AUSTRALIAN SOCIETY OF EXPLORATION GEOPHYSICISTS

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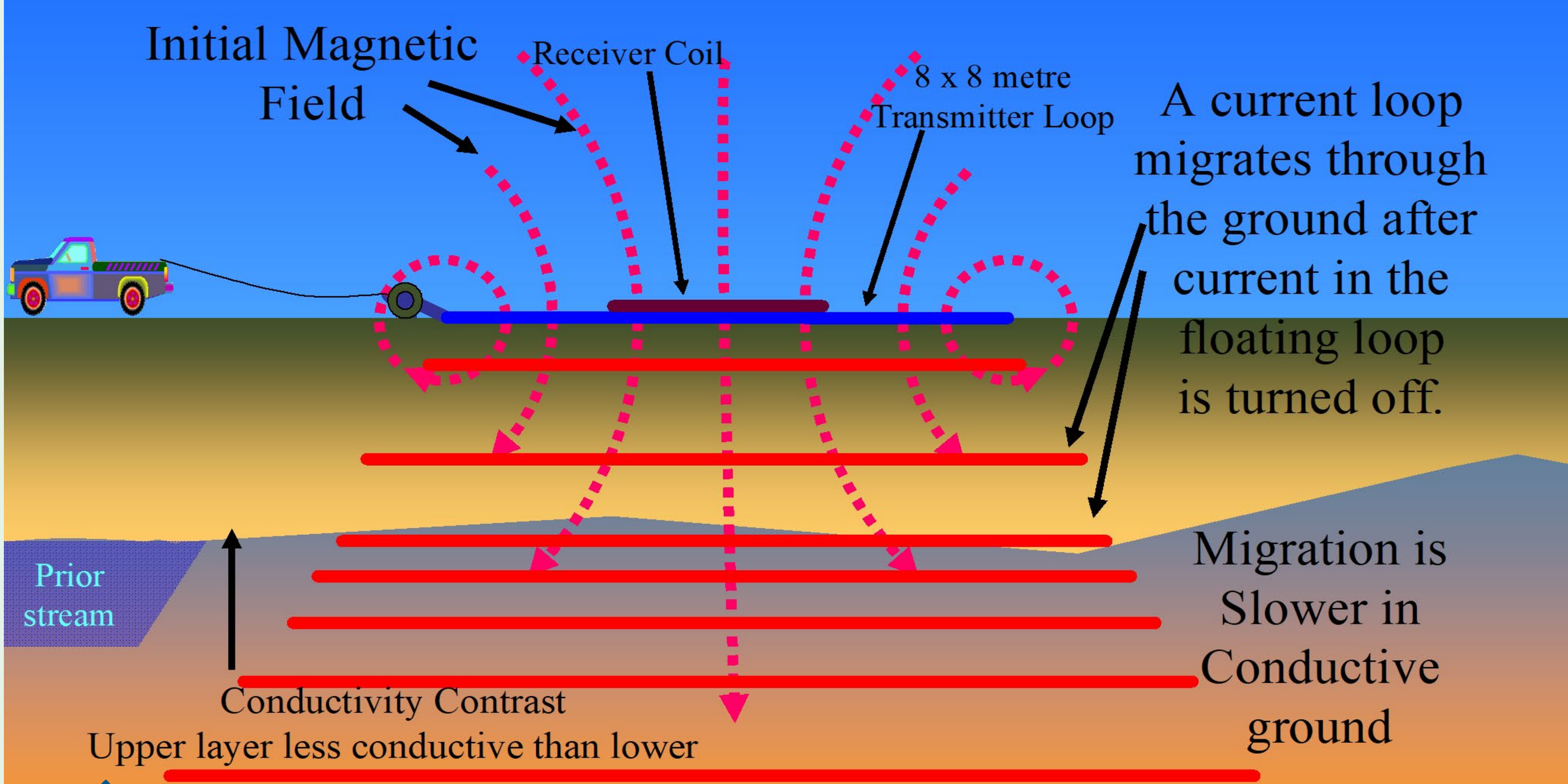
ASEG 2024

GROUNDWATER IMAGING

TEMConfigurator, a new transient electromagnetic forward modelling interface, & evaluation of AgTEM-Wallaby and AgTEM-Wallaroo towed Transient Electromagnetic Systems.

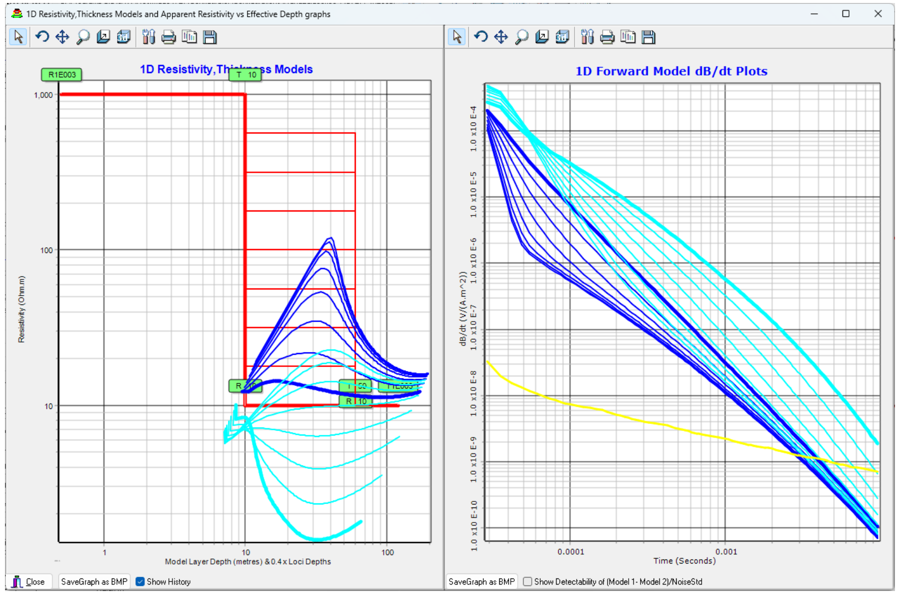
By David Allen
James Ohanga
& Matthew Stockings of Groundwater Imaging Pty Ltd, Dubbo, Australia

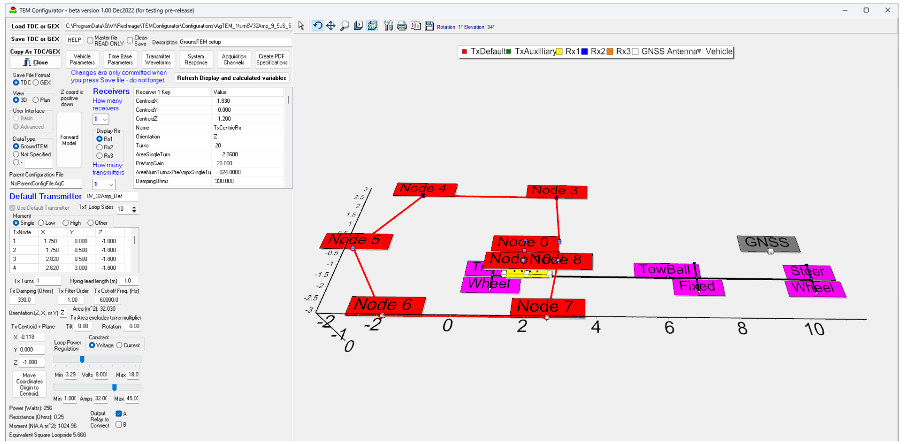
Towed Transient Electromagnetic System

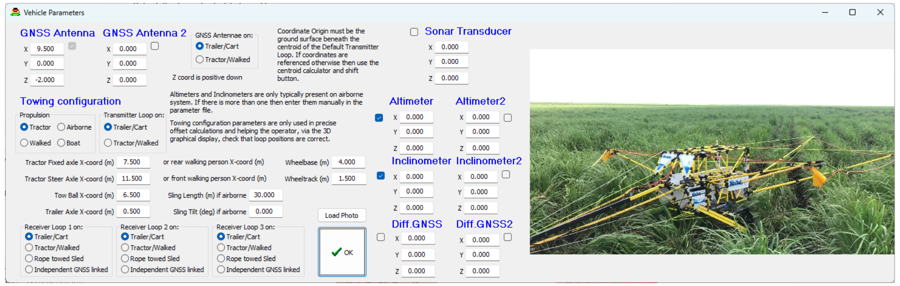


TEM Configurator

- An interface for evaluating and comparing Transient Electro-Magnetic survey equipment configurations.
- 1D layered type curve generation using AarhusInv64.exe
- Open source Pascal code for reading, writing and handling configuration files.







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GROUNDWATER IMAGING

AgTEM - Wallaby

- An enduring off-road towed Transient Electromagnetic system suited to rapid coverage of cleared agricultural land and rangeland.
- Receiver loop null coupled with transmitter loop
- 1 to 5 turns each rated to 50 Amps
- Folds for gateways and narrow gaps.
- Optionally augmented by a front loop (Slingram)
- Towed by 400kg to 3000 kg vehicles.

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AgTEM - Wallaroo

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- A lightweight collapsable system of configurable parts for transient electromagnetic survey
- 1 person can achieve 20km of survey per day walking propelled by an electric tractor controlled by walking within an a movement sensing cradle while holding a cantilevered, hand stabilized, Slingram receiver loop. Also has in-loop receiver.
- Folds for gateways and narrow gaps.
- May be towed by quad bikes
- May be carried by walking persons in most minimal form (12kg main loop)

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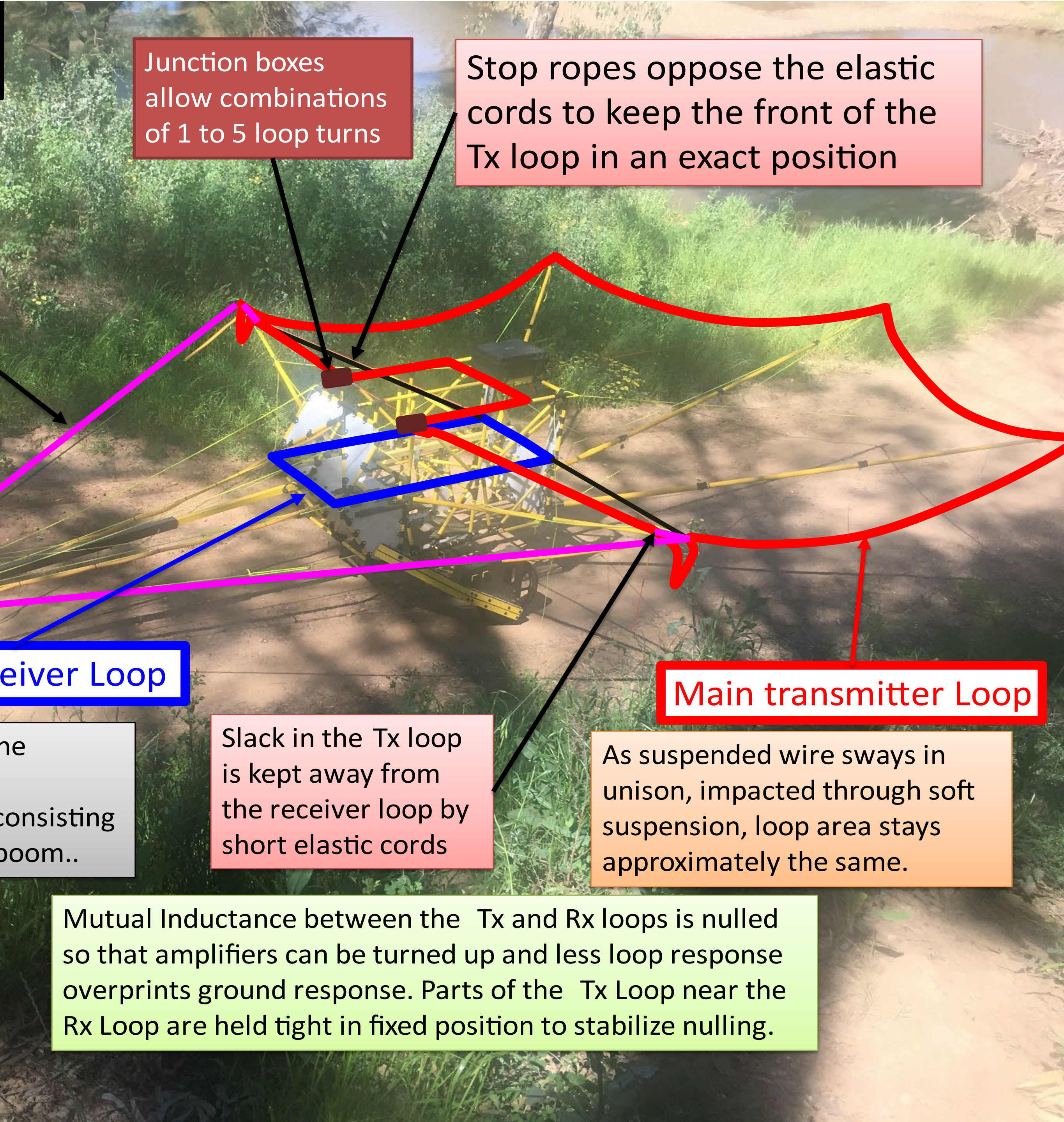
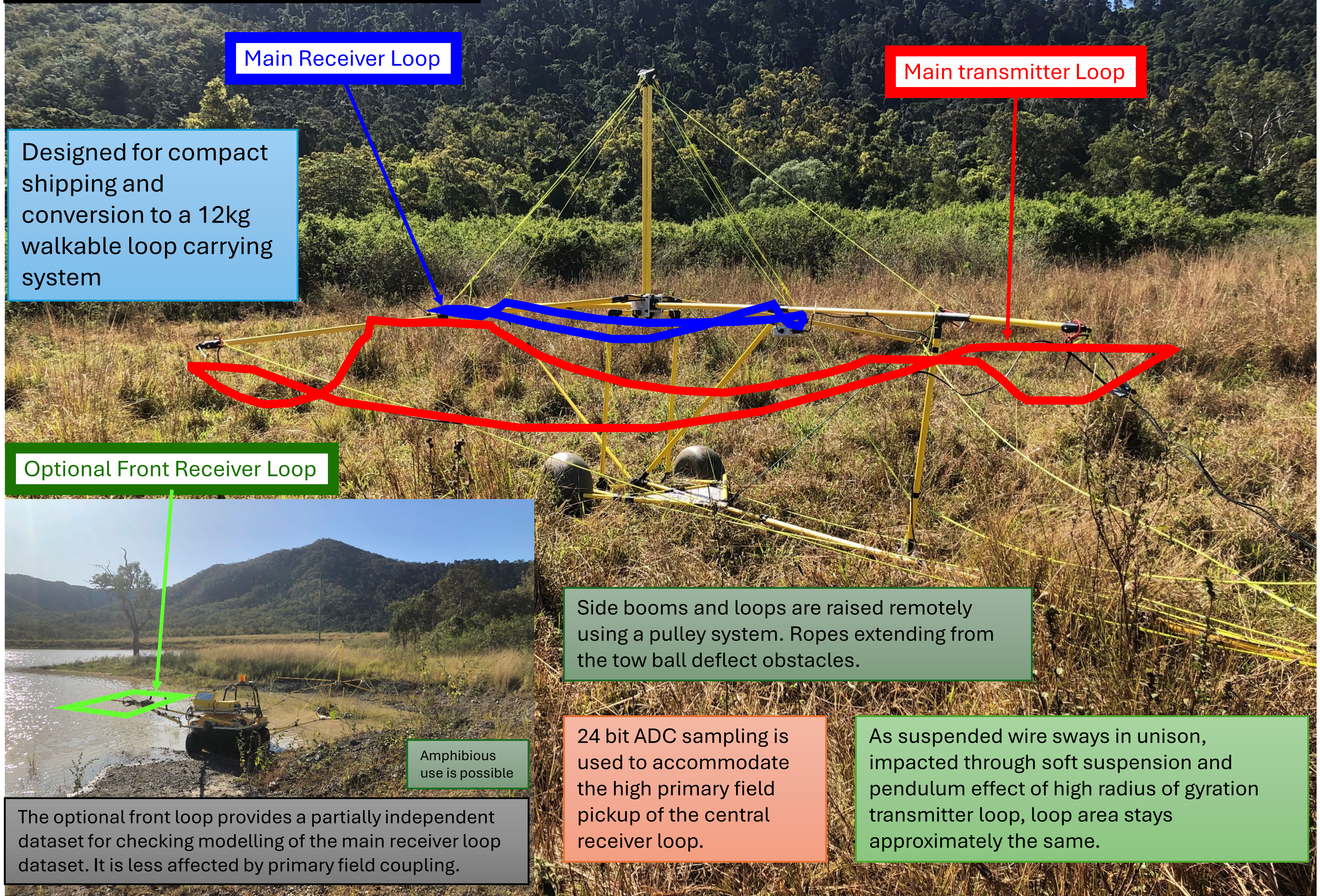
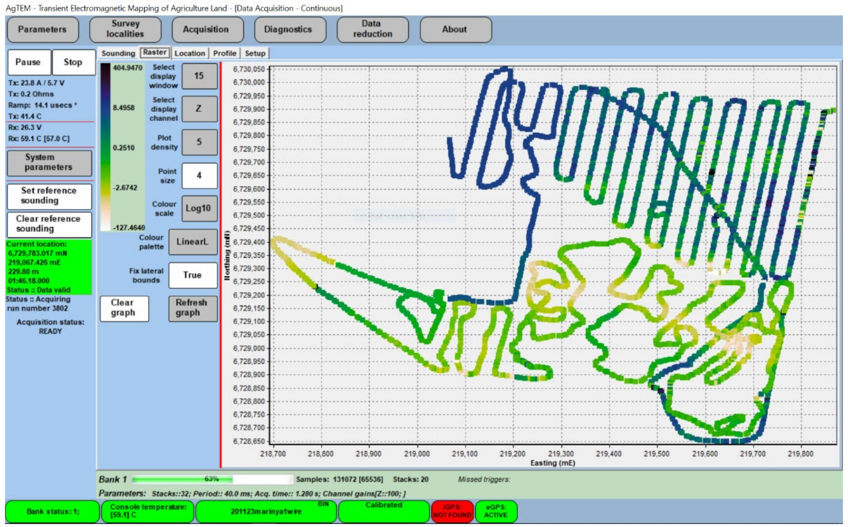
AgTEM-Wallaby



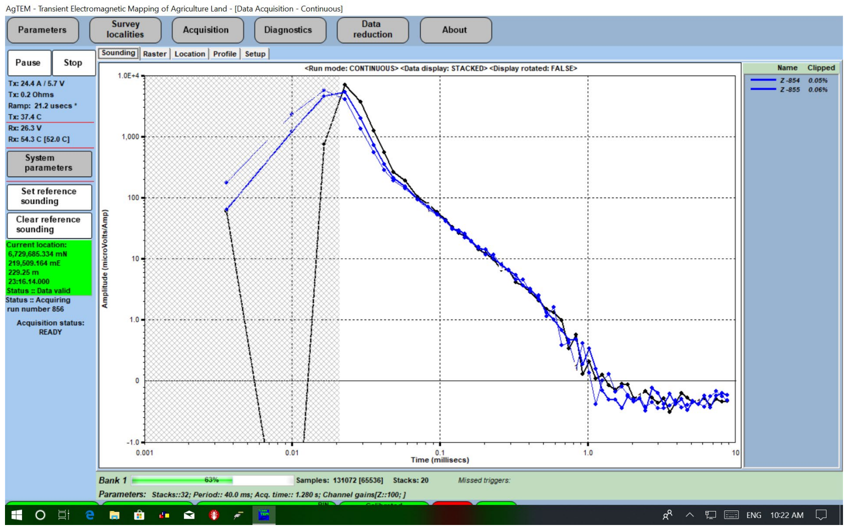
AgTEM-Wallaroo



AgTEM-electronics

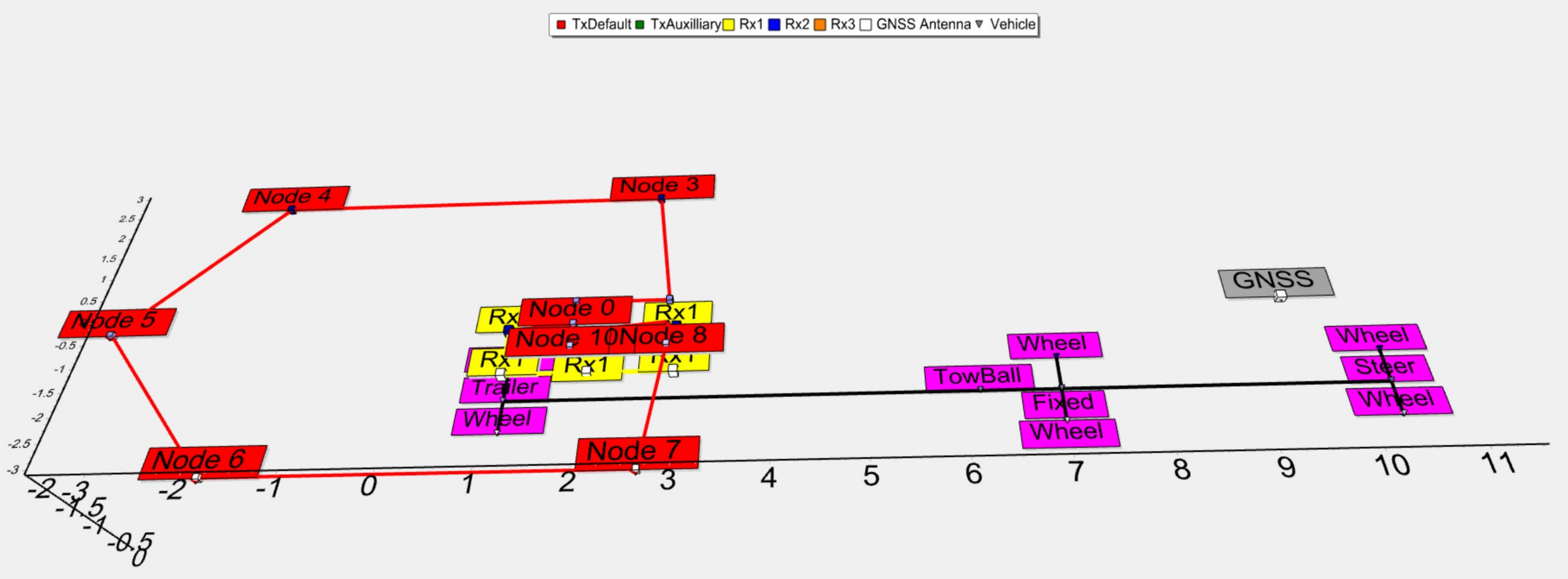


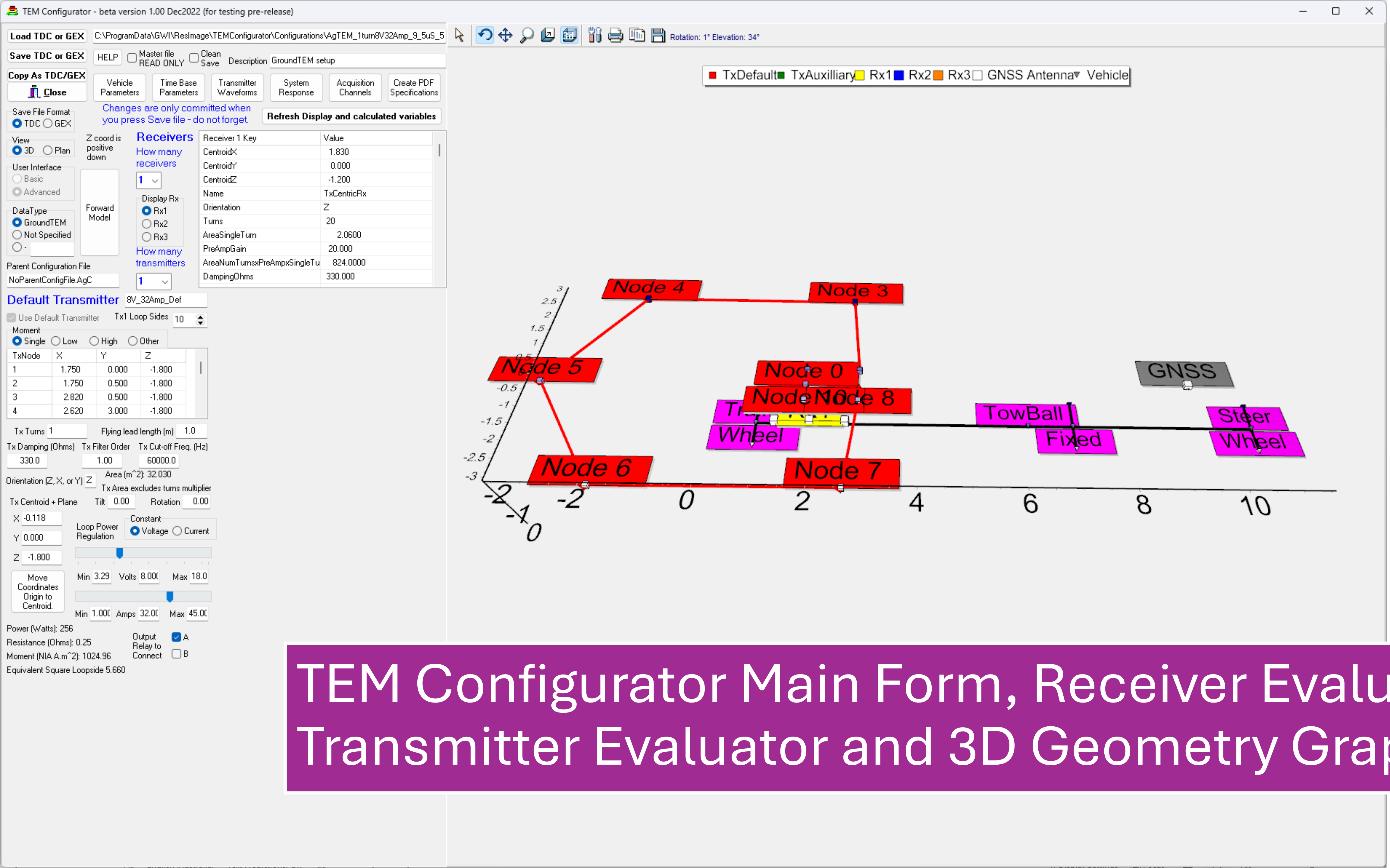
Regulated 3.5 to 18 Volt, 45 Amp TEM transmitter with 3 channel receiver & Dashboard mount operator's console. Also designed for walked operation.



TEM Configurator

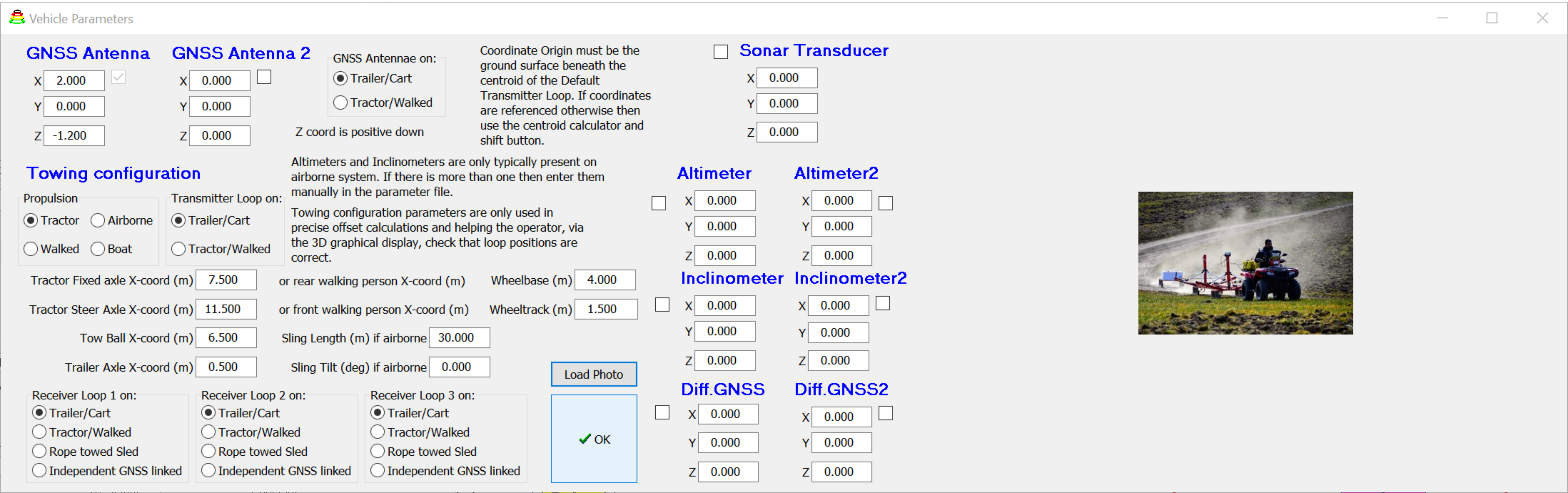
TEMConfigurator displaying loop coordinates from the Wallaby overlapping receiver loop configuration file.



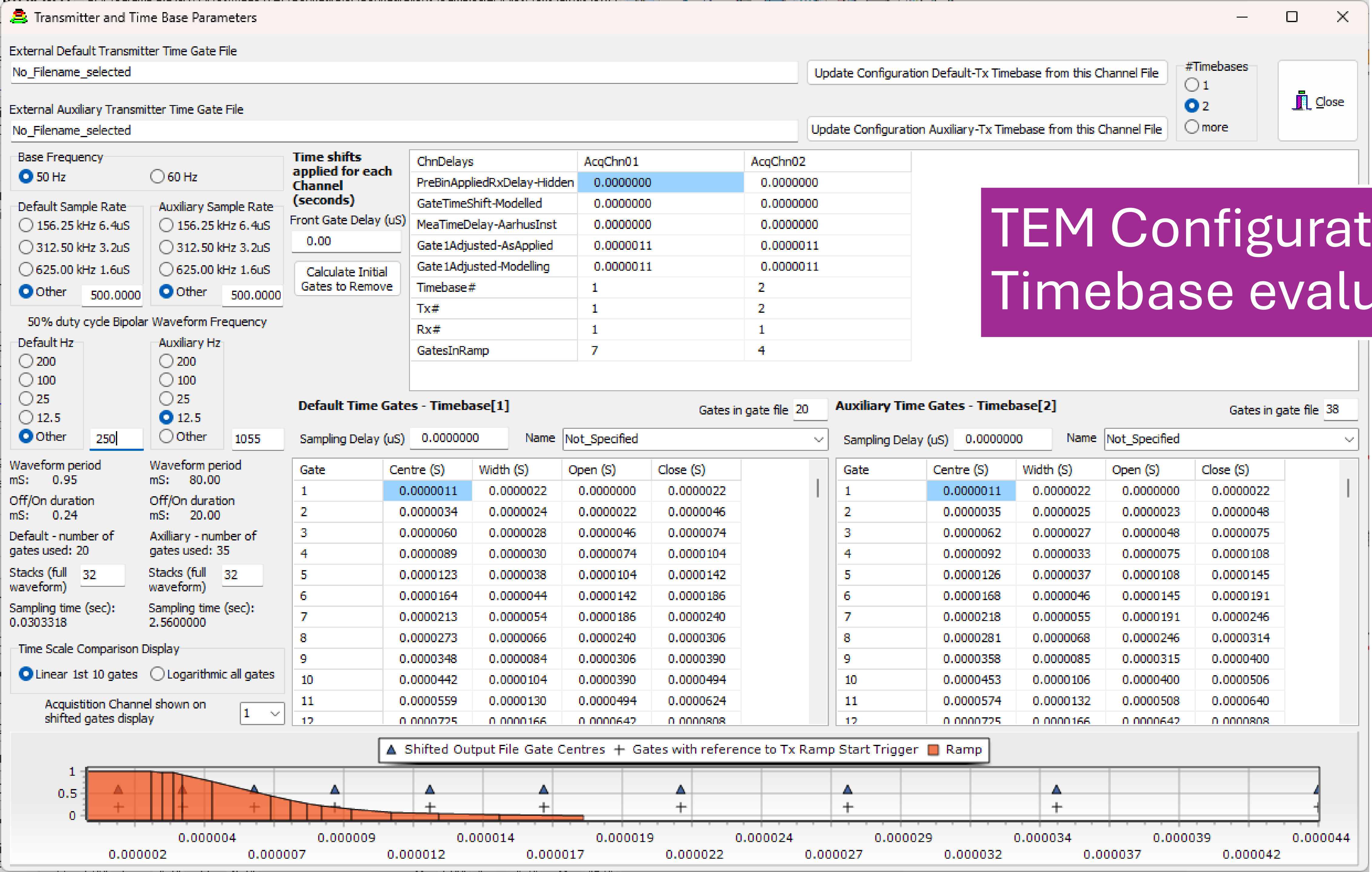


TEM Configurator Main Form, Receiver Evaluator, Transmitter Evaluator and 3D Geometry Graphics

TEM Configurator Vehicle Parameter Evaluator



TEM Configurator Timebase evaluator



TEM Configurator Waveform Evaluator

TransmitterWaveforms

Sampled Waveforms normally are stored simply as part of TEM Configuration AgC files.

Default sampled waveform file

Currently locked to main menu TDC file

Auxiliary sampled waveform file

Currently locked to main menu TDC file

Close

Digitized Tx Waveforms for Modelling

Default Tx Waveform Points 58

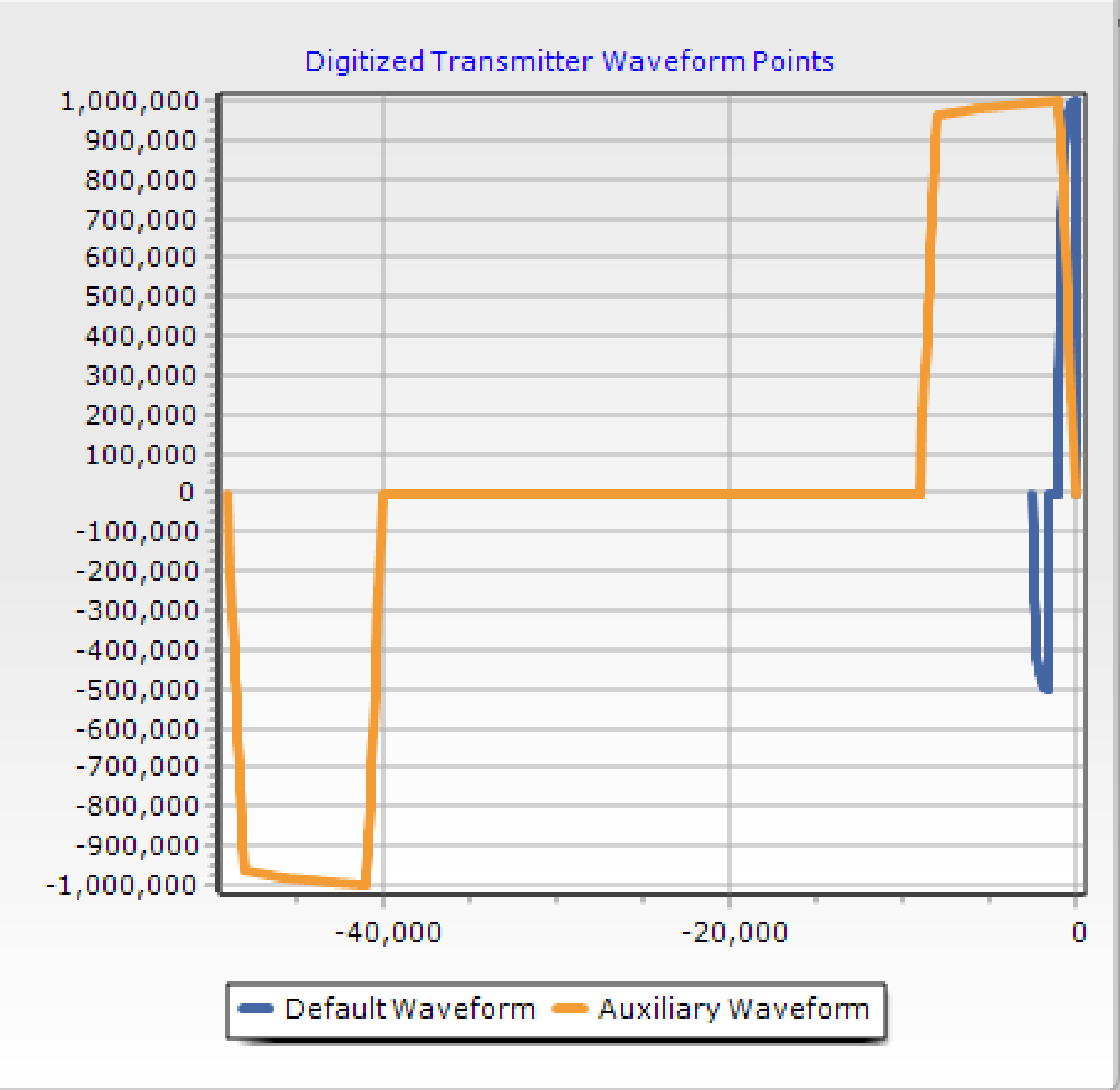
Auxiliary Tx Waveform Points 64

Default Tx Ramp (uS) 17.8

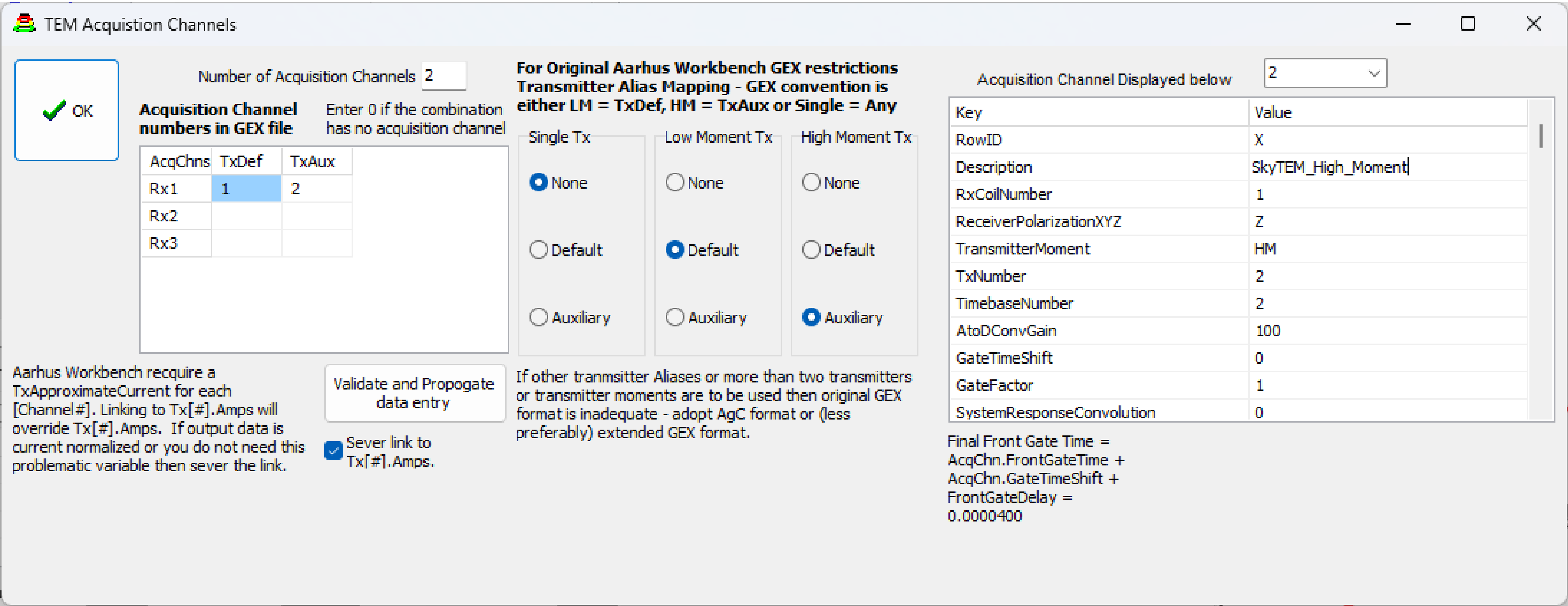
Auxiliary Tx Ramp (uS) 8.0

Time (seconds)	Volts
-0.00249600	0.00000000
-0.00246410	-0.08995380
-0.00243630	-0.15703800
-0.00240520	-0.21894800
-0.00237170	-0.27307200
-0.00233640	-0.31881500
-0.00229650	-0.35950000
-0.00225400	-0.39287600
-0.00220490	-0.42171900
-0.00215440	-0.44330700
-0.00209840	-0.46049200

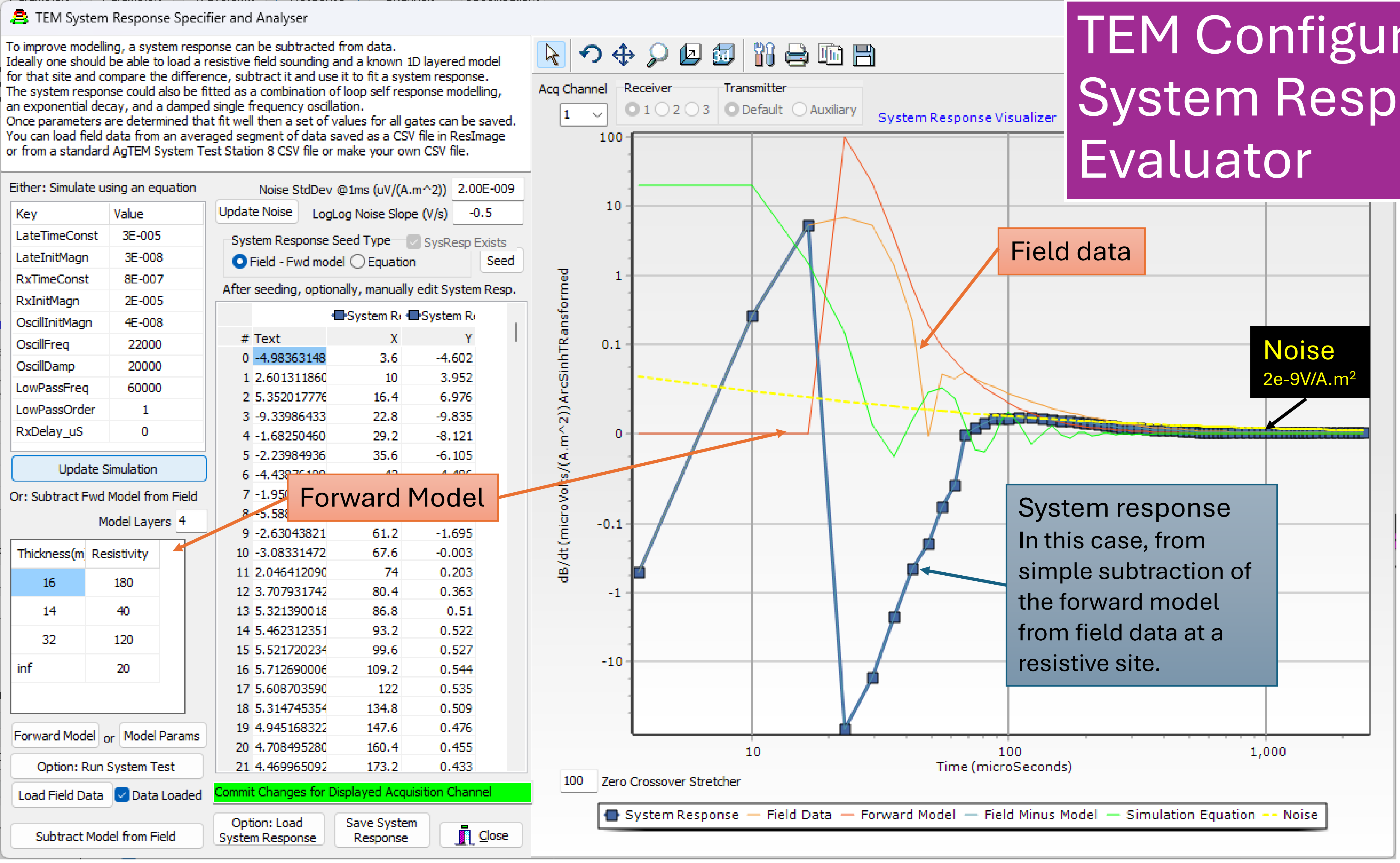
Time (seconds)	Volts
-0.0489810	0.0000000
-0.0487830	-0.2123560
-0.0486808	-0.3187510
-0.0486120	-0.3892250
-0.0485282	-0.4735580
-0.0484794	-0.5218030
-0.0484256	-0.5741720
-0.0483660	-0.6311000
-0.0483000	-0.6926940
-0.0482270	-0.7589060
-0.0481464	-0.8294780



TEM Configurator Acquisition Channel Evaluator



TEM Configurator System Response Evaluator

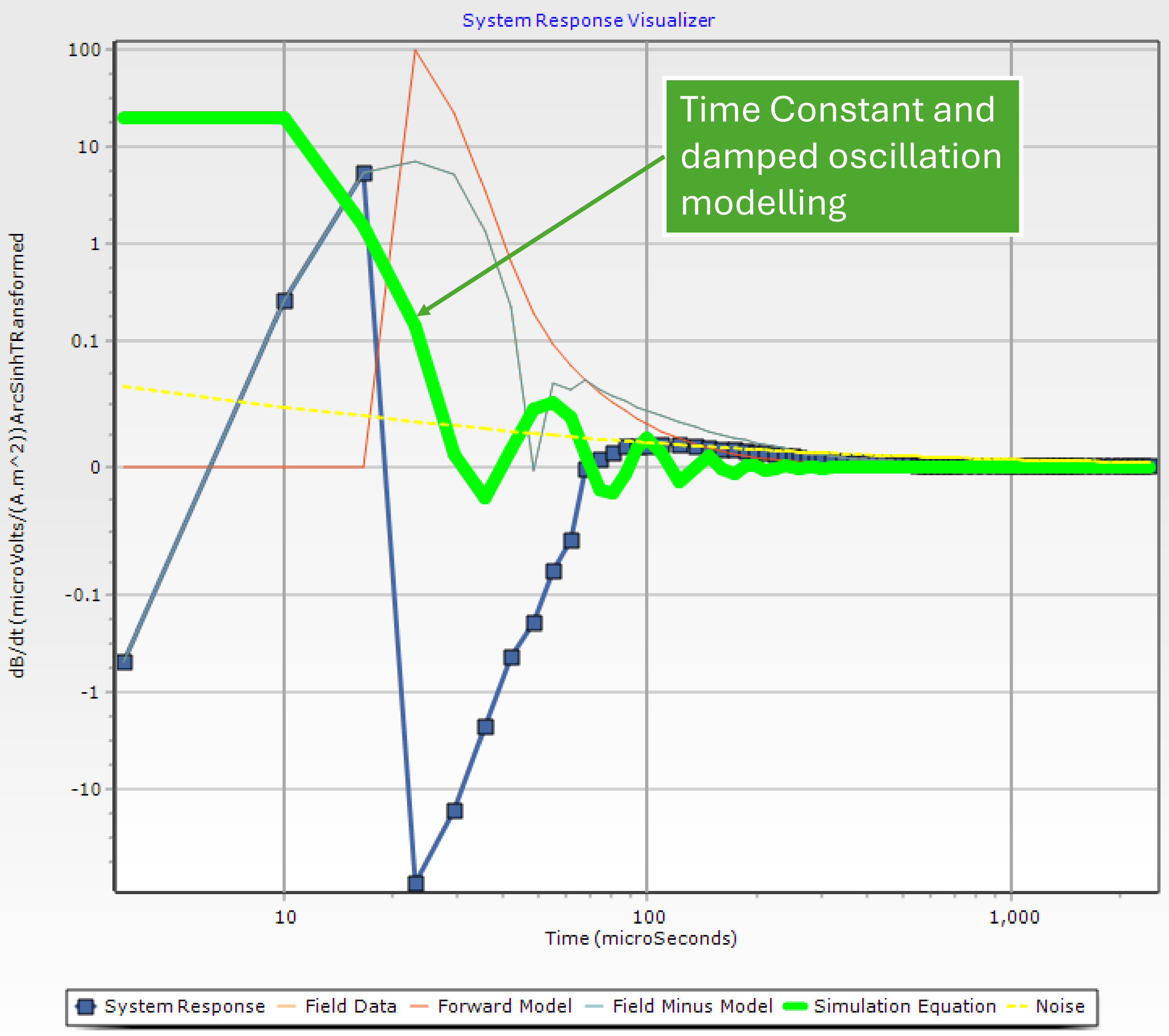


TEM Configurator System Response Evaluator

Modelling multiple time constants with damped oscillating resonance

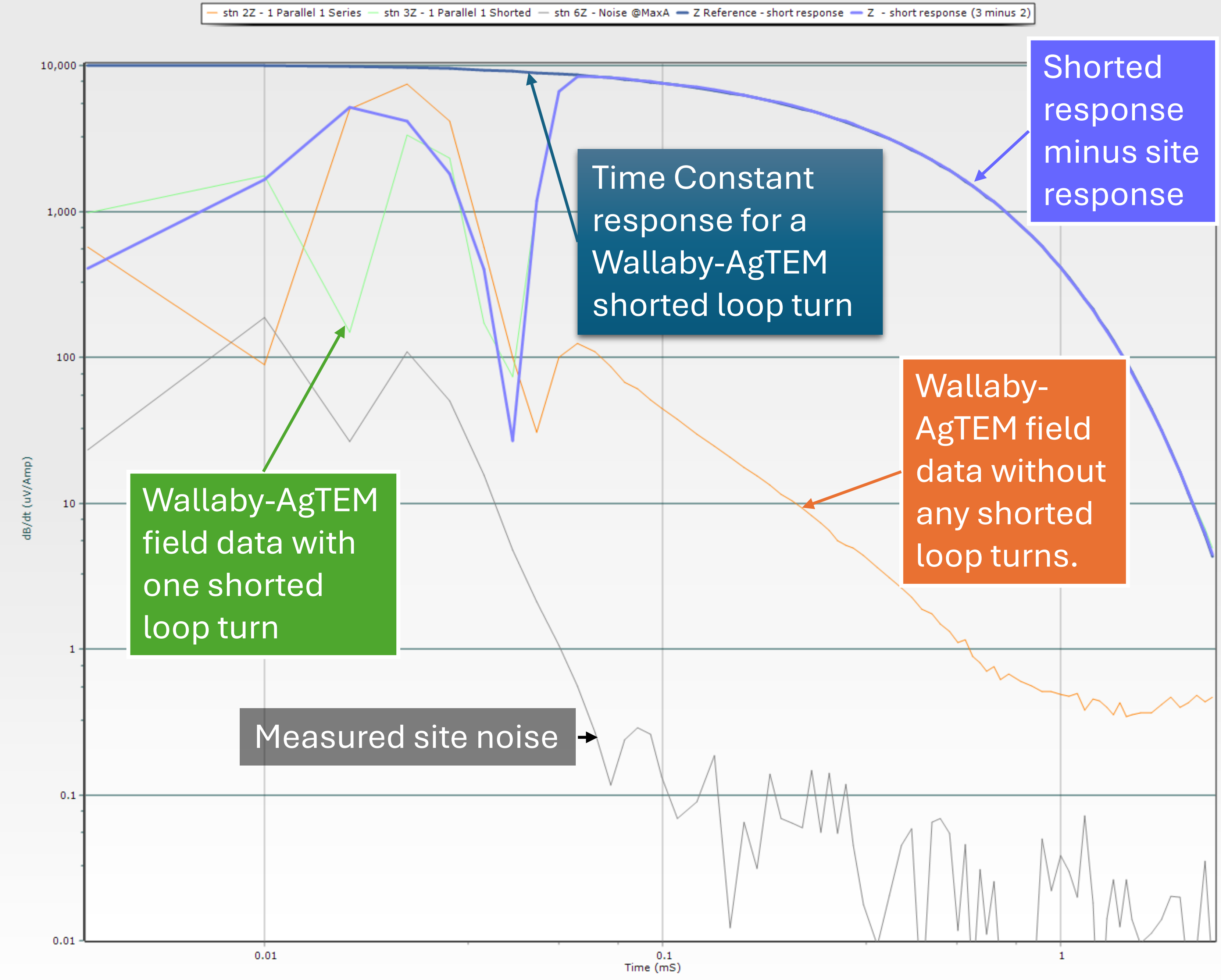
This can be used to model and understand both designed and unwanted parasitic components of system response such as:

- loop self response,
- inductive coupling with the towing vehicle, and
- passing receiver loop wire too close to an inductor on a pre-amp.



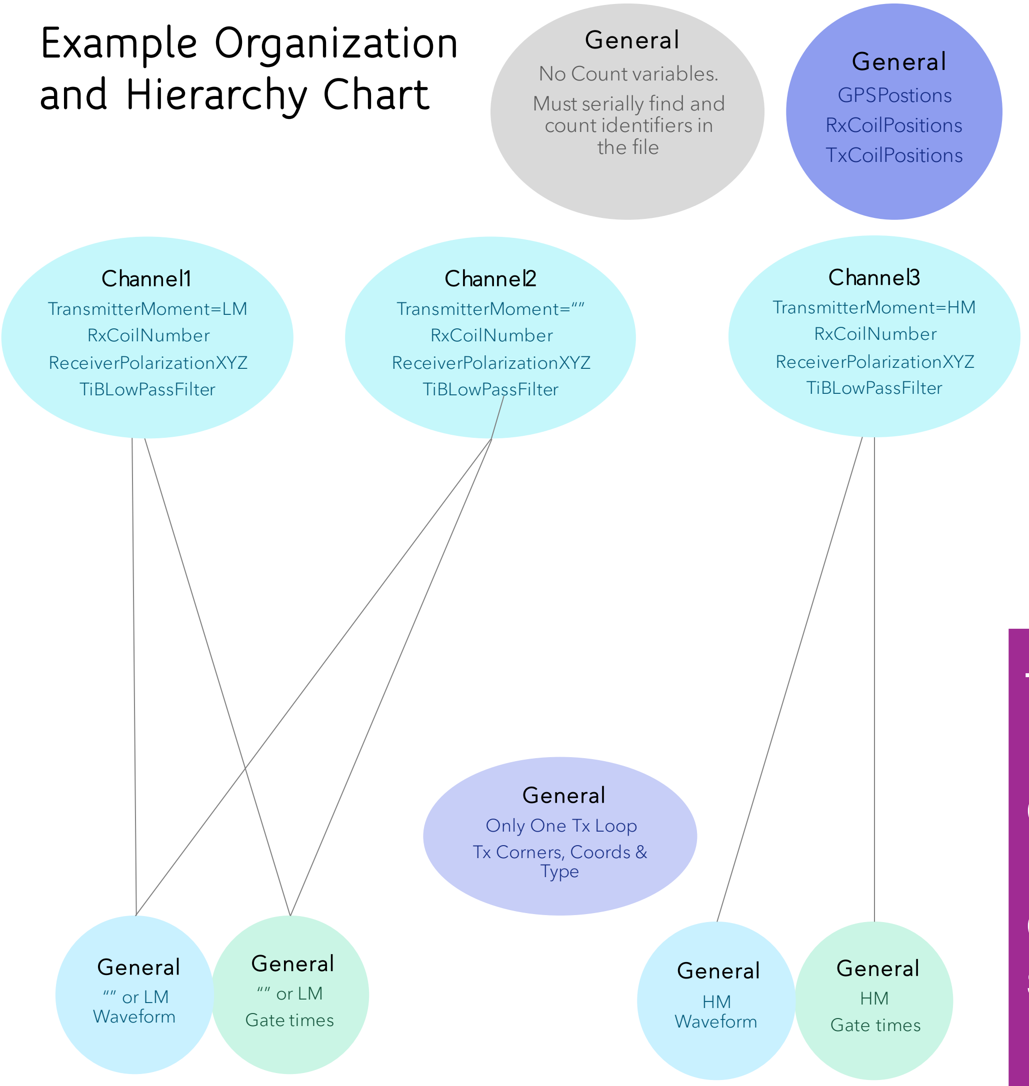
TEM Configurator Shorted Loop System Testing

AgTEM Wallaby In-loop system testing - shorted loop turn test. In this test a stored reference shorted loop decay constant response is compared with contrast of shorted loop measured data minus single loop data with the 2nd loop open circuit. This establishes a largely ground response free dataset for comparison. Noise data is plotted also for comparison. Observe that the shorted loop response excellently matches the decay constant equation response beyond where digital delays, ramp, and coil self-responses are significant.



TEM Configurator - GEX format

Example Organization and Hierarchy Chart



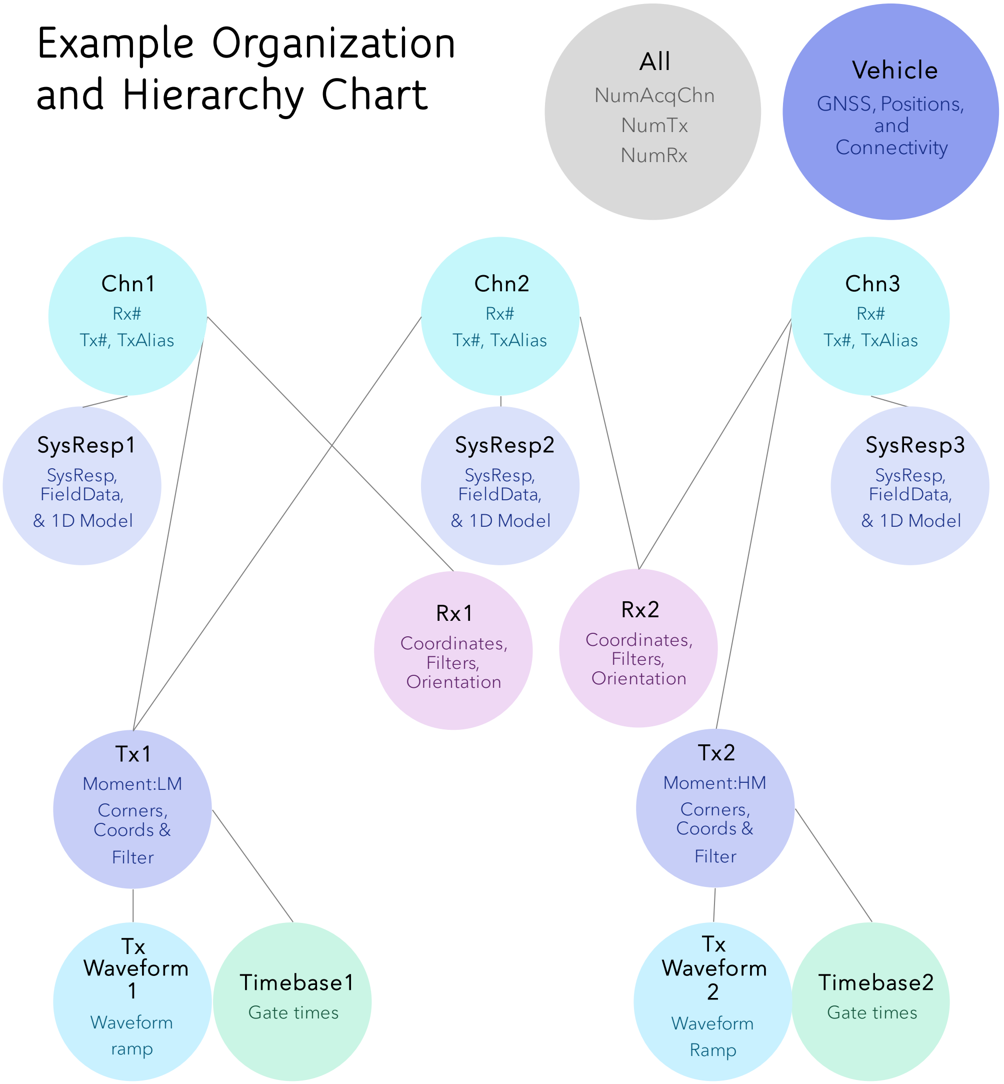
TDC - A new data format for TEM metadata

TEM Configurator uses the new TDC data structure that logically and fully describes any TEM system.

It can also convert to and from legacy GEX format

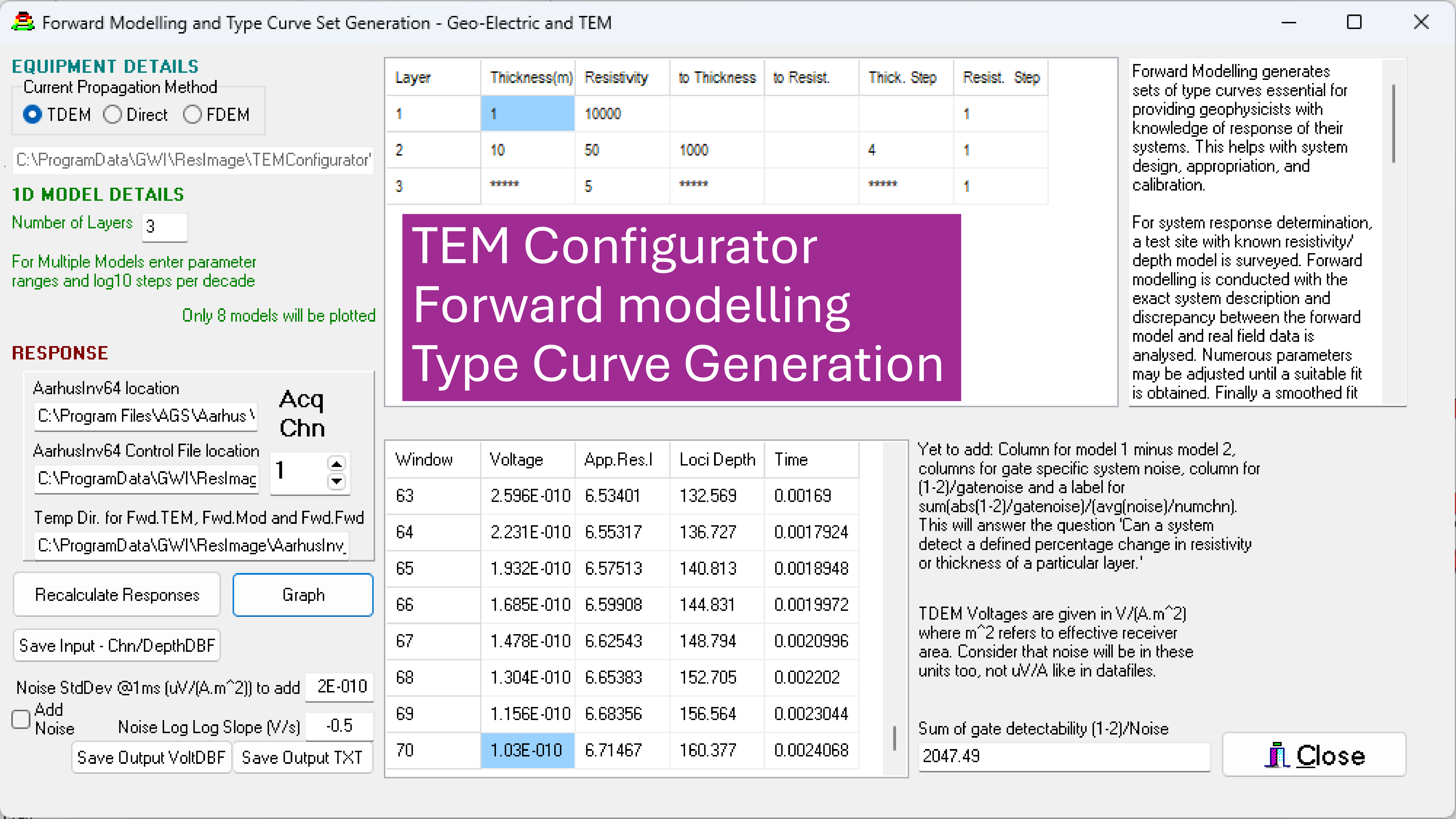
TEM Configurator - TDC format

Example Organization and Hierarchy Chart



TEM Configurator – Type Curve Generation

- Type curves present potential field data responding to sets of earth models. TEM Configurator conducts 1D modelling using **AarhusInv64.exe** from Aarhus Hydrogeophysics Group.
- Presentation of type curves transformed to **Apparent Resistivity** versus 0.4 x current ring **Loci Depth** helps us conceptualize how the earth is responding and to see sensitivity issues and equivalence complications
- Actual layered models are superimposed on the type curves.
- **Apparent Resistivity** is the resistivity that is expected from a homogeneous earth for the voltage detected.
- **Current ring loci depth** is the depth of greatest concentration of current in a 'smoke ring' of current diffusing into the ground after excitation from an artificial source such as a quickly shut down current in a loop of wire. We multiply by 0.4 as the receiver loop has greater sensitivity to the near surface.


Forward Modelling and Type Curve Set Generation - Geo-Electric and TEM
EQUIPMENT DETAILS
Current Propagation Method
TDEM Direct FDEM
C:\ProgramData\GWI\ResImage\TEMConfigurator'
1D MODEL DETAILS
Number of Layers 3
For Multiple Models enter parameter ranges and log10 steps per decade
Only 8 models will be plotted
RESPONSE
AarhusInv64 location
C:\Program Files\AGS\Aarhus \
Acq Chn
AarhusInv64 Control File location
C:\ProgramData\GWI\ResImag
1
Temp Dir. for Fwd.TEM, Fwd.Mod and Fwd.Fwd
C:\ProgramData\GWI\ResImage\AarhusInv_
Recalculate Responses
Graph
Save Input - Chn/DepthDBF
Noise StdDev @1ms (uV/(A.m^2)) to add 2E-010
Add Noise
Noise Log Log Slope (V/s) -0.5
Save Output VoltDBF
Save Output TXT
Layer | Thickness(m) | Resistivity | to Thickness | to Resist. | Thick. Step | Resist. Step
1 | 1 | 10000 | | | | 1
2 | 10 | 50 | 1000 | | 4 | 1
3 | ***** | 5 | ***** | | ***** | 1
TEM Configurator
Forward modelling
Type Curve Generation
Forward Modelling generates sets of type curves essential for providing geophysicists with knowledge of response of their systems. This helps with system design, appropriation, and calibration.
For system response determination, a test site with known resistivity/ depth model is surveyed. Forward modelling is conducted with the exact system description and discrepancy between the forward model and real field data is analysed. Numerous parameters may be adjusted until a suitable fit is obtained. Finally a smoothed fit
Window | Voltage | App.Res.I | Loci Depth | Time
63 | 2.596E-010 | 6.53401 | 132.569 | 0.00169
64 | 2.231E-010 | 6.55317 | 136.727 | 0.0017924
65 | 1.932E-010 | 6.57513 | 140.813 | 0.0018948
66 | 1.685E-010 | 6.59908 | 144.831 | 0.0019972
67 | 1.478E-010 | 6.62543 | 148.794 | 0.0020996
68 | 1.304E-010 | 6.65383 | 152.705 | 0.002202
69 | 1.156E-010 | 6.68356 | 156.564 | 0.0023044
70 | 1.03E-010 | 6.71467 | 160.377 | 0.0024068
Yet to add: Column for model 1 minus model 2, columns for gate specific system noise, column for (1-2)/gatenoise and a label for sum(abs(1-2)/gatenoise)/(avg(noise)/numchn). This will answer the question 'Can a system detect a defined percentage change in resistivity or thickness of a particular layer.'
TDEM Voltages are given in V/(A.m^2) where m^2 refers to effective receiver area. Consider that noise will be in these units too, not uV/A like in datafiles.
Sum of gate detectability (1-2)/Noise
2047.49
Close

Homogeneous half space mathematics

Terminology:

- **Homogeneous Half Space** – Just imagine the earth beneath the surface as if it was all the same. It is a common concept used in geophysics where all the sensors are on the surface.
- **Apparent Resistivity** – The resistivity that could be calculated from a voltage received by an instrument if the earth was homogeneous.
- **Effective Depth** – The depth by which 50% of signal to an instrument is contributed, assuming the earth is homogeneous.

Depth for TEM

Diffusion Depth – The depth at which maximum current flows in the earth in a transient electromagnetic system at a time after current in a horizontal loop is switched off. In TEM systems this is dependent on earth resistivity and simple calculations assume a homogeneous earth. It is not the same as effective depth as receiver loops disproportionately sense in their proximity.

Loci Depth – Old terminology for diffusion depth (definition may be slightly different)

$$d = \sqrt{\frac{2\,t\,\rho_a(t)}{\mu}}$$

1D Imaging of Central Loop Transient Electromagnetic Sounding.
Niels B. Christensen
Aarhus University, Department of Earth Sciences, Laboratory of Geophysics

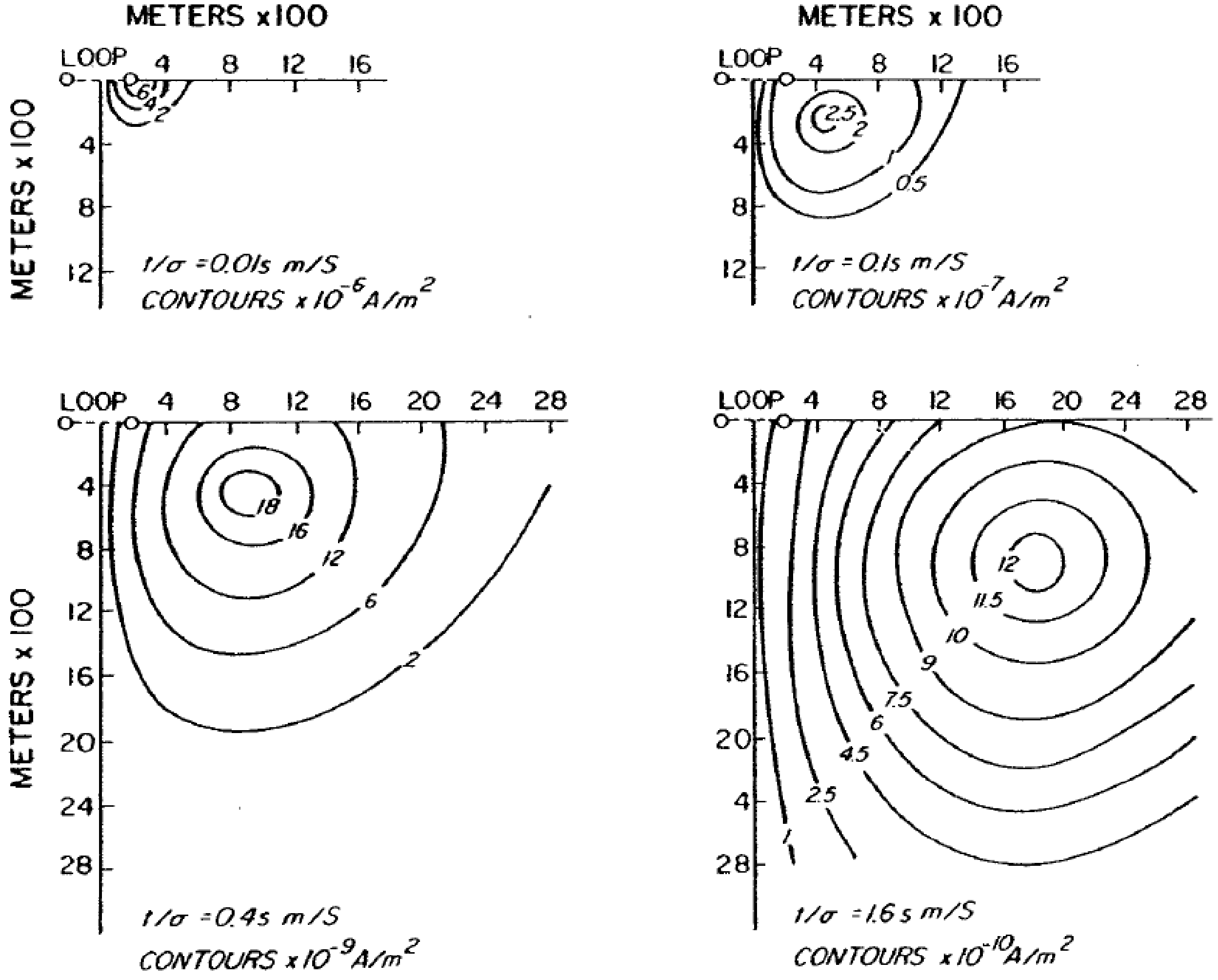


Fig. 19. Contours of the current density in the "smoke ring" of current induced in a uniform conductive half space by a step transient current in a horizontal transmitter loop. Four snapshots in time are provided. The induced current is flowing azimuthally around the vertical axis of the loop, i.e., normal to the plotted section (after Nabighian, 1979).

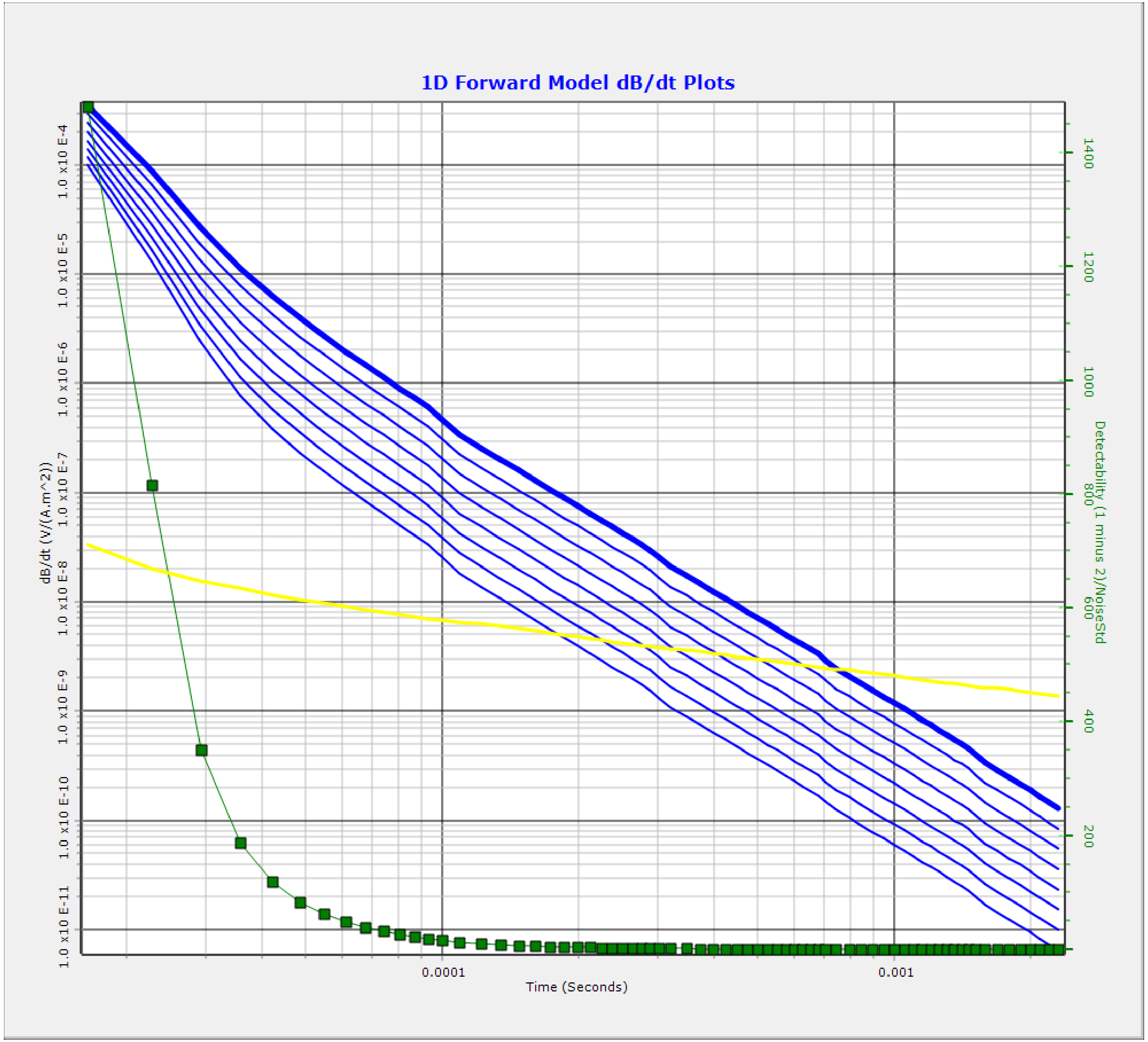
From: **PHYSICS OF THE ELECTROMAGNETIC INDUCTION EXPLORATION METHOD**

G. F. West and J. C. Macnae‡*

TEM Configurator Forward Models of Halfspaces

Halfspace Model Resistivities:
Starting with the bold line are:

1 – 5.0 ohm.m
2 – 6.7 ohm.m
3 – 8.9 ohm.m
4 – 11.9 ohm.m
5 – 15.8 ohm.m
6 – 21.1 ohm.m
7 – 28.1 ohm.m
8 – 37.5 ohm.m



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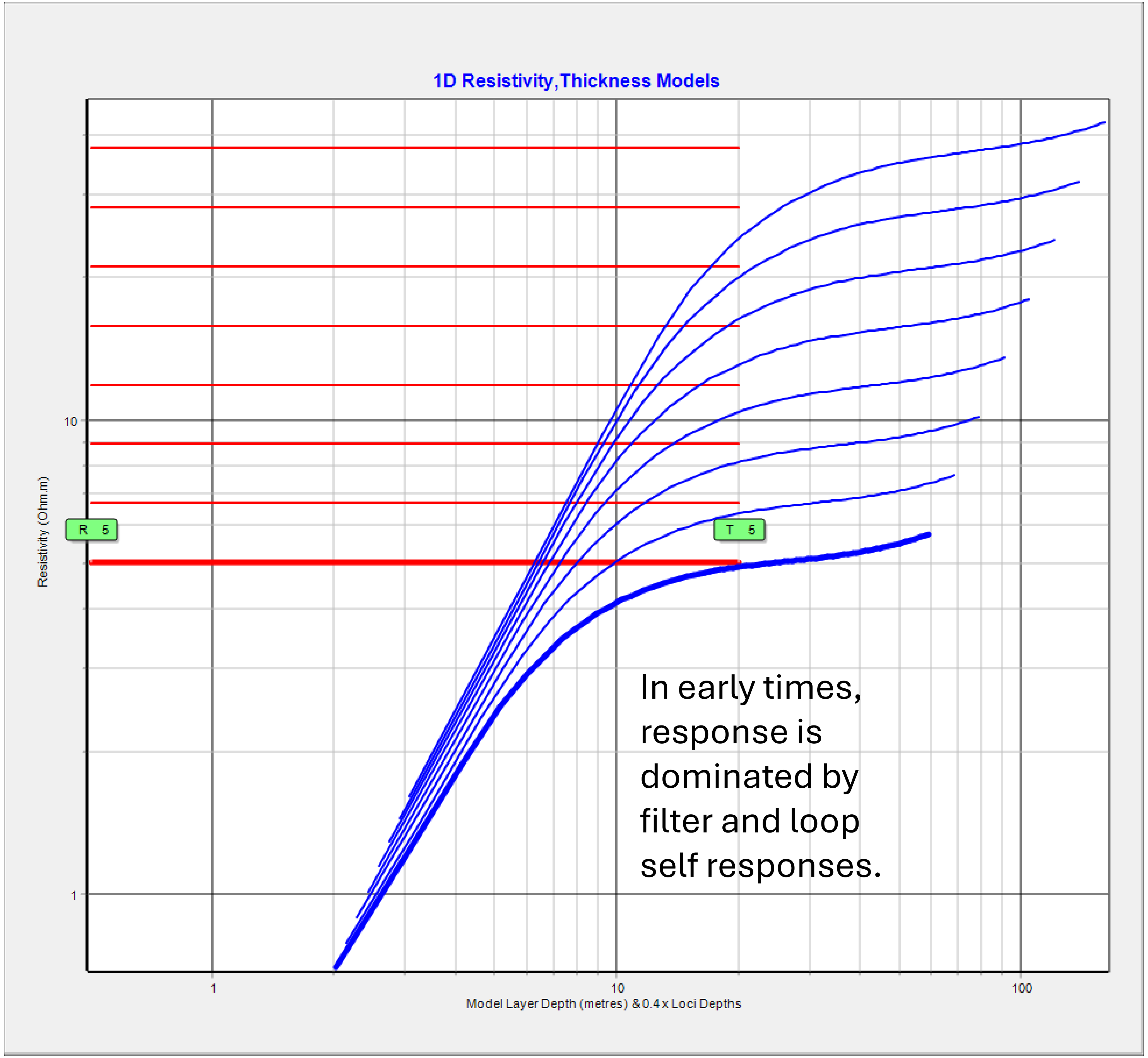
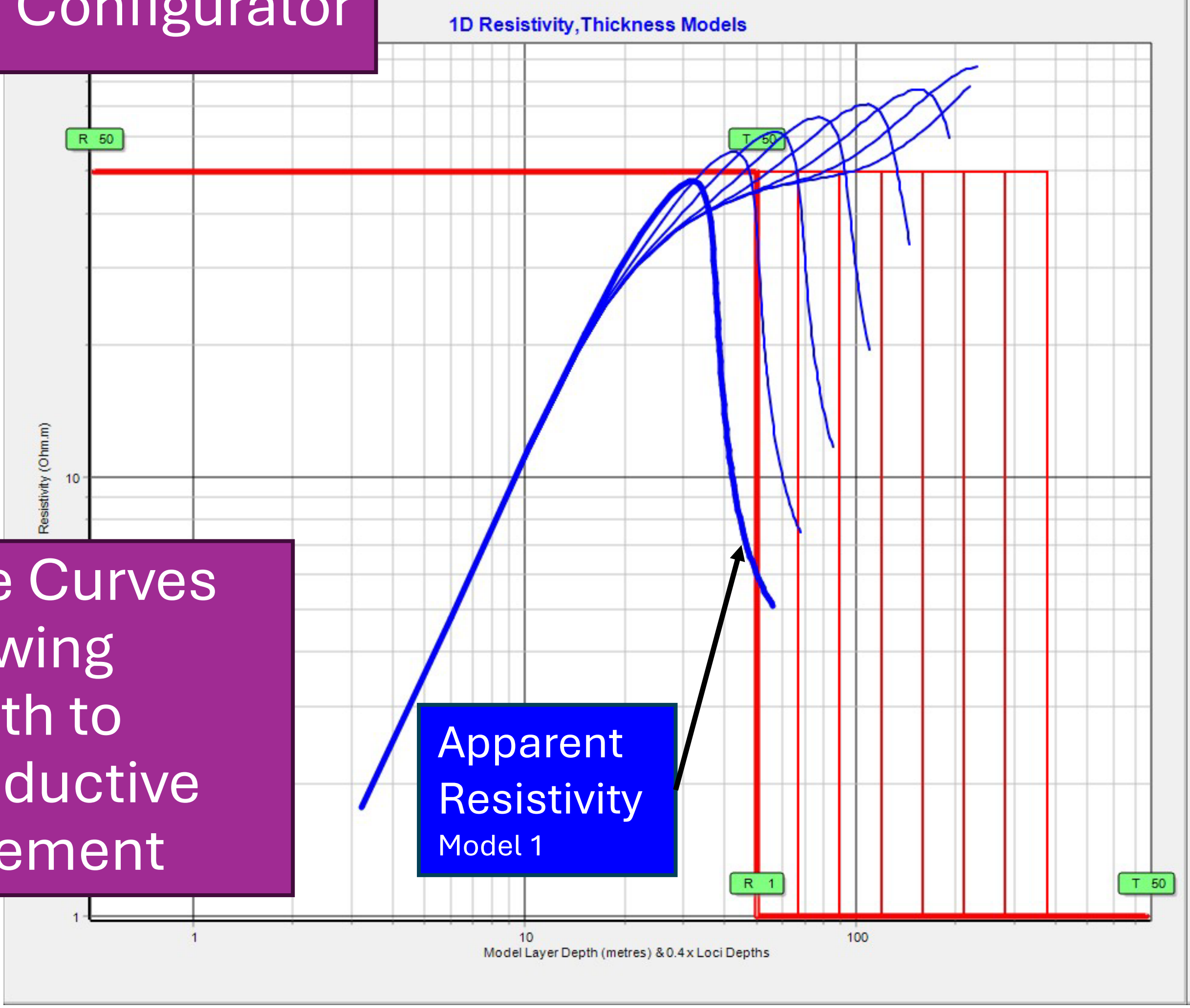
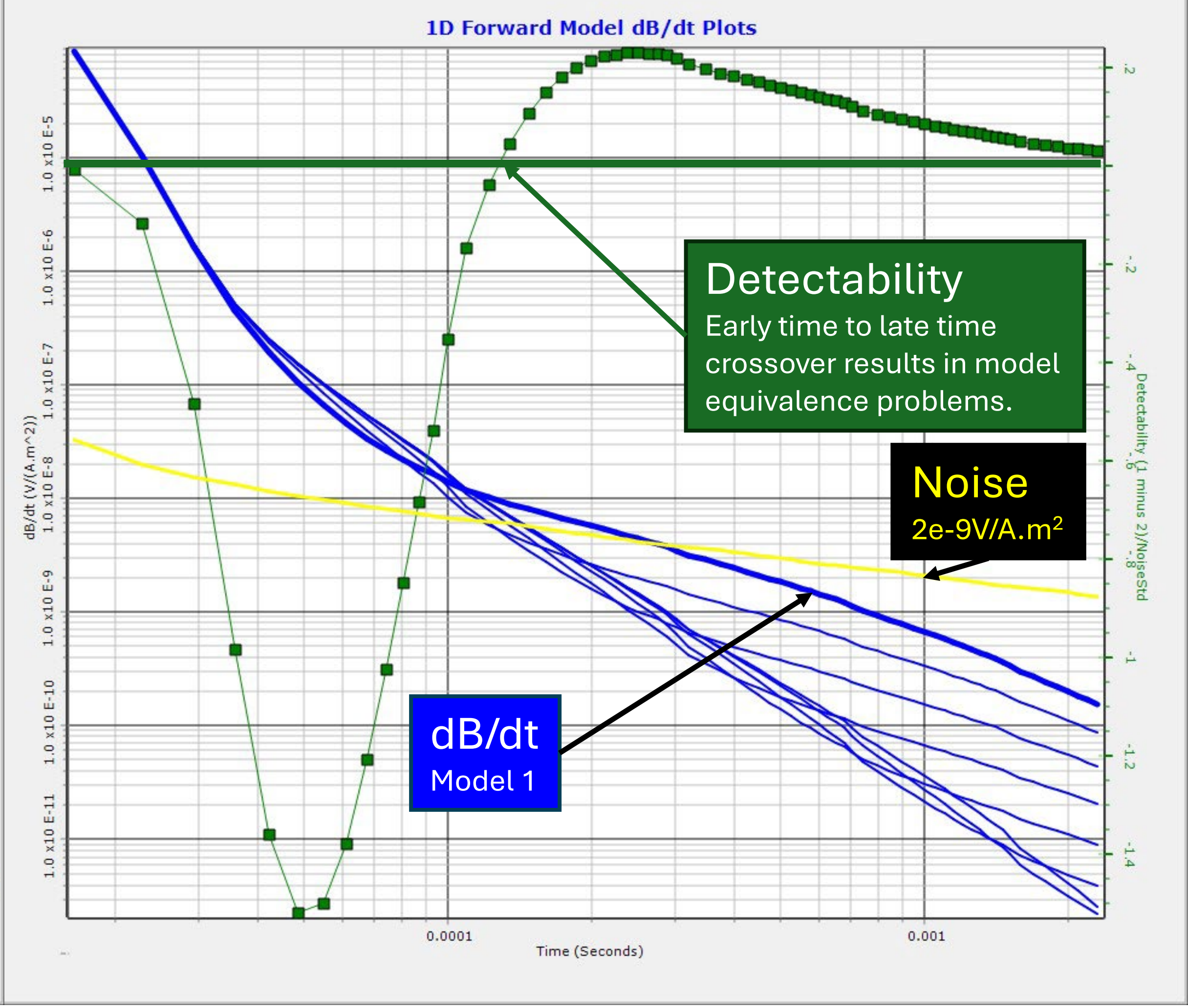
7 – 28.1 ohm.m
8 – 37.5 ohm.m



TEM Configurator

Type Curves showing Depth to Conductive Basement





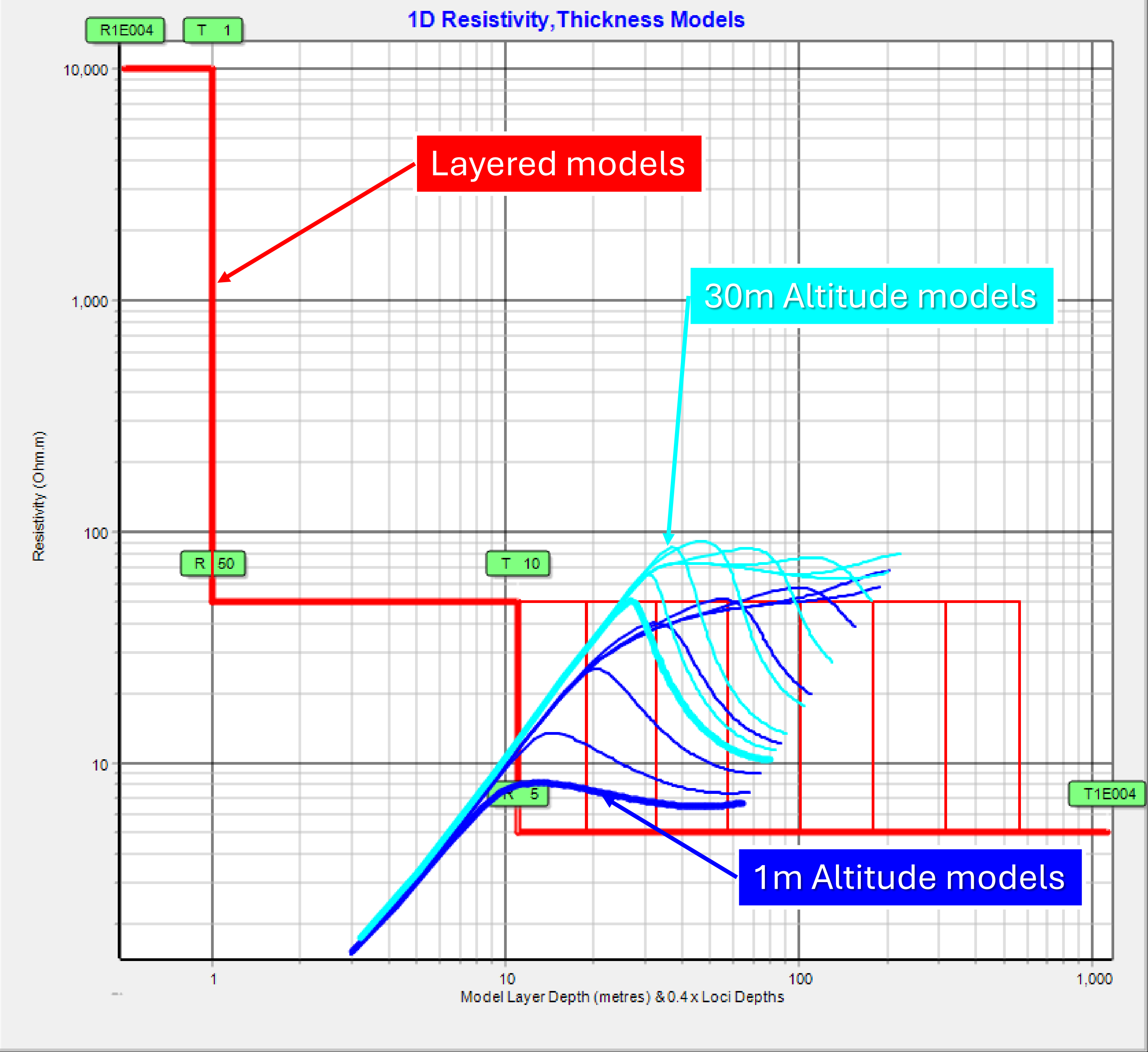
Layer	Resistivity	Thickness
1-Alluvium	50 Ohm.m	50m 67m 89m 115m 158m 211m 281m 375m
2-Basement	1 Ohm.m	infinite

Noise: 2e-9 @ 1mS with slope of 0.5

Evaluation of a detectability curve (Green) for a given noise threshold (Yellow) for forward models (Blue) of layered models (Red) as given in the table included for Wallaby In-loop configuration with 36 Amps and one Tx loop turn. The left graph presents forward models as late time apparent resistivity versus 0.4 x Loci Depth while the right graph presents the same forward models as dB/dt versus time. Detectability is calculated contrasting the heavy blue curve with the adjacent curve. The noise threshold in this example is high such as is typical for short stack times and rapid travel over rough ground.

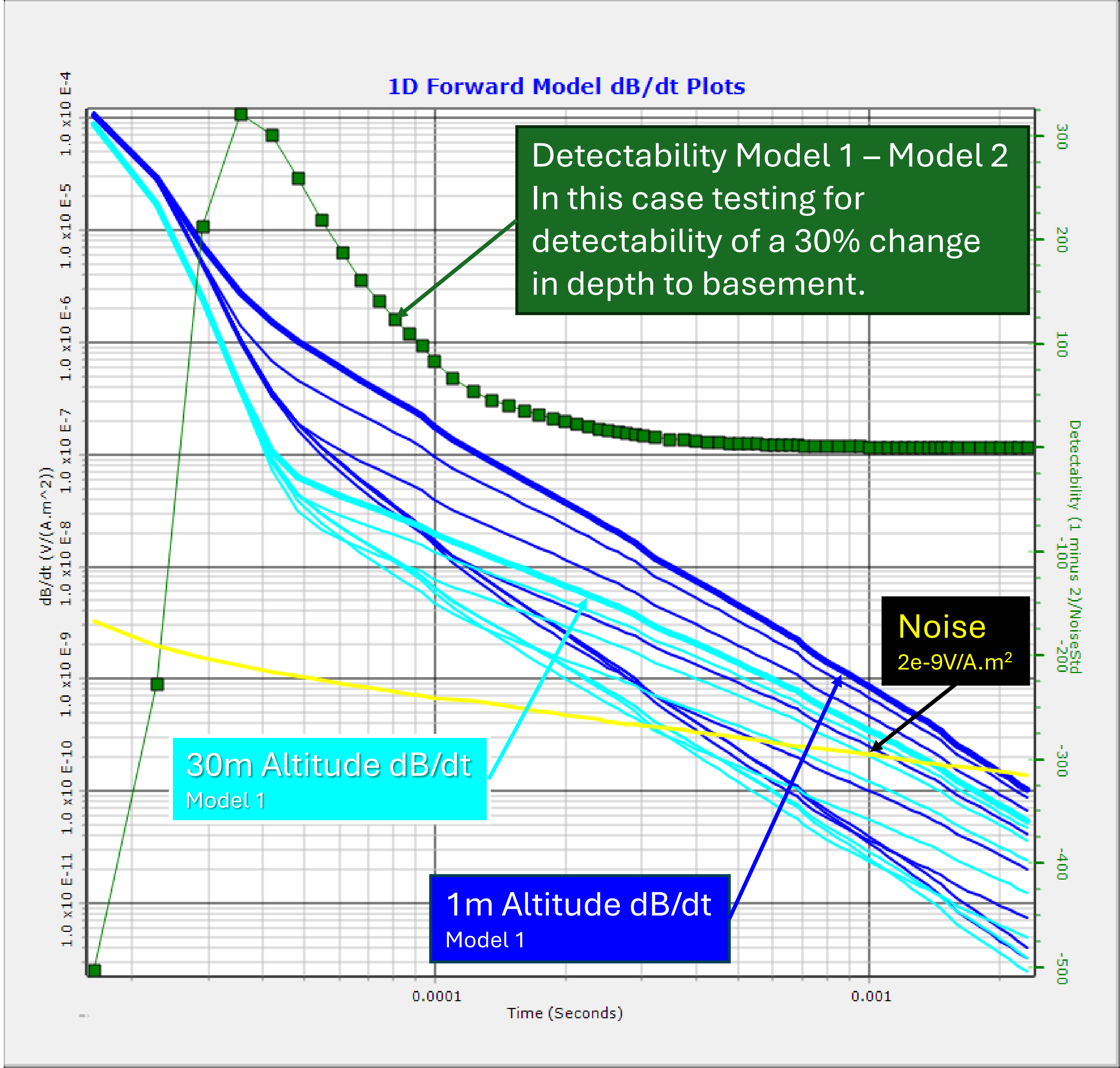
TEM Configurator 30m altitude versus 1m altitude

A resistivity versus 0.4 x loci depth example from the forward modeller. Red lines present modelled resistivities and depths, green boxes display resistivity of the layer below, and thickness of the layer above each box. Type curves for eight models are displayed in dark blue. Aqua coloured lines display the last chosen models and configuration. In this case, the dark blue lines are for the overlapping loops configuration of AgTEM Wallaby and the Aqua colour lines present equivalent models but with layer 1 changed to 30m thick to simulate what would happen if Wallaby was used airborne.



TEM Configurator 30m altitude versus 1m altitude

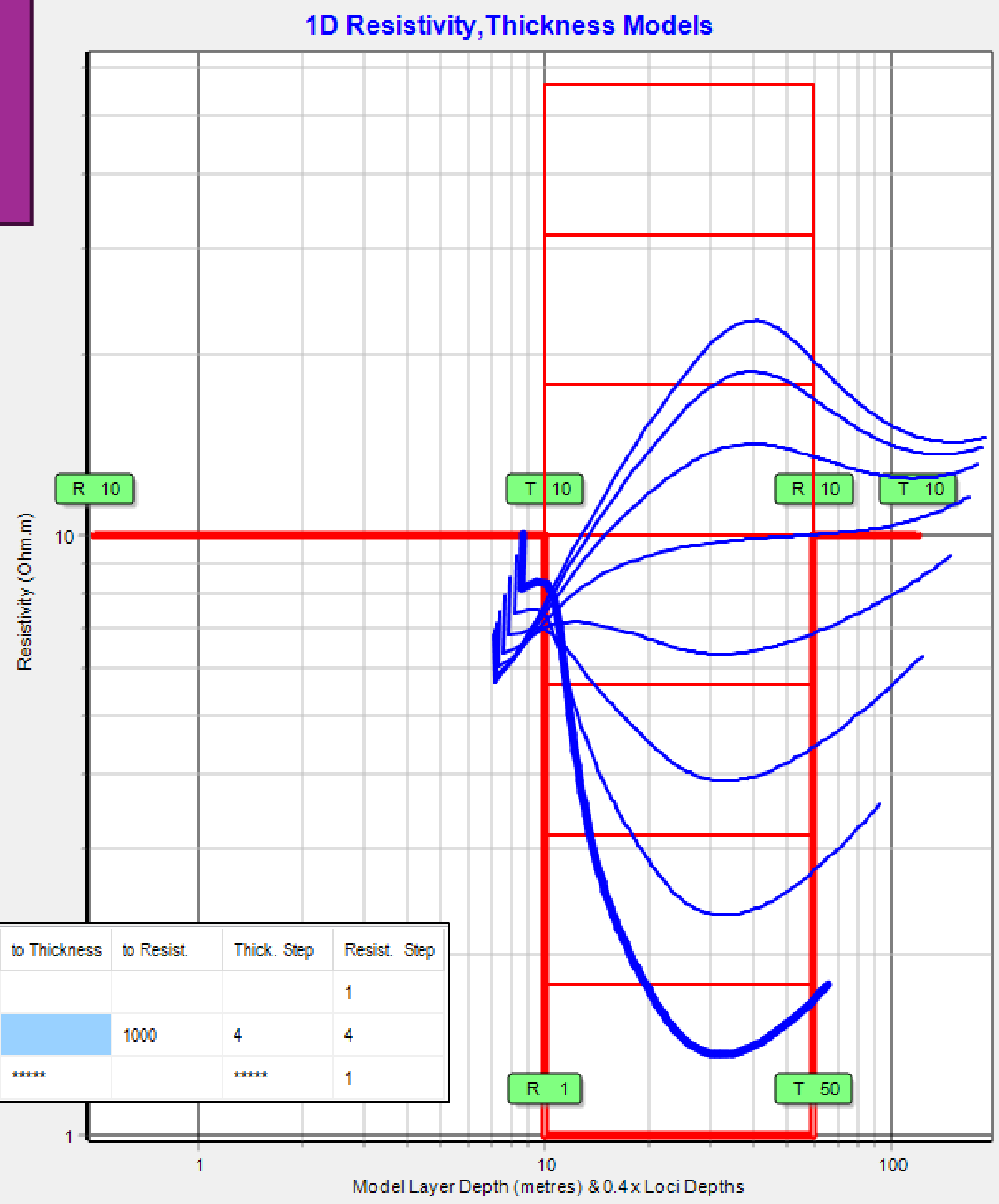
For the models in the previous graph, this is example from the forward modeller of dB/dt versus time type curve generation. Eight models are displayed in dark blue. Aqua coloured lines display the last chosen models and configuration. In this case, the dark blue lines are for the overlapping loops configuration of AgTEM Wallaby and the Aqua colour lines present equivalent models but with layer 1 changed to 30m thick to simulate what would happen if Wallaby was used airborne. A green detectability curve displays relative contrast between model 1 and 2 normalized to noise standard deviation, which is provided in the yellow curve.

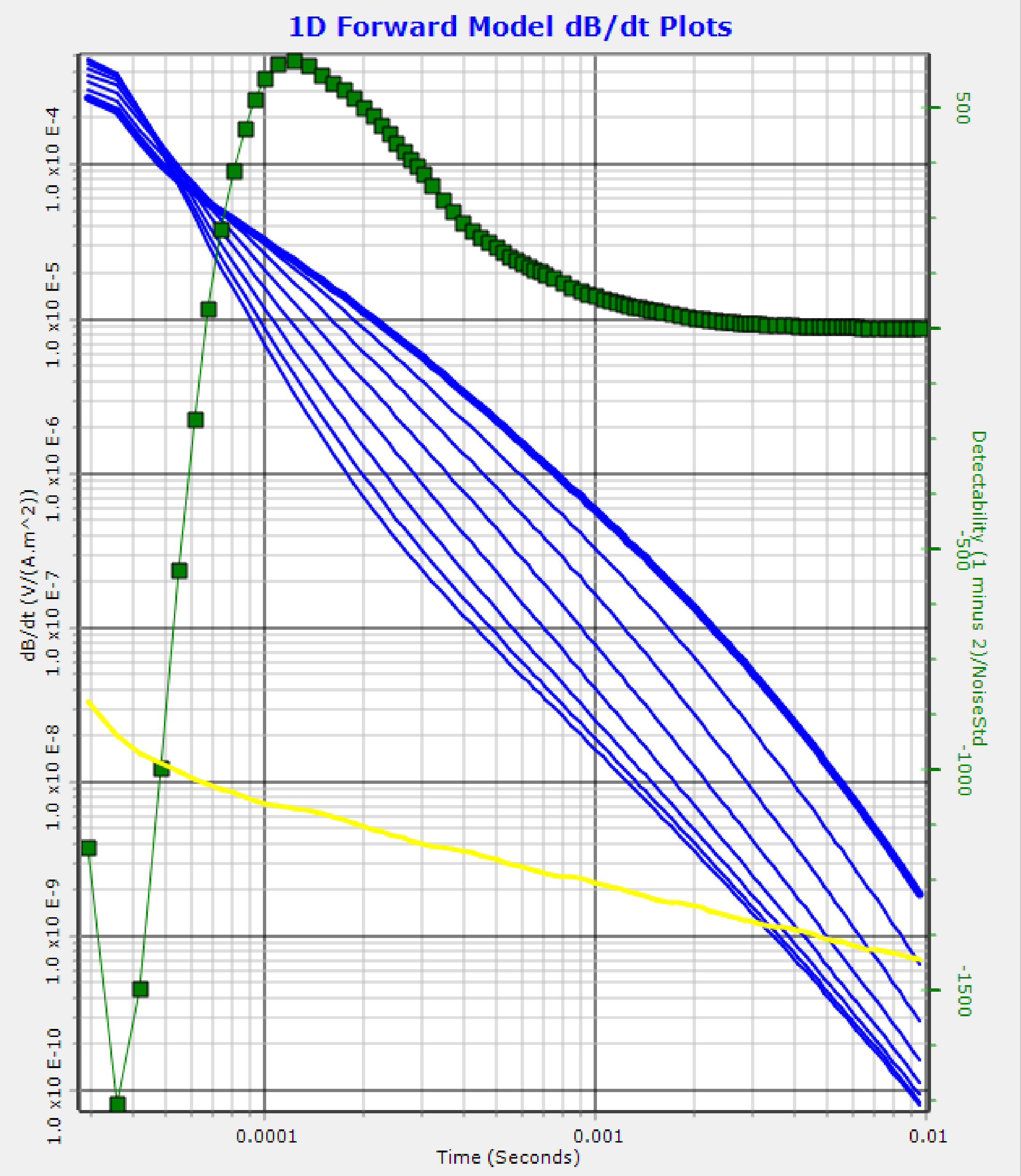


TEM Configurator Type curves

with layers:
1: Neutral
2: Conductive to Resistive
3: Neutral

1D Resistivity,Thickness Models and Apparent Resistivity vs Effective Depth graphs





Layer	Thickness(m)	Resistivity	to Thickness	to Resist.	Thick. Step	Resist. Step
1	10	10				1
2	50	1		1000	4	4
3	*****	10	*****		*****	1

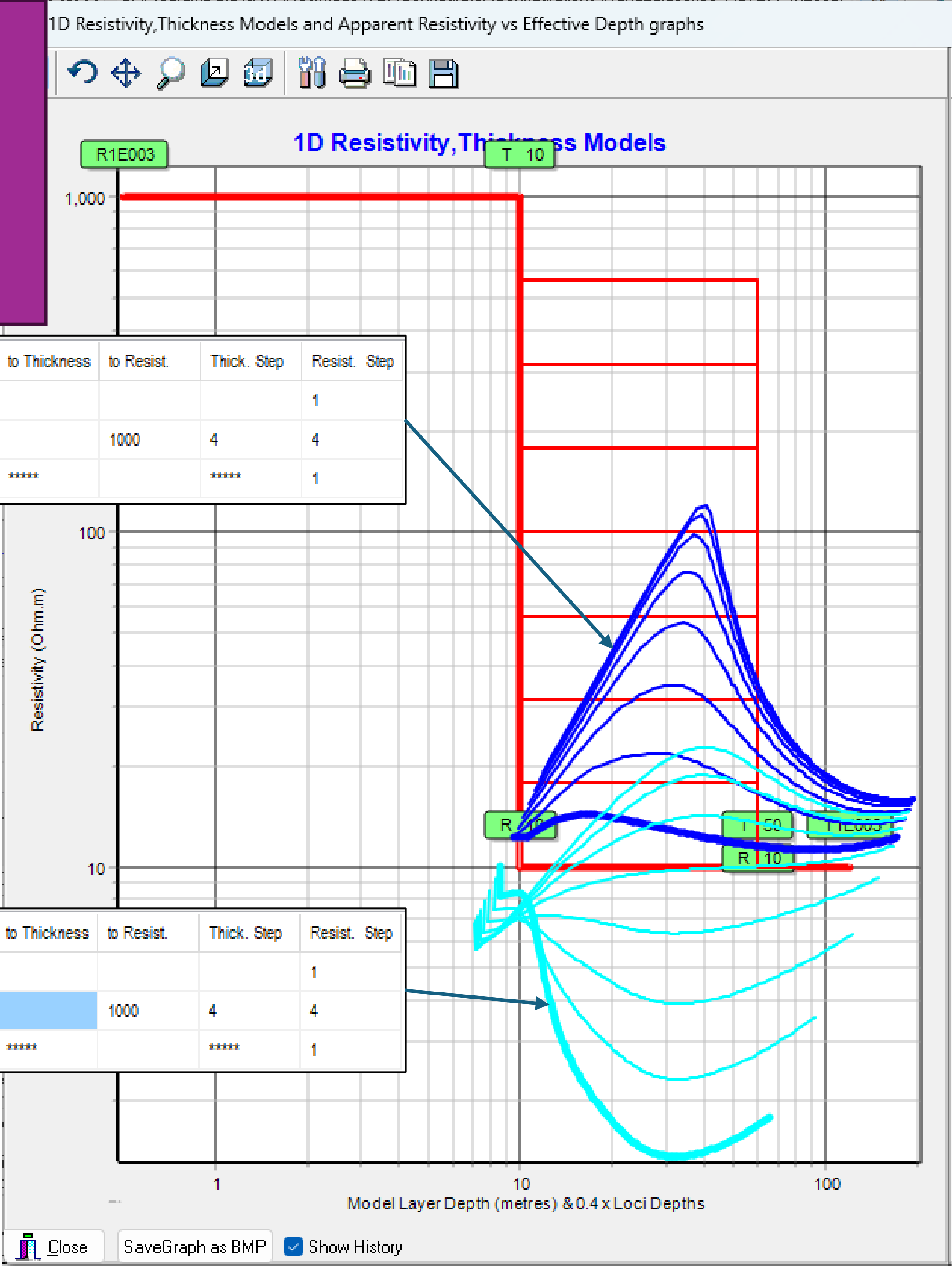
Close SaveGraph as BMP Show History

SaveGraph as BMP Show Detectability of (Model 1 - Model 2)/NoiseStd

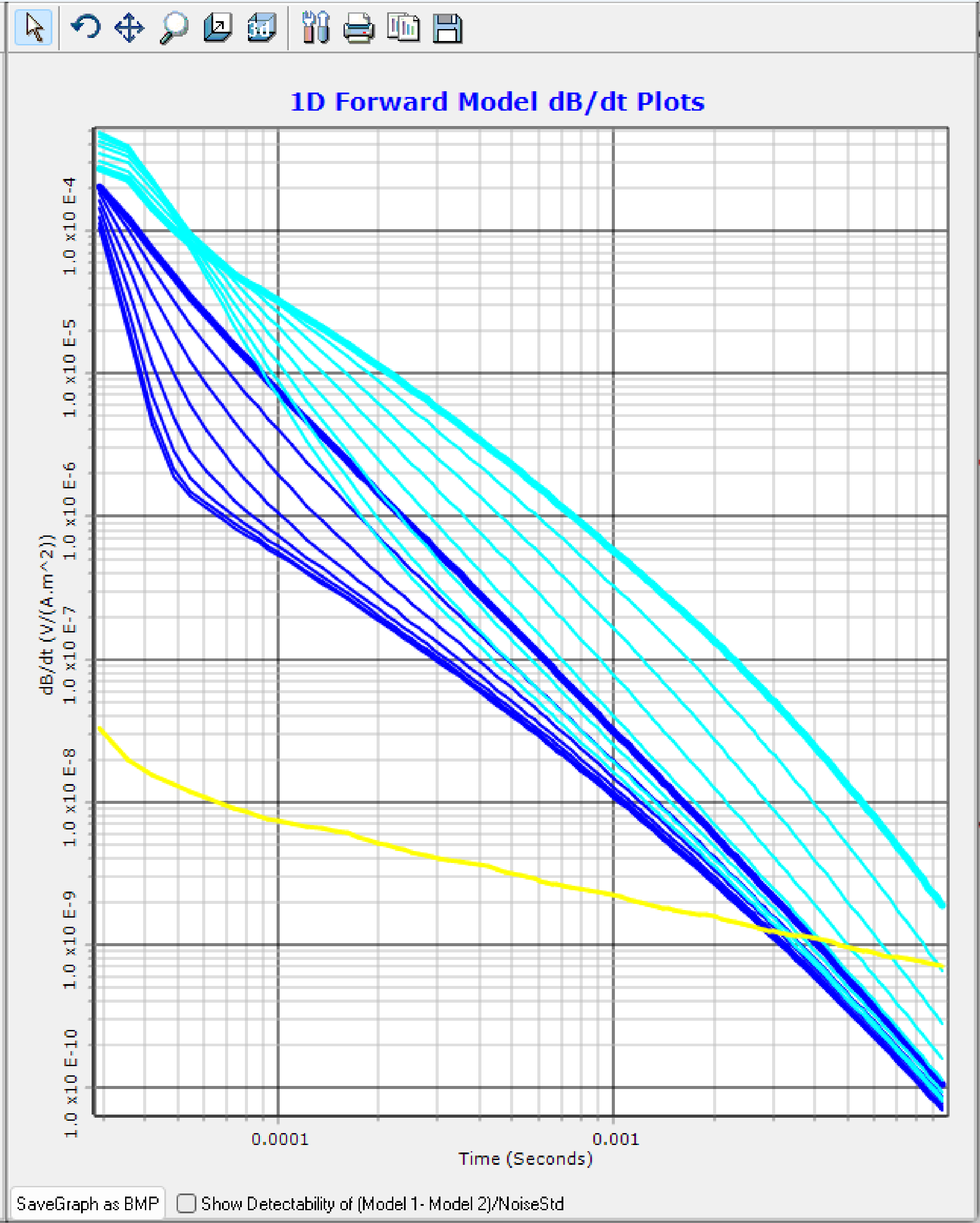
TEM Configurator Type curves

with layers:
1: Resistive
2: Conductive to Neutral
3: Neutral (10 ohm.m)

Layer	Thickness(m)	Resistivity	to Thickness	to Resist.	Thick. Step	Resist. Step
1	10	1000				1
2	50	10		1000	4	4
3	*****	10	*****		*****	1



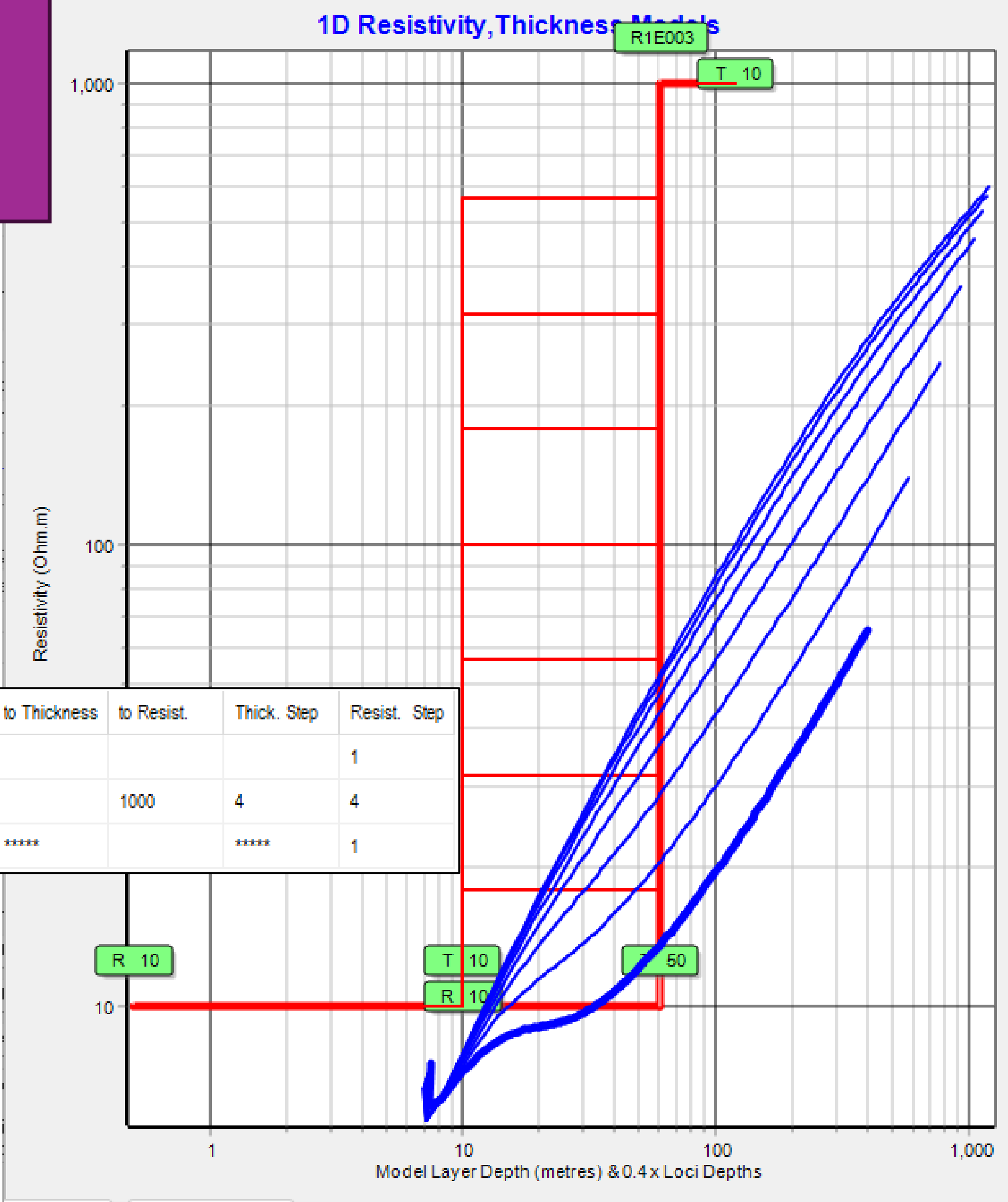
Layer	Thickness(m)	Resistivity	to Thickness	to Resist.	Thick. Step	Resist. Step
1	10	10				1
2	50	1		1000	4	4
3	*****	10	*****		*****	1



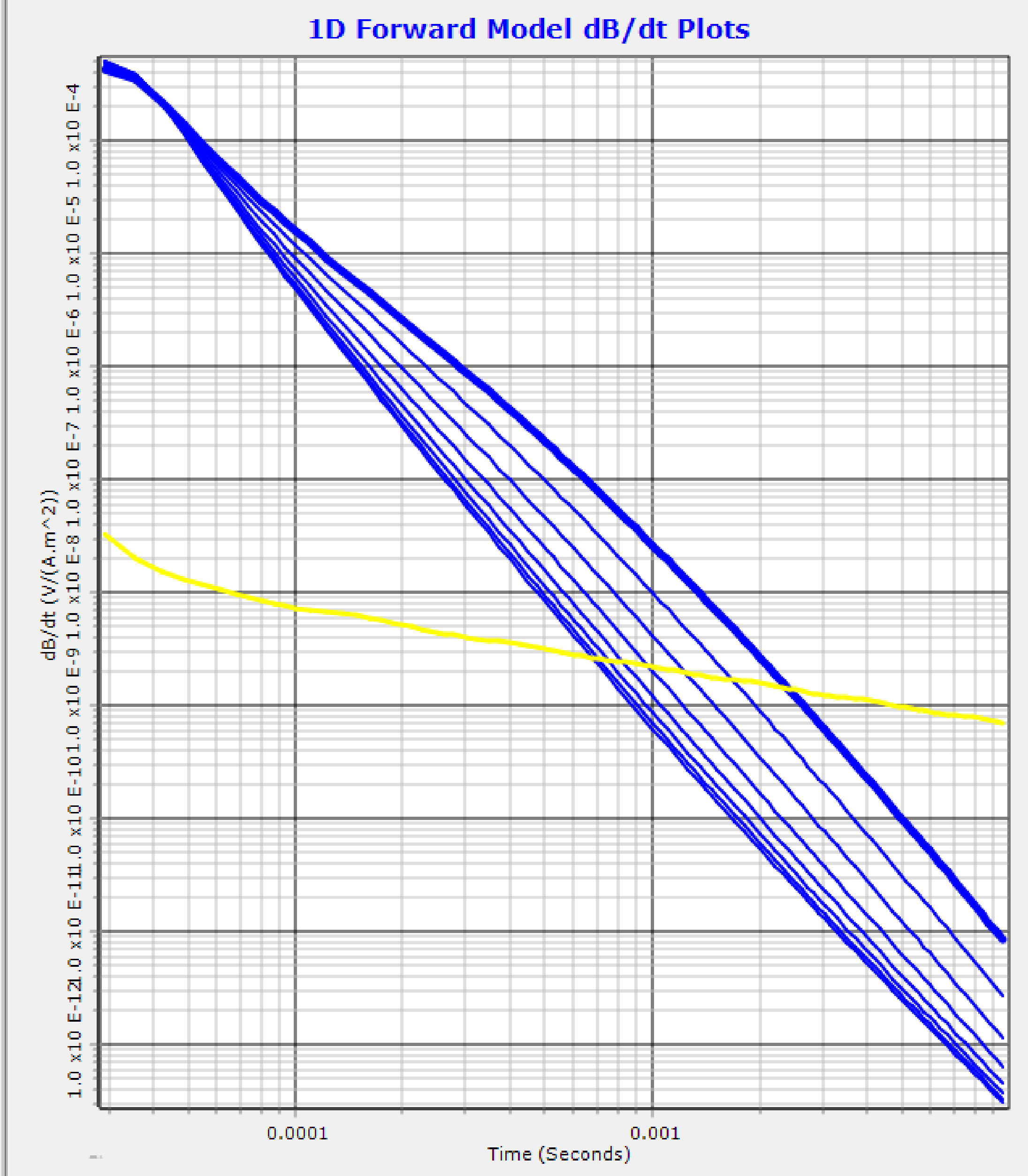
TEM Configurator Type curves

with layers:
1: Neutral (10 ohm.m)
2: Neutral to Resistive
3: Resistive

1D Resistivity,Thickness Models and Apparent Resistivity vs Effective Depth graphs



Layer	Thickness(m)	Resistivity	to Thickness	to Resist.	Thick. Step	Resist. Step
1	10	10				1
2	50	10		1000	4	4
3	*****	1000	*****		*****	1



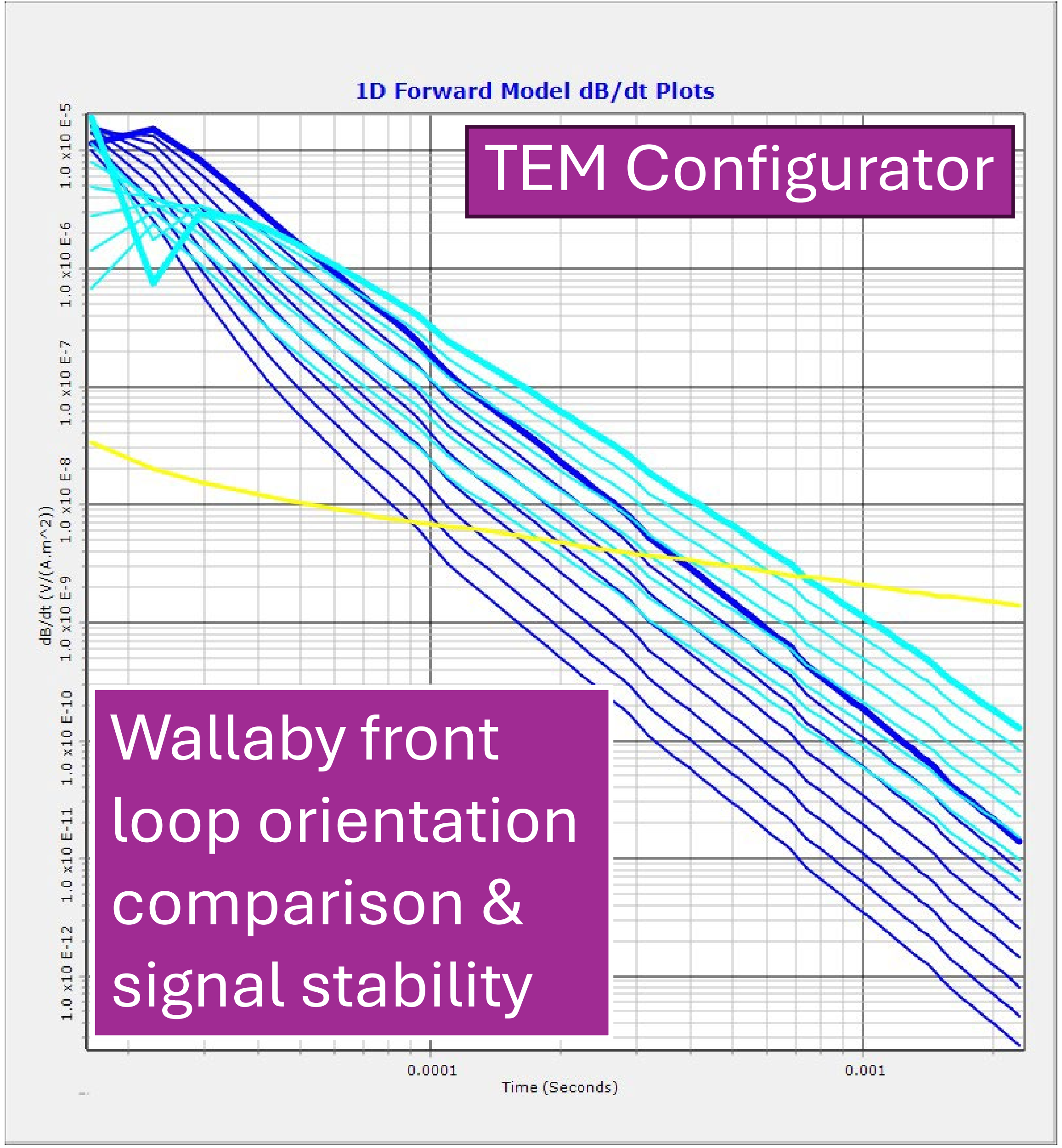
Blue - Receiver Axes with X-Orientation.

Aqua - Receiver Axes with Z-Orientation.

Yellow - Noise @ 1mV=2e-9 V/(A.m^2) with 0.5slope.

In early channels, X-Orientation signal dominates making Z-Orientation data sensitive to tilting.

Note that X-Orientation could also have a dominance of metal vehicle response as it couples axially with the vehicle.



Halfspace Model Resistivities:
Starting with the bold line are:

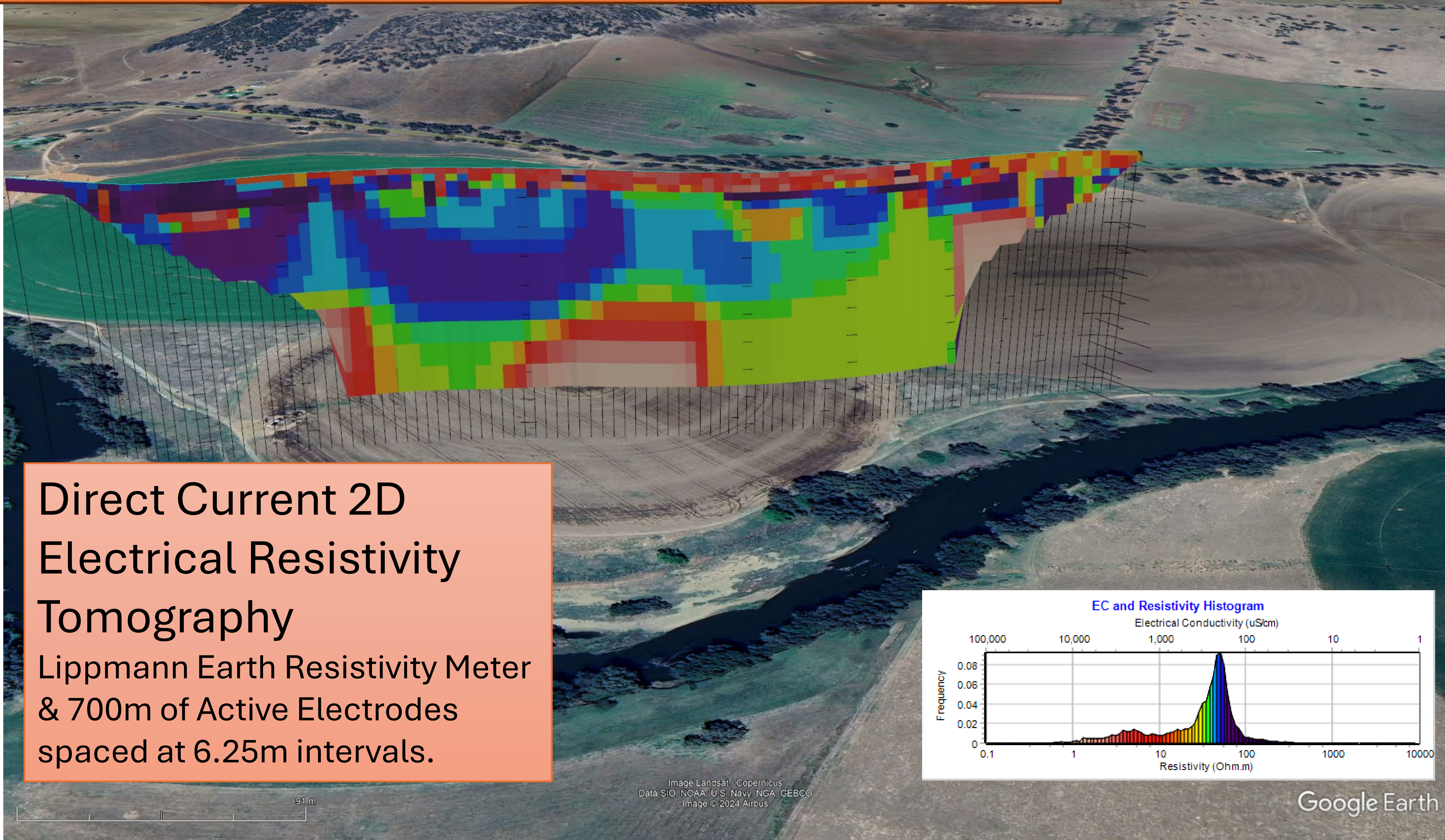
1 – 5.0 ohm.m
2 – 6.7 ohm.m
3 – 8.9 ohm.m
4 – 11.9 ohm.m
5 – 15.8 ohm.m
6 – 21.1 ohm.m
7 – 28.1 ohm.m
8 – 37.5 ohm.m

This analysis is also relevant to other instruments. tTEM, which has ONLY a Slingram Z-component loop, is vulnerable to Z and X orientation mixing as the short-base sled pitches across rough ground.
Loupe collects only Slingram data but in three components and they model data as change in total field, thus eliminating the orientation sensitivity problem. An additional problem, however, is generated when a relatively low sensitivity coil is used to detect X-orientation data and the high noise on this component is mixed into total field data, unduly affecting the noise floor.

Observing this data we can see that a 20 degree pitch change will change the 2.8e-5 z-component data at 30uS over a 5 ohm.m half space to (2.8e-5).(cos(20)+(8.0e-5).sin(20)=5.36e-5 or 1.91 time of the correct value. On tussocky or ploughed ground a 20 degree tilt on a short base sled is common.

Calibrating towed TEM data:Test site data

Direct Current Electrical Resistivity Tomography – Zhou array configuration. Modelled resistivity is projected up 160m



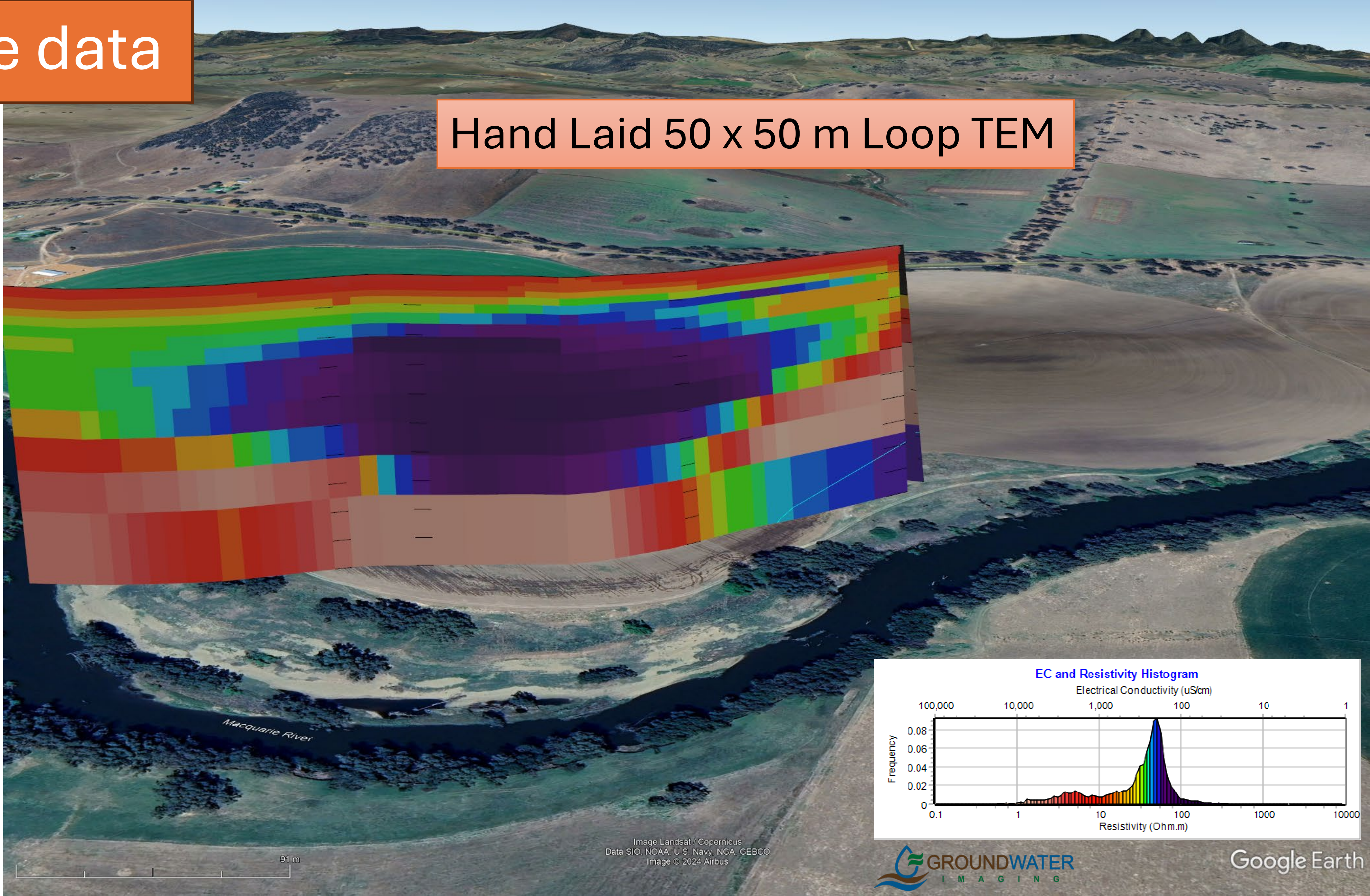
Direct Current 2D Electrical Resistivity Tomography

Lippmann Earth Resistivity Meter & 700m of Active Electrodes spaced at 6.25m intervals.

GROUNDWATER IMAGING

Test site data

Transient Electromagnetics with 50m x 50m hand laid loops. Modelled resistivity projected up 160m. This image is modelled with system response corrected to reveal the near surface conductive layer for which loops of this dimension are otherwise unable to discriminate very effectively. The aqua colour line represents depth of investigation characteristic.



Test site data

Determining a layered model at the test site to forward model.

Zhou			Wenner			TEM 50 x 50			Fwd Model		
From	To	Res	From	To	Res	From	To	Res	From	To	Res
0	16	180	0	10	200	0	30	1000	0	16	180
16	30	40	10	20	50	30	60	15	16	30	40
30	72	120	20	60	120	60	70	5	30	62	120
72	inf	20	60	inf	45	70	inf	30	62	inf	20

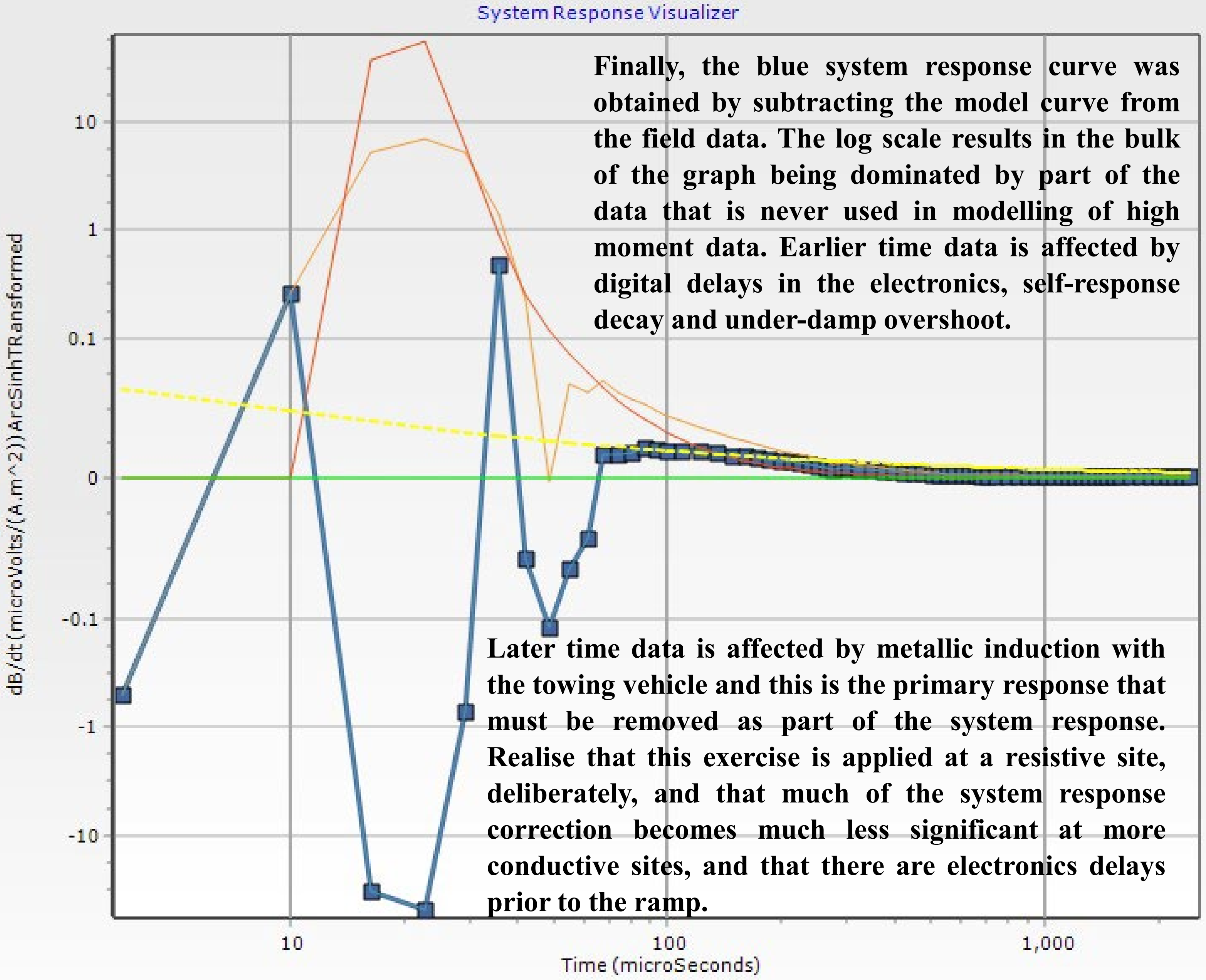
In_loop Receiver
20xGain
20 turn

TEM Configurator – System Response Evaluator for towed TEM

Test site data

High moment (38 Amps x 32m^2) Wallaby system response assessment for the in-loop receiver with 20 turns and 20x pre-amplification. Field data is displayed in orange, assessed noise threshold in yellow, and the forward model in red

Thickness(m	Resistivity
16	180
14	40
32	120
inf	20



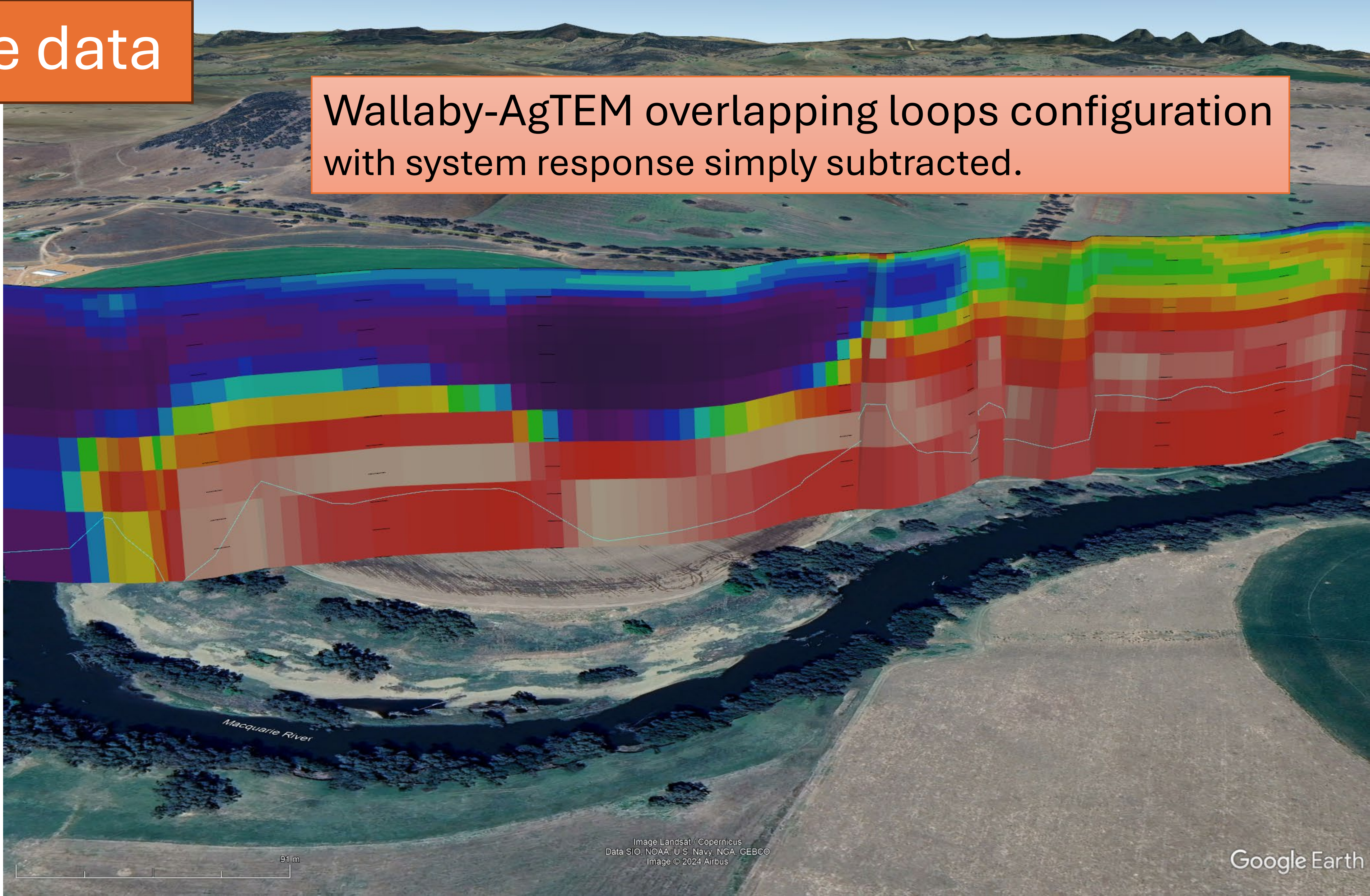
Finally, the blue system response curve was obtained by subtracting the model curve from the field data. The log scale results in the bulk of the graph being dominated by part of the data that is never used in modelling of high moment data. Earlier time data is affected by digital delays in the electronics, self-response decay and under-damp overshoot.

Later time data is affected by metallic induction with the towing vehicle and this is the primary response that must be removed as part of the system response. Realise that this exercise is applied at a resistive site, deliberately, and that much of the system response correction becomes much less significant at more conductive sites, and that there are electronics delays prior to the ramp.

Test site data

Wallaby In-Loop transient electromagnetics. Modelled Resistivity projected up 160m (525 feet), 2 Parallel 1 Series Turns, 38Amps, 150 Watts

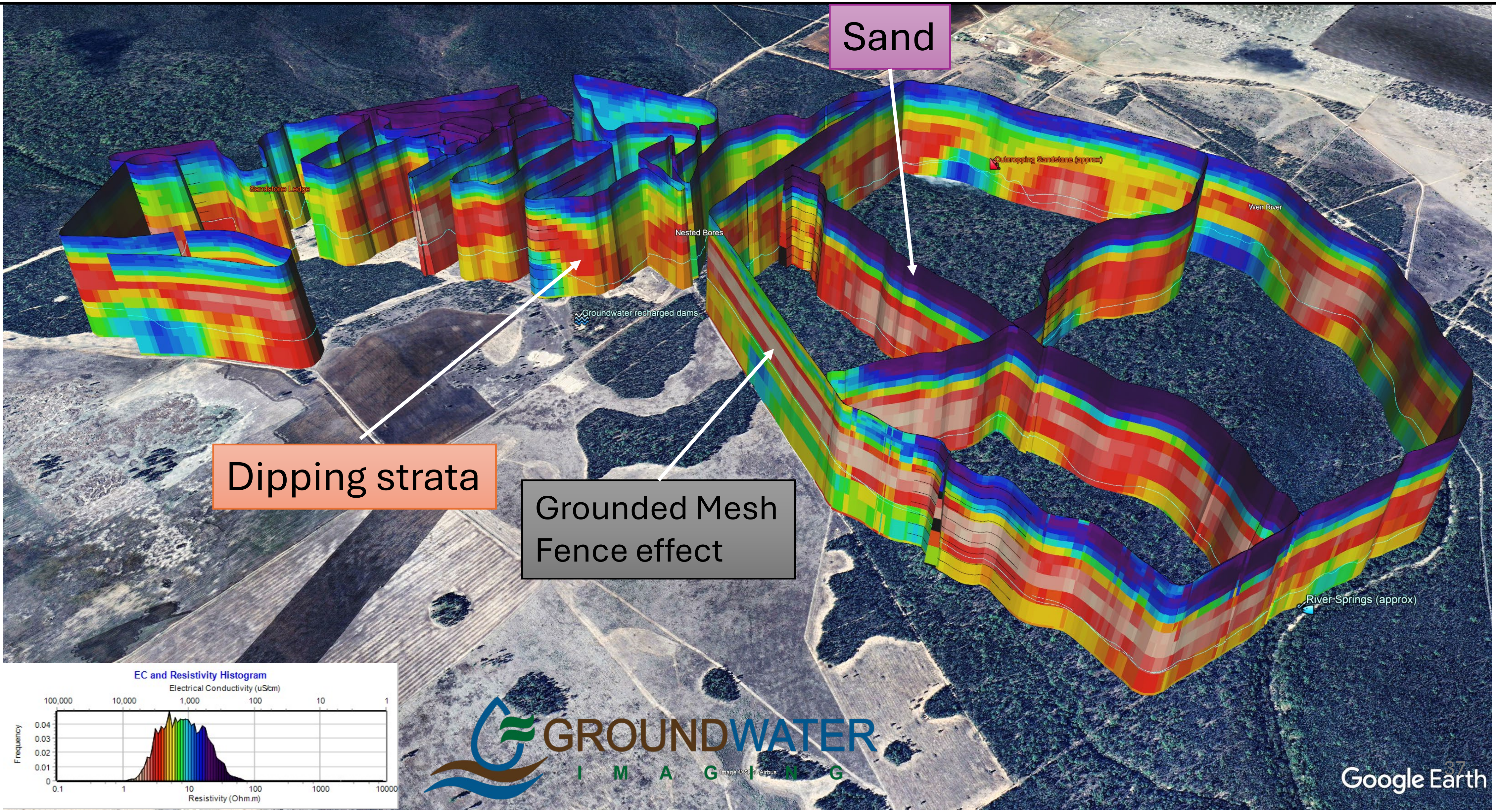
Wallaby-AgTEM overlapping loops configuration with system response simply subtracted.



GROUNDWATER IMAGING

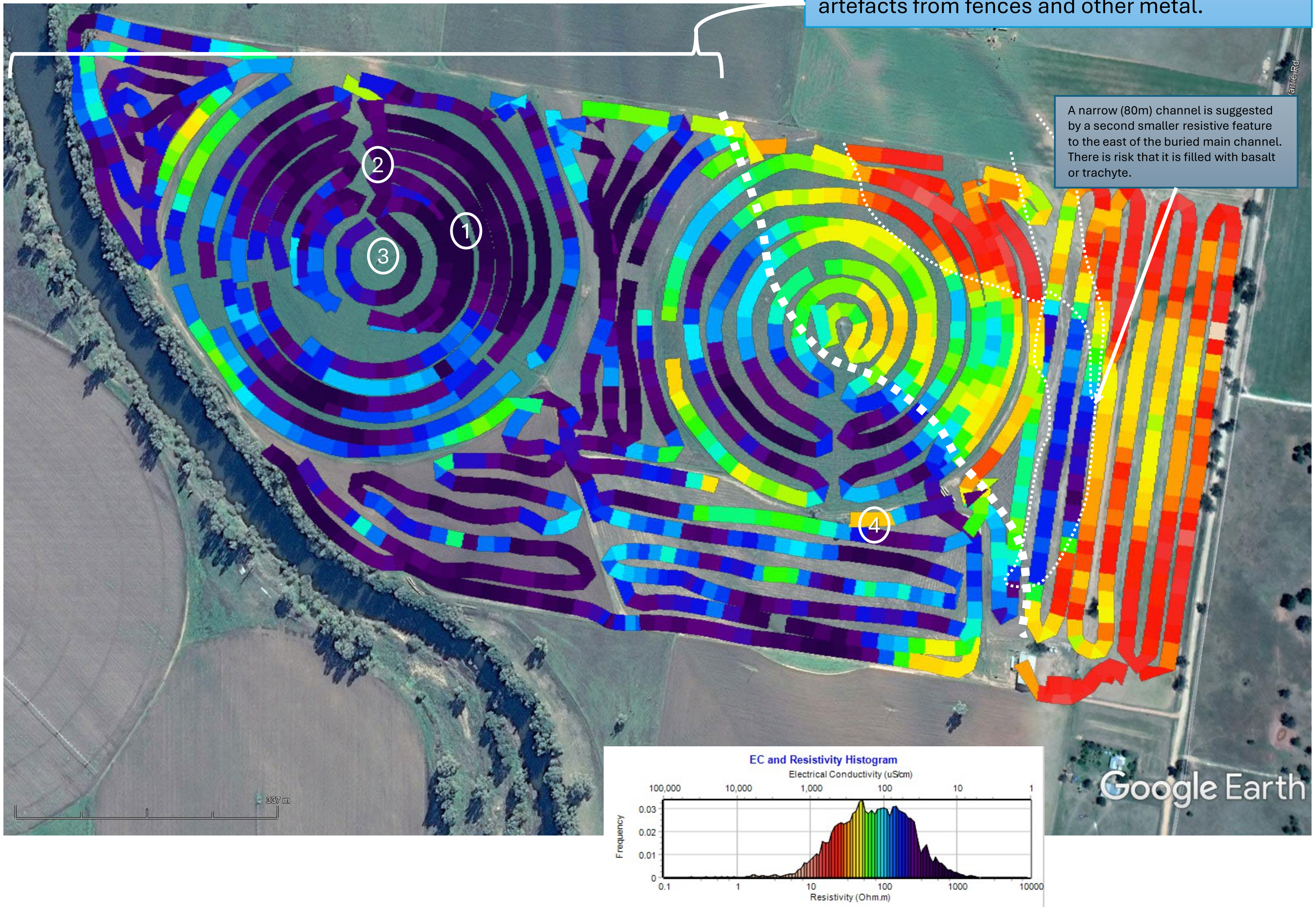
Wallaroo_AgTEM - Modelled Resistivity projected up 100m.

Aqua line reveals estimated Depth of Investigation. Vertical Exaggeration x4.



AgTEM Modelled Resistivity at 20m deep

A broad layer of deep resistive sediment (Cobbles) is inferred here interrupted by artefacts from fences and other metal.



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GROUNDWATER IMAGING

ASEG 2024