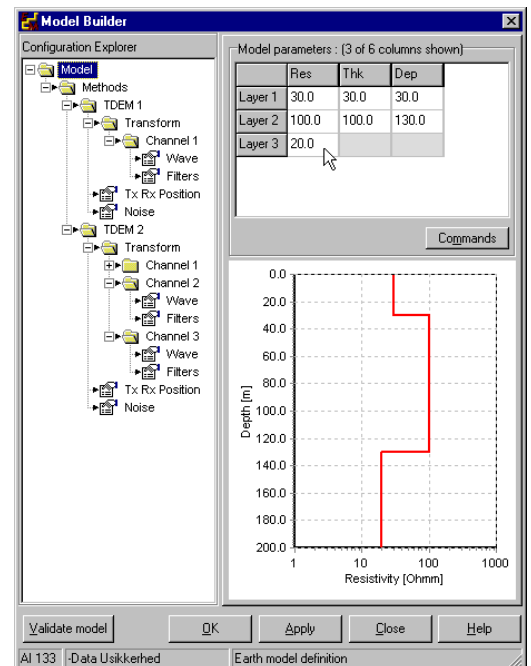
Window "Workspace Manager"

The transmitter/receiver configuration can be visualized in a 3-D plot window.



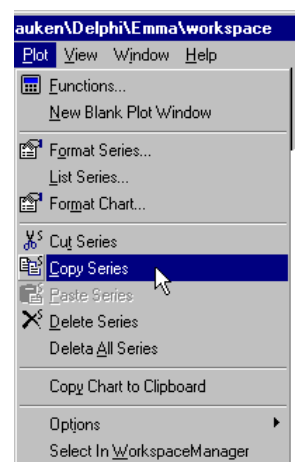
3-D visualization of transmitters and receivers

The "Model Builder" is used to define the geophysical model and the geophysical methods used. This window contains many different parameters. However, most parameters being predefined, you usually have to change just a few.



The "Model Builder"

The last menu to be mentioned here is the "Plot" menu, used to format model response plots. You can choose to print or to copy them to other programs. The "plot" menu contains other facilities, which e.g. calculate the relative difference between two model responses or copy/move curves from one plot window to another.



Plot menu

## 1.2 Exercise: Principal Responses

The first exercise with EMMA aims at giving you an intuitive understanding of the transient model response for typical Danish hydrogeological models.

The used transient array is simplified compared to the most commonly used 40 x 40 m Protom



47, but has the same physical characteristics, such as moments, waveform ramps and filters.

For the exercises, use the workspace "Emma/Problems/Problems Workspace", in which templates are defined for all model and transmitter/receiver configurations used in the exercises below.

To become familiar with the transient response, it is a good idea to generate responses in both dB/dt and Rhoa, dB/dt being the field measurement format, and Rhoa a transformation of dB/dt facilitating the data quality estimation.

Make a plot of the "Intuition" model, as follows: Choose "Intuition" (under "Templates") and then "Workspace/Display Wizard" (or choose "Display Wizard" from the right mouse-click menu of the "Workspace Manager"). Follow the Wizard, pressing the "Next" button. A plot appears showing the dB/dt response from a model with parameters as shown in Figure 1.1. Notice the large dynamic area of the curve in both time and dB/dt.

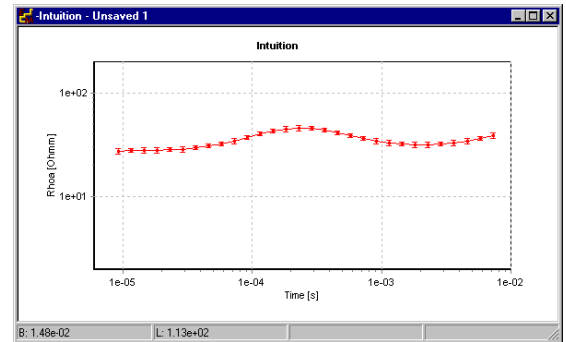
Layer	Rhoa [ $\Omega\text{m}$ ]	Thickness [m]
1	30	30
2	100	60
3	10	

Table 1.1 Model parameters for the "Intuition" model simulating a moraine layer on top of an aquifer layer. The bottom layer is Tertiary clay

Now, calculate the same curve in Rhoa: Return to the "Workspace Manager", double-click on "Intuition" (or choose "Workspace/Model Builder"). Study the many different parameters used to define the "Intuition" model.

To make a calculation in Rhoa, you select in TDEM1 the check box "Convert to Rhoa". Then, push the "OK" button. After a few seconds the Display Wizard reappears.

Now, try to make responses for the models in Table 1.2 and Table 1.3. Calculate responses in



Plot

both Rhoa and dB/dt. In order to compare the model responses, all Rhoa curves are plotted in the same plot window. To do this you must, BEFORE pressing the "OK" button in the Display Builder" 1) select the check box "Add to active plot window" at the bottom of the "Display Builder", and 2) select/activate the plot window you want. Now you can press "Apply" or "OK".

Layer	Rhoa [ $\Omega\text{m}$ ]	Thickness [m]
1	30	30
2	100	

Table 1.2 Model parameters simulating a model with a moraine top layer, not finding a good conductor - West Jutland.

Layer	Rhoa [ $\Omega\text{m}$ ]	Thickness [m]
1	100	

Table 1.3 Model parameters simulating a model with no moraine top and no Tertiary bottom layer.

Notice, how much the curves change if the 10  $\Omega\text{m}$  layer in Table 1.1 is removed (the model in Table 1.2). Notice also, how difficult it is, from the Rhoa curves, to determine the model behind.

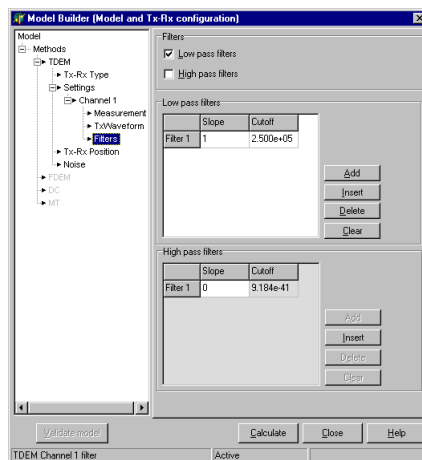
Don't forget to save the models in the workspace - they are named "Unsaved" followed by a number. One way of doing this is to select the model in question in the "Workspace Manager" keeping down the "Alt" button simultaneously. Another way is using the "Workspace" menu.



### 1.3 Exercise: Filters

We hope the above exercise made you somewhat familiar with EMMA. The following exercise should make you understand the importance of filters to the TEM response at early times. Start by closing all plot windows from the first part-exercise, e.g. by choosing "Window/Close All Plots".

In the "Workspace Manager", choose the model named "Filters". It is a very simple model, viz. a 200  $\Omega\text{m}$  half-space (like the model in Table 1.3). On the page "Model/Methods/TDEM1/Transform/Channel1/Filters" in the "Model Builder" you can verify that the cut-off frequency is set to 250 kHz. Run the model and make a Rhoa plot. Now, run model responses with the cut-off frequencies defined in Table 1.4. using the "Filter" model as template and modifying the cut-off frequency.



The page "Channel 1/Filters"

Modelname	Cut-off frequency [Hz]
Filter - non	no filter
Filter 250 kHz	250.000
Filter 100 kHz	80.000

Table 1.4 Different cut-off frequencies. The model names are suggestions ...

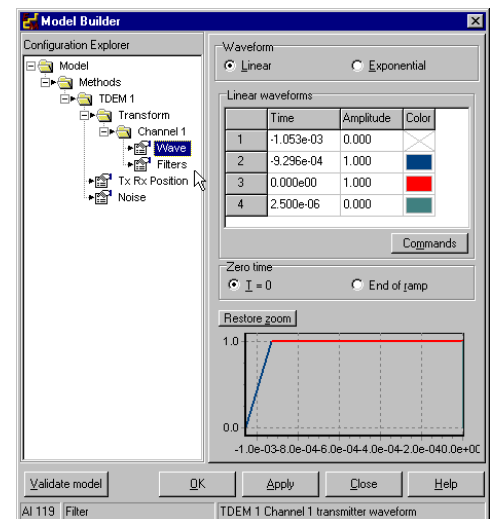
Plot all responses in the same plot window, to compare them. Calculate the relative difference between the unfiltered curves and the 250 kHz curve/80 kHz curve by selecting e.g. the unfiltered curve and the 250 kHz curve, and then press "Plot/Function".

What is the relative difference between the responses? How does the filter effect decrease with time? When is the effect less than 5%?

### 1.4 Exercise: Ramps and Time Shifting

After the above demonstration of the filter effect in TEM data, it could be useful to investigate the effect of varying the length of the cut-off ramp.

In the "Model Builder", open the model "Waveform". Go to the page "Channel 1/Wave" in which the cut-off ramp is defined: the current is turned on at  $-1.e-2$  sec. and turned off at 0.0 sec. The time used to switch-on the current is  $1.e-3$  sec. cut-off takes  $2.5e-6$  sec. (See Fig. 2.5). Calculate the model response and plot the response in a new window. Make another response in which the cut-off time (ramp 4) under "Wave" is changed to e.g.  $5.e-6$  sec. Plot this in the same window as before. How does the ramp length influence the response?



The page "Channel 1/Wave"

Don't forget to save the computed responses.

An internal synchronization error in the receiver instrument, or between receiver and transmitter, essentially affects the response at early times. This is illustrated by simulating that the transmit-

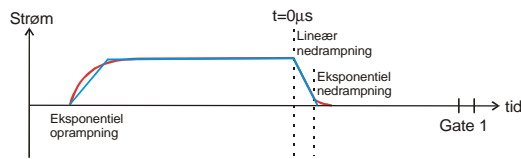


Figure 1.2 Cut-off ramp. The red curve showing a theoretical current in the transmitter coil. The blue curves, approximating the red curve, are those modelled in EMMA.

ter current cut-off does not start at 0.0 sec., but at e.g. 0.5e-6sec. or 1.e-6 sec.

Based on the "Wave" template, shift the cut-off ramp by 5e-6 sec. and 1.e-6 sec., respectively. Make a plot with all three curves and estimate (calculate) the effect of the synchronization error.

### 1.5 Exercise: Analyses

The third part-exercise intends to give you a feeling of which model parameters effect the model reponse. A comparison with the actual uncertainty analysis of the model parameters is included.

Start from the model named "Analysis". The model parameters are shown in Table 1.5. Calculate a response for this model and plot it in a new plot window. The response is calculated in Rhoa.

Layer	Rhoa [ $\Omega\text{m}$ ]	Thickness [m]
1	30	30
2	100	60
3	10	

Table 1.5 Model parameters for the "Analysis" model. Same model as shown in Table 1.1.

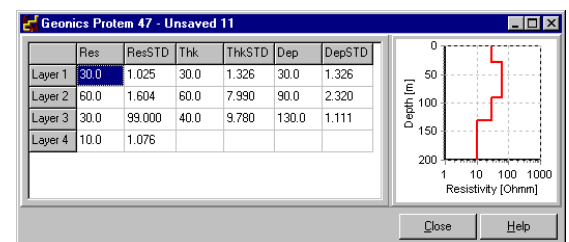
To find out which parameters are most essential for the model response development, you can, one by one, slightly modify the model parameters. Changing e.g. the resistivity of the third layer by a factor 1.2 to each side (8.3  $\Omega\text{m}$  and 12  $\Omega\text{m}$ ), you compare with a similar change of e.g. the resistivity of the second layer (83  $\Omega\text{m}$  and 120  $\Omega\text{m}$ ). Do the examples shown in Table 1.6.

Modelname	Layer	Parameter
Analysis 1	3	Resistivity = 8.3 $\Omega\text{m}$
Analysis 2	3	Resistivity = 12 $\Omega\text{m}$
Analysis 3	2	Resistivity = 83 $\Omega\text{m}$
Analysis 4	2	Resistivity = 120 $\Omega\text{m}$
Analysis 5	2	Thickness = 50 m
Analysis 6	2	Thickness = 72 m

Table 1.6 Parameter modifications of the model shown in Table 1.5. Parameters are changed by a factor 1.2 to each side. Model names are suggestions.

Describe which parameter modifications most essentially change the model response. What does that tell you about the sensitivity of the different model parameters? - i.e. which parameters can be only slightly modified before causing great changes in the model response, and which can be modified a lot?

EMMA makes an analysis automatically. Return to the very first model analysis and show the "Display Wizard" window. On the stage in the wizard named "Display", choose "Table". Follow the wizard and open a table with model parameter uncertainties.



Model

The uncertainties are displayed as factors - i.e. an uncertainty (standard deviation, STD) of 1.1 on, e.g. the resistivity 10  $\Omega\text{m}$  means that there is 66% probability that the parameter is between 10  $\Omega\text{m}$  / 1.1 and 10  $\Omega\text{m}$  \* 1.1 or an interval of 9.1  $\Omega\text{m}$  - 11  $\Omega\text{m}$ .

Uncertainties are calculated on basis of a linearized model. This means that great uncertainties are "just great", and the analysis must be considered qualitatively and not quantitatively. It is normally said that a parameter determined better





than a factor 1.2 is well determined, whereas in the interval 1.2 - 1.5 it is determined. From 1.5 to 2.0 the parameter is poorly determined, and above 2.0 undetermined (see Table 1.7).

Definition	Interval
Well determined	<1.2
Determined	1.2 - 1.5
Poorly determined	1.5 - 2.0
Undetermined	> 2.0

Table 1.7 Intervals for determination of parameters.

These uncertainties are often not considered as factors, but percentage deviations. This is acceptable with small deviations, which appears from above example. Presumed the resistivity determined with an uncertainty of 10% instead of a factor 1.1, the parameter interval would had been 9.0  $\Omega\text{m}$  - 11  $\Omega\text{m}$  - not differing much from the real interval.

Study the stated uncertainties. Do they correspond with your expectations from previous results (Table 1.5)?

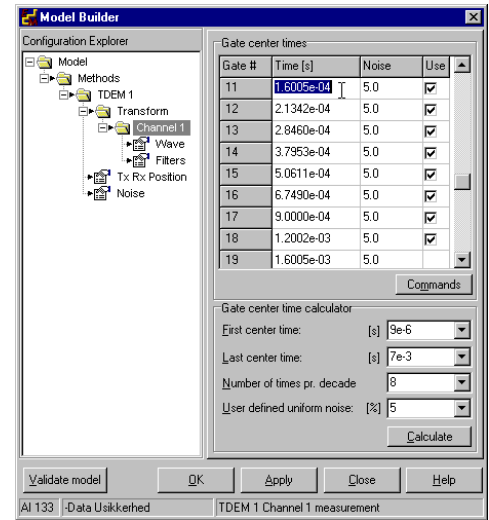
### 1.6 Exercise: Data Uncertainty versus Model Parameter Uncertainty

The following exercise illustrates the connection between data uncertainties and parameter definition.

Start from the model shown in Table 1.8, in the workspace named "Data Uncertainty". To each model data is added a standard deviation of 5% (factor 1.05). The data uncertainty appears from the page "Channel 2" in the "Model Builder". Run this model and plot data. The error bar length is the data value divided by 1.05 to the data value multiplied by 1.05.

Layer	Rhoa [ $\Omega\text{m}$ ]	Thickness [m]
1	30	30
2	100	100
3	10	

Table 1.8 Model parameters for "Data Uncertainty".



The page "Setting/ Channel 1/ Measurement"

Make a model with standard deviation 10% for all data. How does that effect the standard deviations for the parameters?

### 1.7 Exercise: Moment Size versus Parameter Uncertainty

This exercise illustrates the connection between parameter uncertainty and a non-uniformly distributed data uncertainty. The data uncertainty depends on the ability of the receiver instruments to suppress noise and on the size of the transmitter moment.

In the exercise we simulate a 30x30 m transmitter-loop, with a current of 1 A, 3A and 75 A, respectively. The model appears from Table 1.9.

Layer	Rhoa [ $\Omega\text{m}$ ]	Thickness [m]
1	30	30
2	100	100
3	20	

Table 1.9 Models for Current 1 A, Current 3 A, Current 75 A

Calculate responses and analyses for models Current 1A, Current 3A, and Current 75A, Plot responses and notice how the noise level become relatively lower with increased transmitter-current (moment).



Estimate the parameter analyses for the three cases. Which parameters have changed degree of determination?

### 1.8 Exercise: Apriori Information

When the geophysical model is used for geological interpretation, the geophysical interpretation tools are essential in confirming or not the existence of certain layers. This is done by adding extra layers to the model or changing parameters for a certain layer.

This exercise illustrates how a model determination changes with inclusion of apriori information of one or more model layers. The model appears from Table 1.10.

Layer	Rhoa [ $\Omega$ m]	Thickness [m]
1	30	30
2	60	60
3	30	40
4	10	

Table 1.10 Model parameters for the model "Apriori Information"

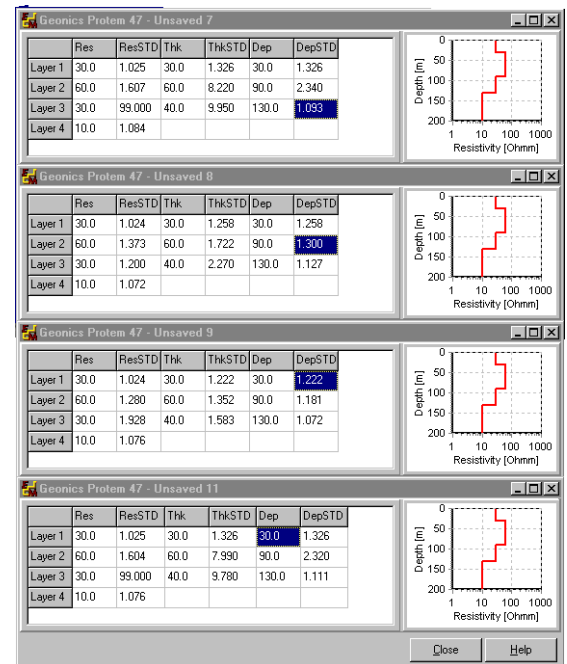
Make a plot of the model responses and study the analysis. Which parameters are well defined, which poorly?

What happens with parameter definitions if the resistivity of the third layer is added an apriori uncertainty of factor 1.2?

Why does it influence not only the determination of the third layer, but just as much the other model layers?

How are parameter determinations influenced if depth to the bottom of layer 2 is added an apriori uncertainty of factor 1.2?

How are parameter determinations influenced if the resistivity for layer 4 is added an apriori uncertainty of factor 1.2?



Analysis