Central Queensland Coal Project

Appendix 6f – Transient Electromagnetic Survey

Central Queensland Coal

CQC SEIS, Version 3

October 2020

CQC Ogmore AgTEM survey for Groundwater Investigation

Tooloombah Creek – Bar-H – Mamelon Crossing

Stxy River Tidal Limit, Ogmore

September 2019

For Central Queensland Coal

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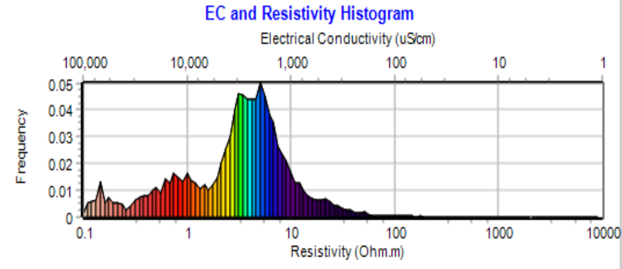
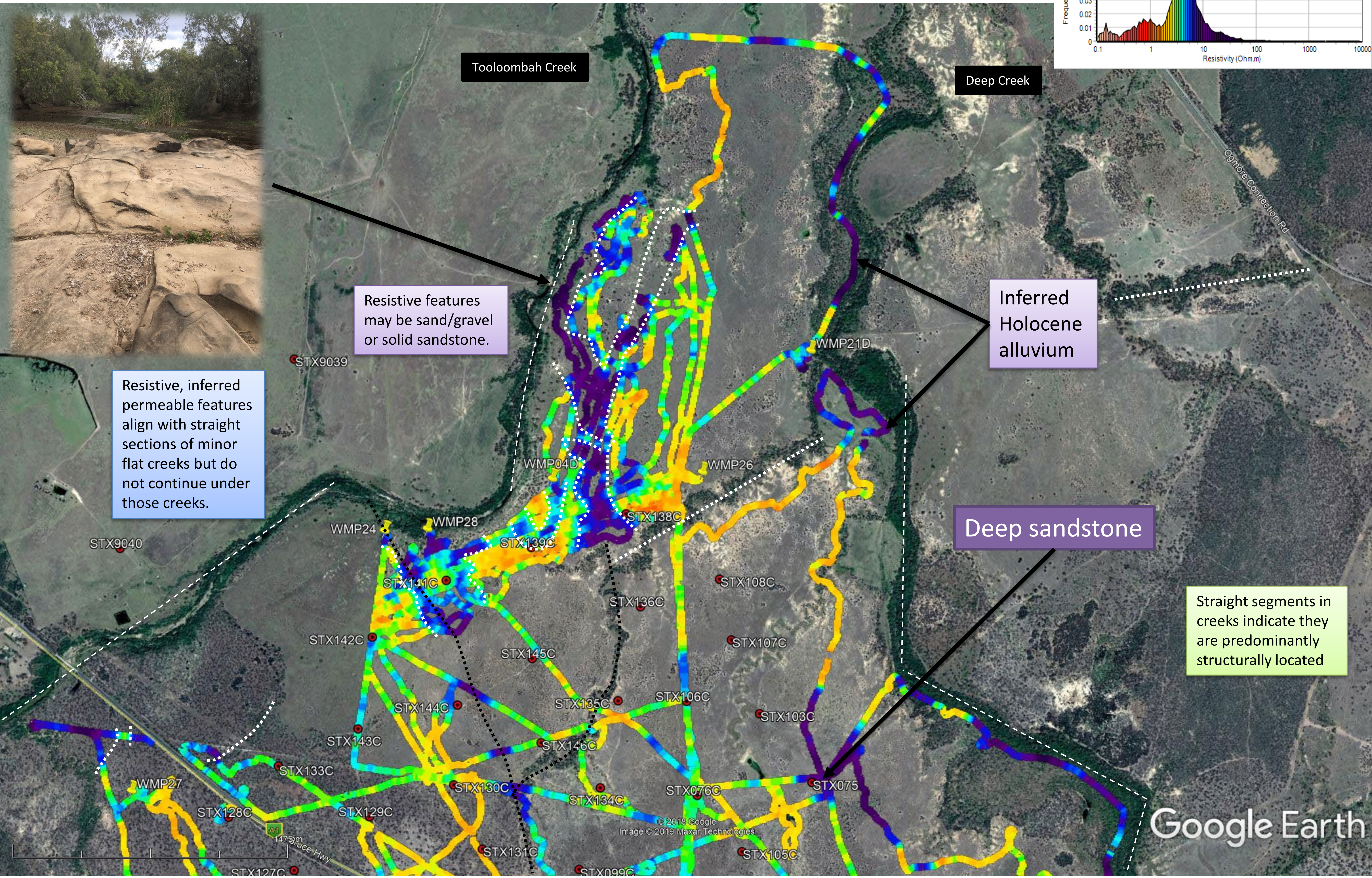
Executive Summary

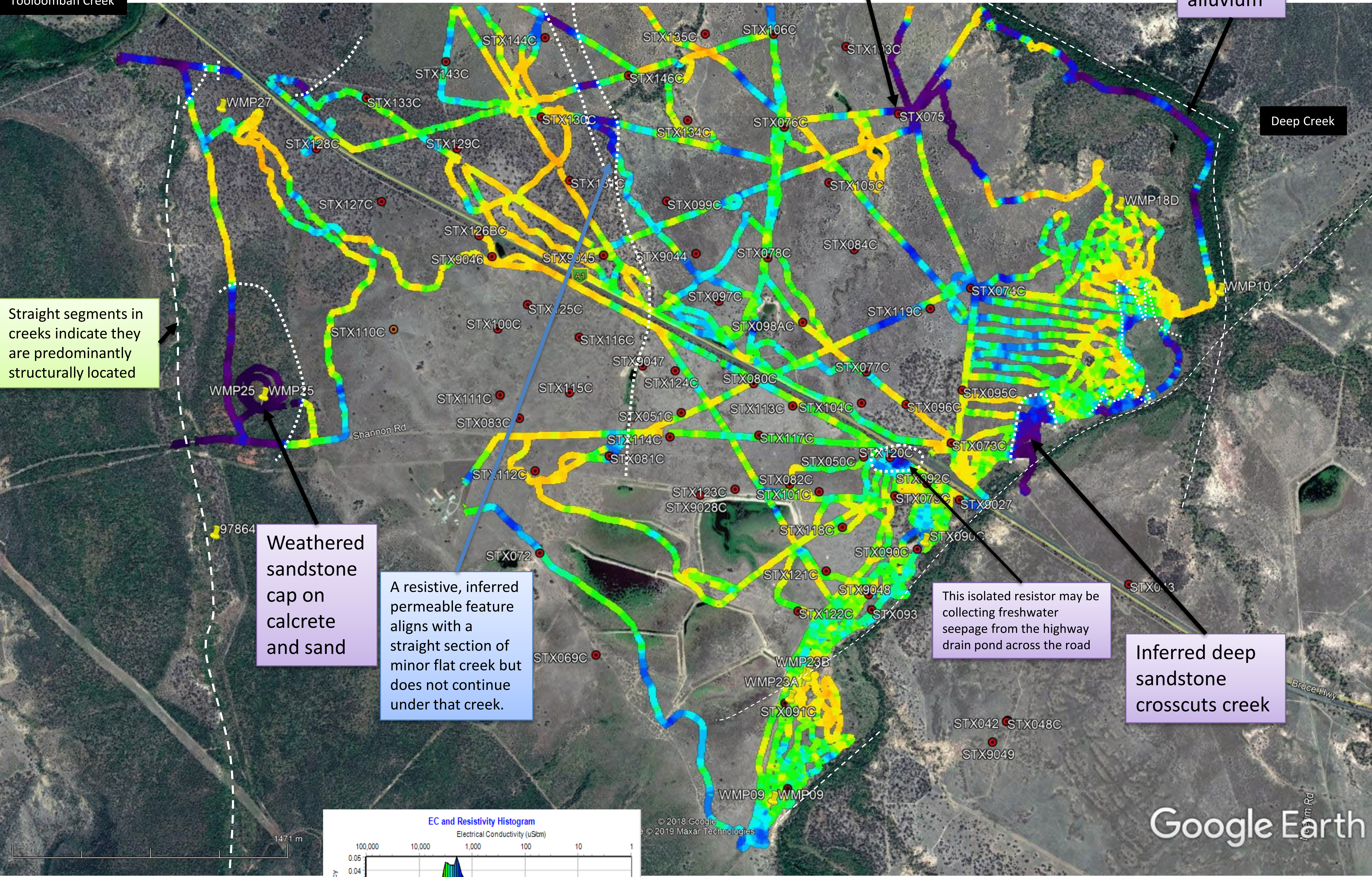
- Electrical conductivity (a measure of the proportion of ions in solution) was mapped at various depths across a number of properties south of Ogmore in central Queensland using AgTEM in support of improved groundwater conceptualisation and modelling for the Central Qld Coal Project. Clays and saline aquifers show as electrically conductive, whereas in contrast, good aquifers and fresh basement rock show as electrically resistive.
- Initial groundwater conceptualisation and modelling (CDM Smith, 2018) simply aggregated all Cenozoic sediments into one hydrostratigraphic unit without delineation between Quaternary (Holocene) Alluvium (Qa) and Quaternary Pleistocene Alluvium (Qpa) as mapped at 1:100,000 Scale Geological Series Marlborough Sheet 8852. AgTEM survey, along with drill log reassessment, has reasonably established that the more permeable alluvium mapped as Holocene is restricted to deep cut but rare alluvial channels, similar to the existing creeks, but infilled with sand. The sand is electrically resistive and has been clearly defined in the AgTEM data where access was available.
- Sandstone layers of high hardness also are electrically resistive and evident in the AgTEM data with outcrop corresponding with some other places where electrically resistive features come to the surface in the AgTEM data. The sandstone layers outcrop in the creeks in some places and are considered to be part of the Styx Coal Measures sequence. Other layers within the Styx Coal Measures are deeply weathered and seem to be indistinguishable from alluvium in the top ten or so metres. Shapes of the off-creek electrically resistive features suggest that the sandstones may be more paleochannel-shaped rather than simple horizontal dipping layers. Another suggestion is that electrically resistive features relate to hardening of sands to form sandstones along faults where hydrothermal fluid and/or igneous intrusions heated the coal measures including the sandstone – such that it is locally solid and potentially of very low permeability.
- Due to deep weathering, which has strongly stratified the resistivity response, it is difficult to correlate resistivity with any particular lithology (with the exception of the high electrical resistivity sandstone). This same weathering has affected and largely defined the hydrological properties of this remaining strata in the same way it has affected resistivity.
- Based on the AgTEM survey results, it is recommended that future groundwater modelling should recognise the more permeable, and well sorted, 'Holocene' alluvium is restricted to rare deep cut infills. The mapped 'Pleistocene' alluvium is thought to be over the Early Cretaceous coal measures however the surface weathering profile seems to make the two indistinguishable. This alluvium could simply be a reworking of the weathered coal measures so in composition it can be very similar – both are of a generally unsorted mixture of grain sizes. Considering that at places there is sandstone at the surface which appears to be Early Cretaceous and that weathering extends even beneath such solid layers in the drill holes logged, the surface weathering profile should be considered as a hydrological unit separate from the 'Holocene' sands found in the creeks and in rare infilled creeks evident in the AgTEM data. This surface weathering profile can, however, be considered to be part of the same hydrological unit as the 'Pleistocene' Alluvium.
- A good approach to setting up the conceptual model is to use the geophysics to interpret bodies to be modelled, but taking into account the geomorphological plausibility of geometry of bodies suggested by the geophysics and to also check this model against available borehole data. With an in-depth understanding of the drilling datasets, site geologists potentially will make further use of the detail in this AgTEM dataset at a local scale as they compare the two.

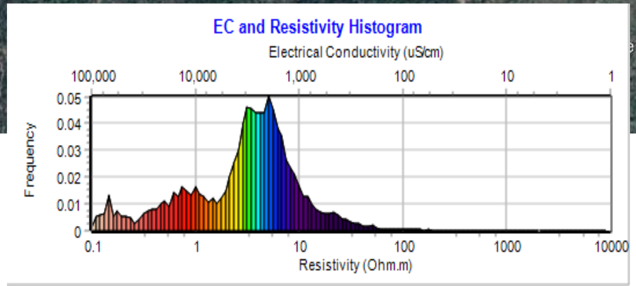
Modelled Resistivity @ 12m deep + Interpretation





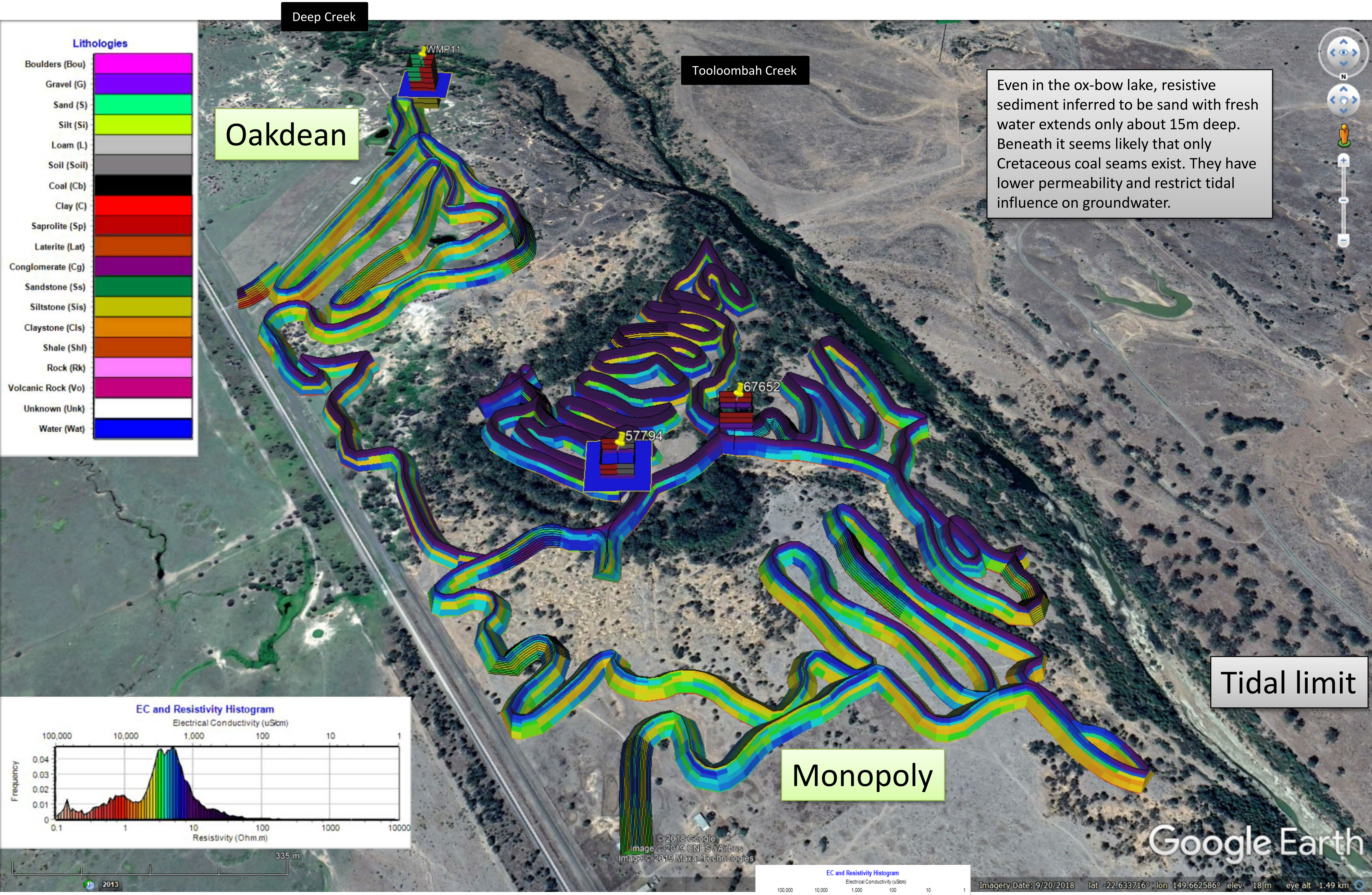
Modelled Resistivity @ 12m deep + Interpretation

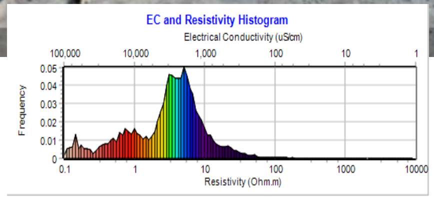




Modelled Resistivity projected up 30m

Looking south





Contents

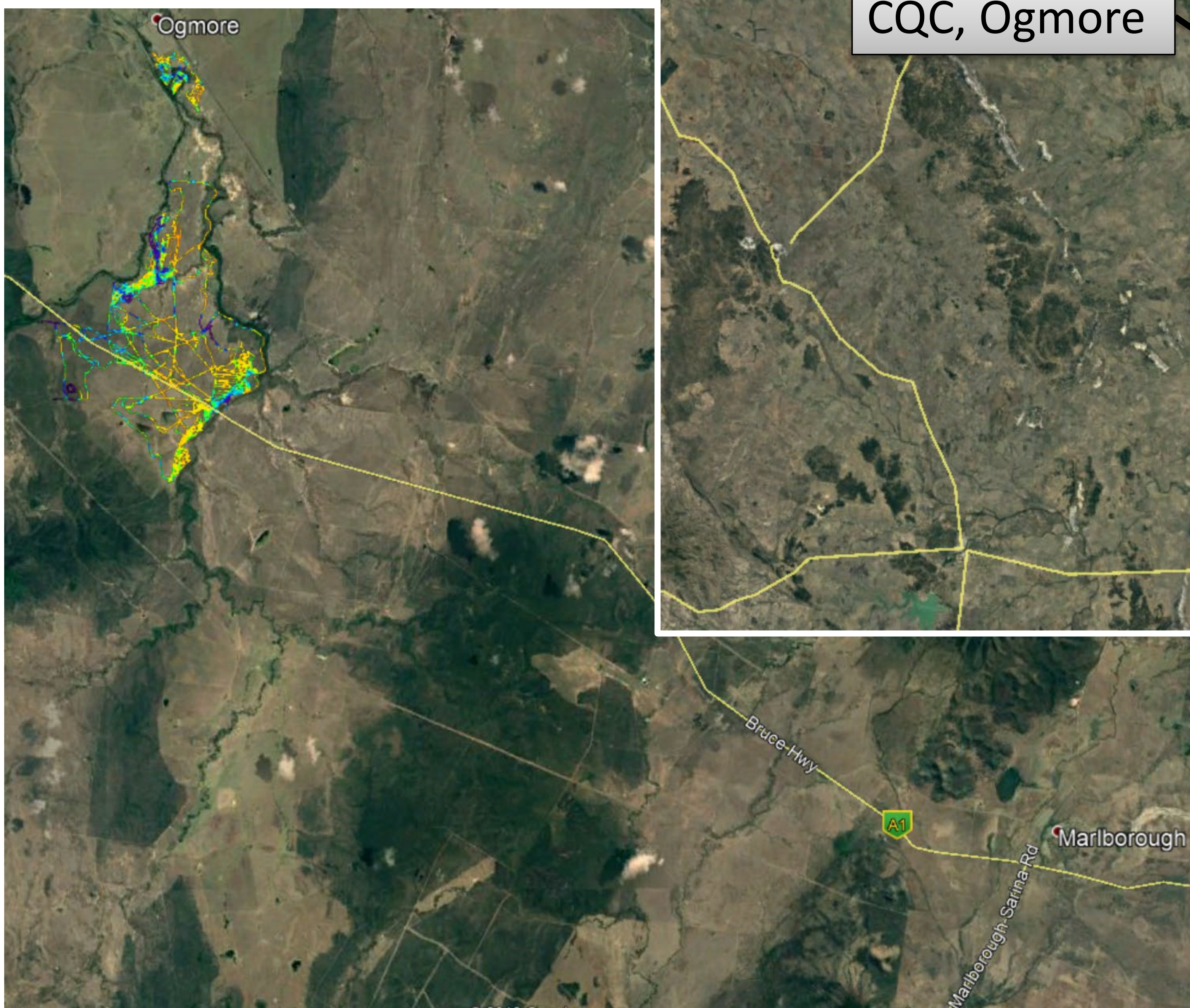
Context and Aim

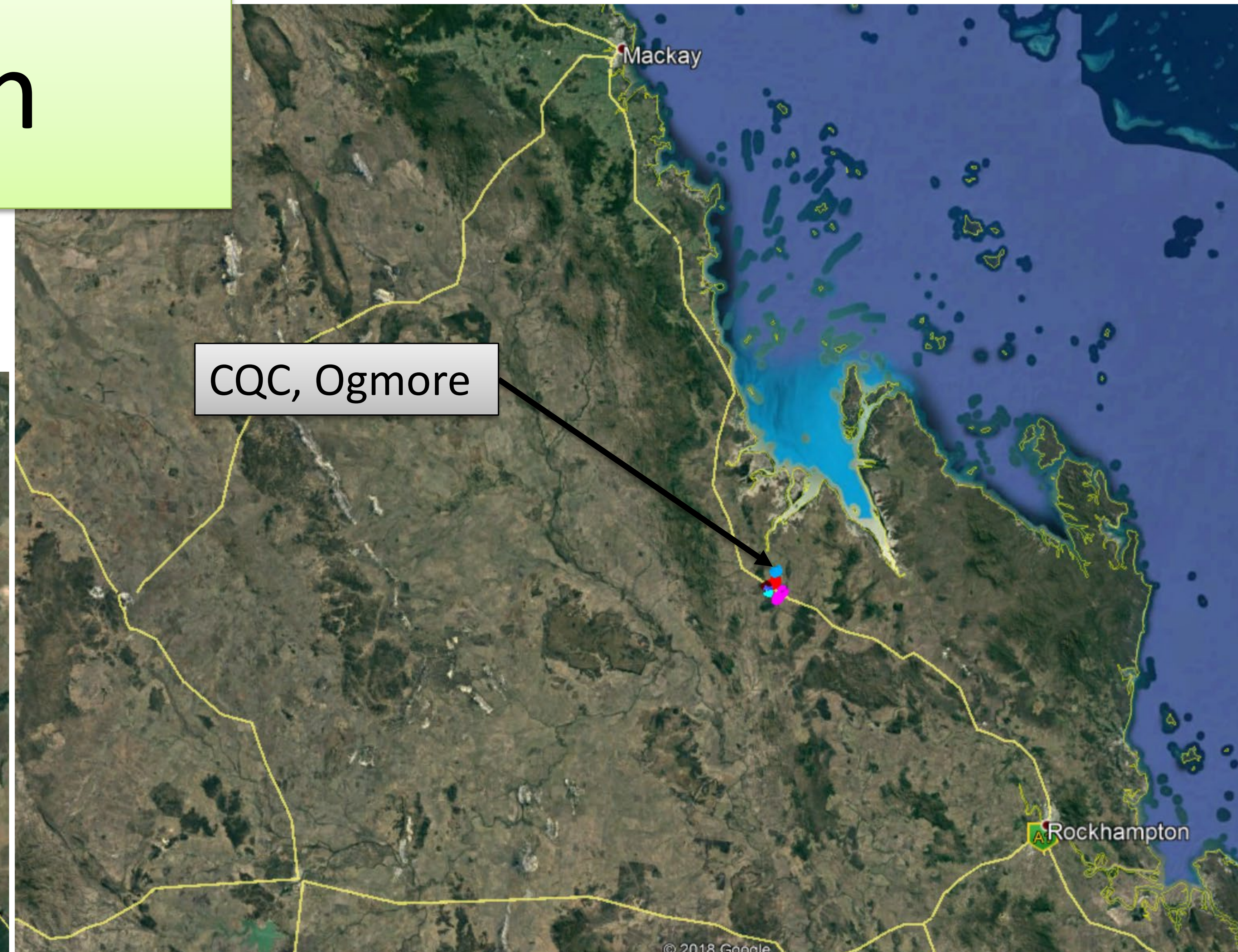
- Groundwater modelling required for coal mining approval at the CQC site south of Ogmore was lacking detail of near surface unconfined sand aquifers. AgTEM survey has been used to map and define these aquifers for further modelling.

Method Summary

- Variation in the depth, lithology, saturation and groundwater salinity of the geological facies at the site has been mapped using towed transient electromagnetics, drill chip lithology, outcrop, soils and float rock appraisal. 3D graphics has been applied to relate the various sources of information.

Location


Ogmore
Bruce Hwy
A1
Marlborough
Marlborough-Sarina Rd
© 2018 Google


Mackay
CQC, Ogmore
Rockhampton
A1
© 2018 Google

Geophysical Methods Introduction

- A quick and comprehensive way of looking at a shallow (0 to 100m deep) groundwater resource is to image it with towed transient electromagnetic devices. The resultant EC image will reveal, in a blurred manner, the proportion of ions in solution in the groundwater and rock at various depth – usually this means that dry ground, good aquifers and fresh basement rock show as electrically resistive and contrast with clays and saline aquifers that show as electrically conductive. Determining exactly what each feature represents is then a matter of interpretation which is usually solved by comparison with borehole logs and a bit of logic (eg. basement rock will be at the base, an unsaturated zone will be at the top and prior river channels will be shaped concave-up).

Why use Electrical Conductivity Imaging for Groundwater Investigation

- reveal spatial details not observable by any more economically viable means
- EC responds clearly and conclusively to recharge pathways and saline groundwater.

LOW EC
- Lack of Clays
- Low Saturation
- Fresh pore water
- Impervious fresh rock

HIGH EC
- Clays
- High Saturation
- Saline pore water
- Weathered rock

Background information

Creeks at this site are deeply incised – shown here is the ascent out of Tooloombah Creek into Bar-H from Mamelon

At the base of parts of the creeks, solid sandstone exists. In this specimen, there are what appear to be squashed entrained mud clasts.

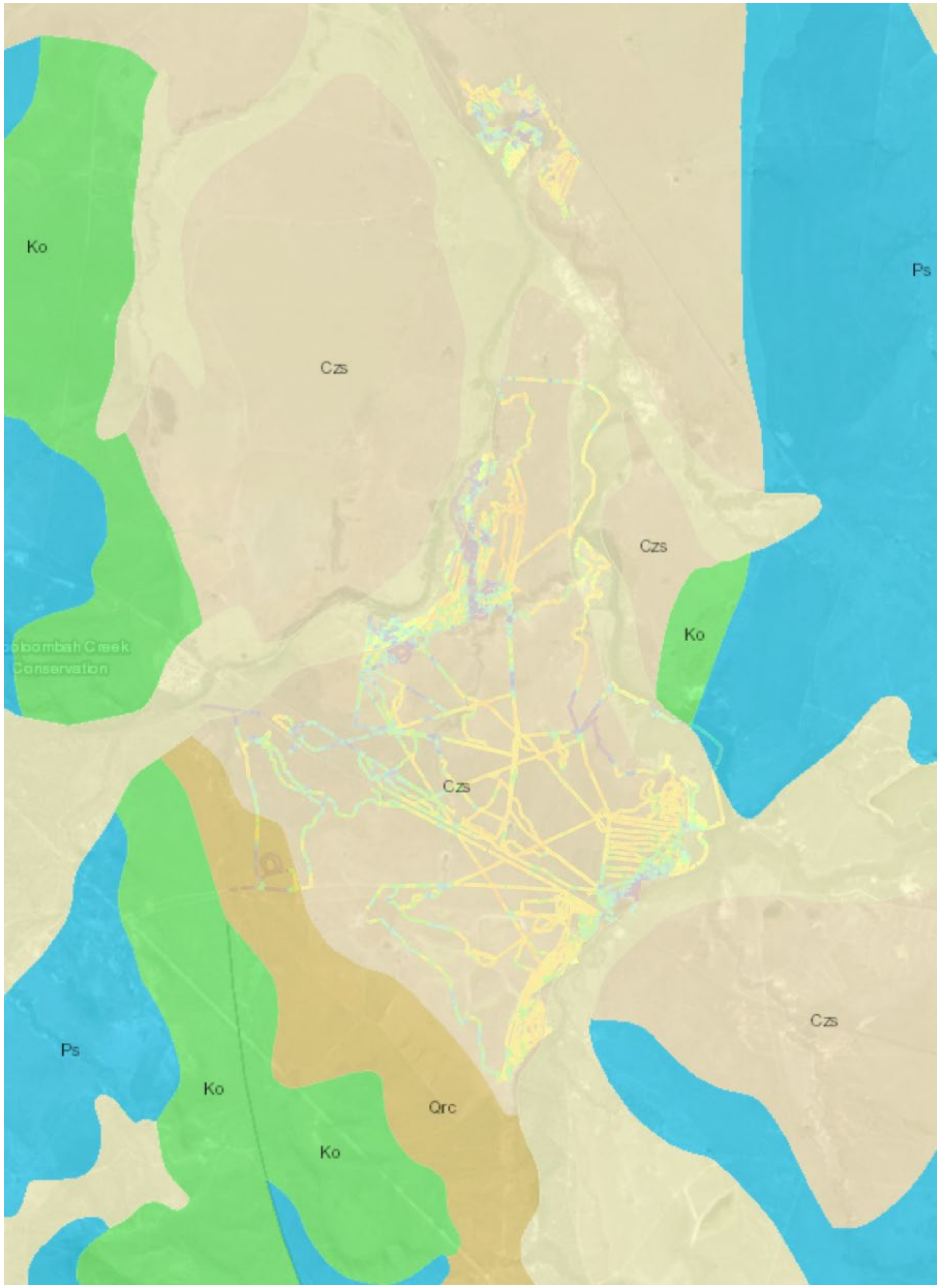
Some float resembling igneous dyke rock was found on the elevated plains but no dykes or sills were identified.

Government geological mapping comparison

Previous government geological mapping is of a regional nature inadequately coarse for this study.

From the GA mapping portal it is displayed here with resistivity modelled at 20m deep beneath it. This government mapping honours neither the creek alignment nor resistivity contrasts we observed.

Some more detailed raster mapping available is better but similarly lacks detail. This is because the soil surface hides palaeochannels.



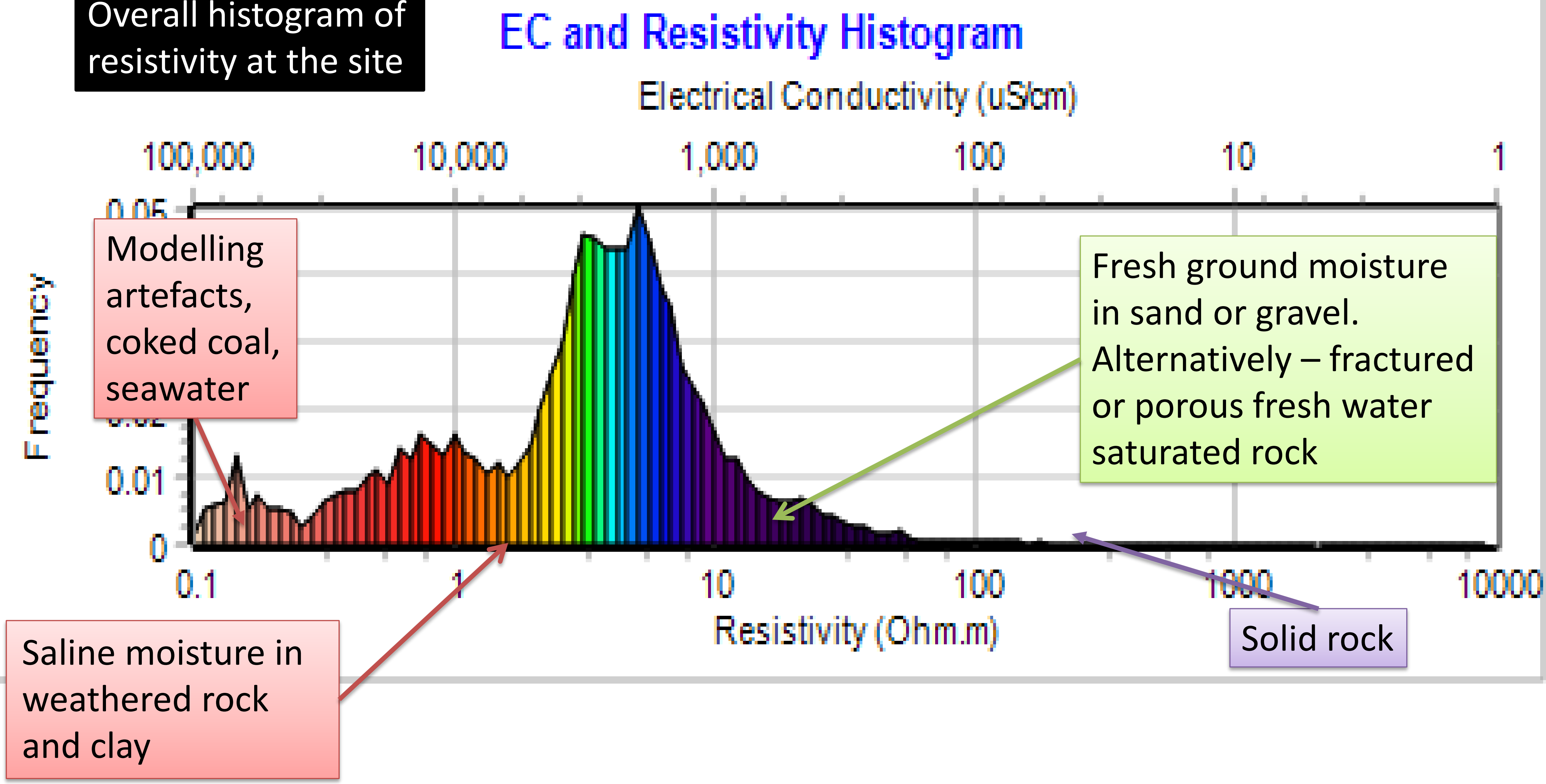
Results Presentation

- TEM data has been presented as depth slices in Google Earth
- In Google Earth 3D oblique orientation, other data is presented in combination with the TEM depth slices including outcrop photos, lithology logs and TEM transects. Interpretation comments are added.
- 3D presentations of data at individual sites along with bore lithology graphics and photos are presented.

Resistivity scale used in Google Earth Images

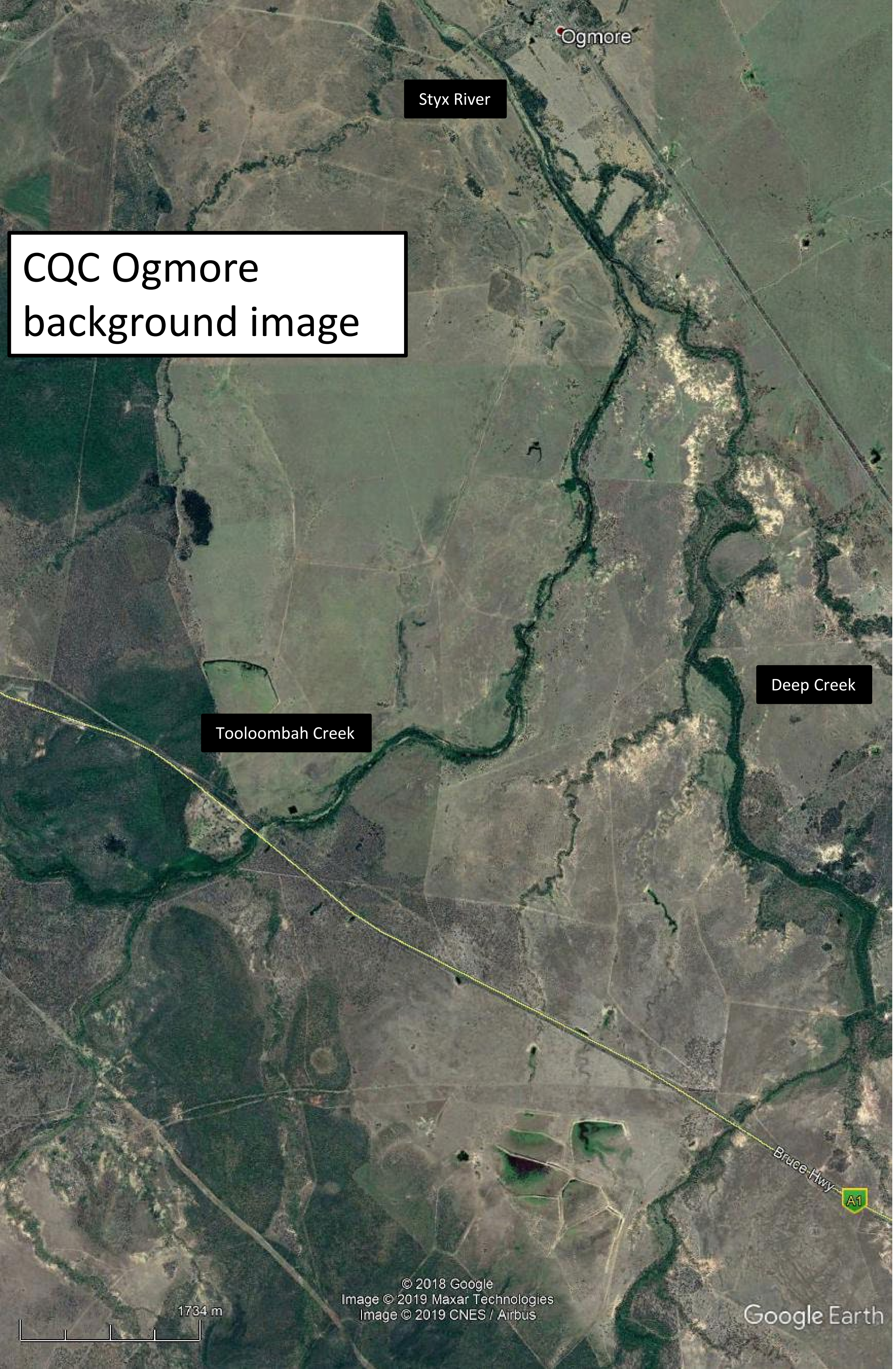
The inverse of Resistivity is Electrical Conductivity (EC).

Overall histogram of resistivity at the site

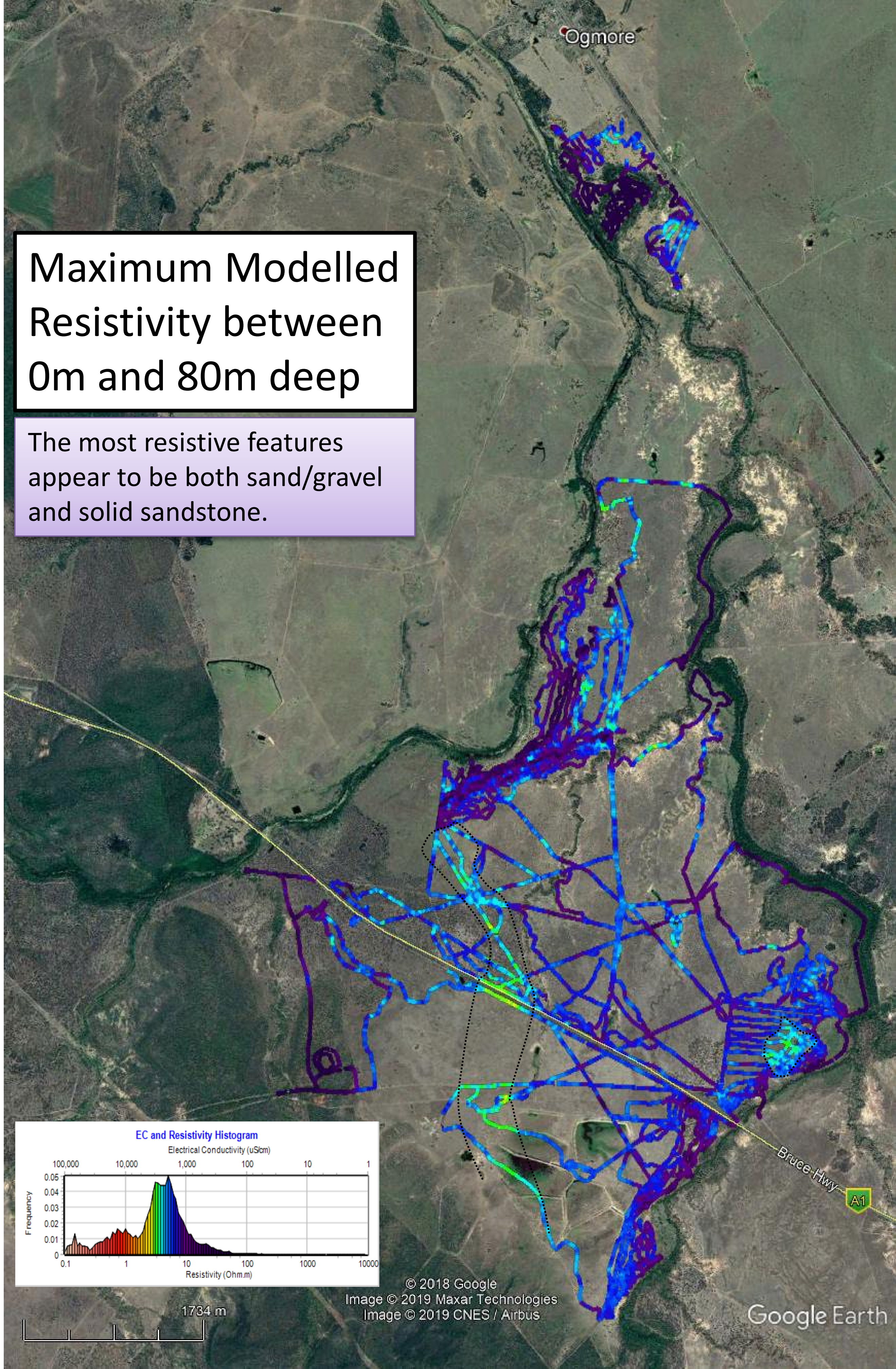


Treat modelled resistivities in these datasets as relative, not absolute.

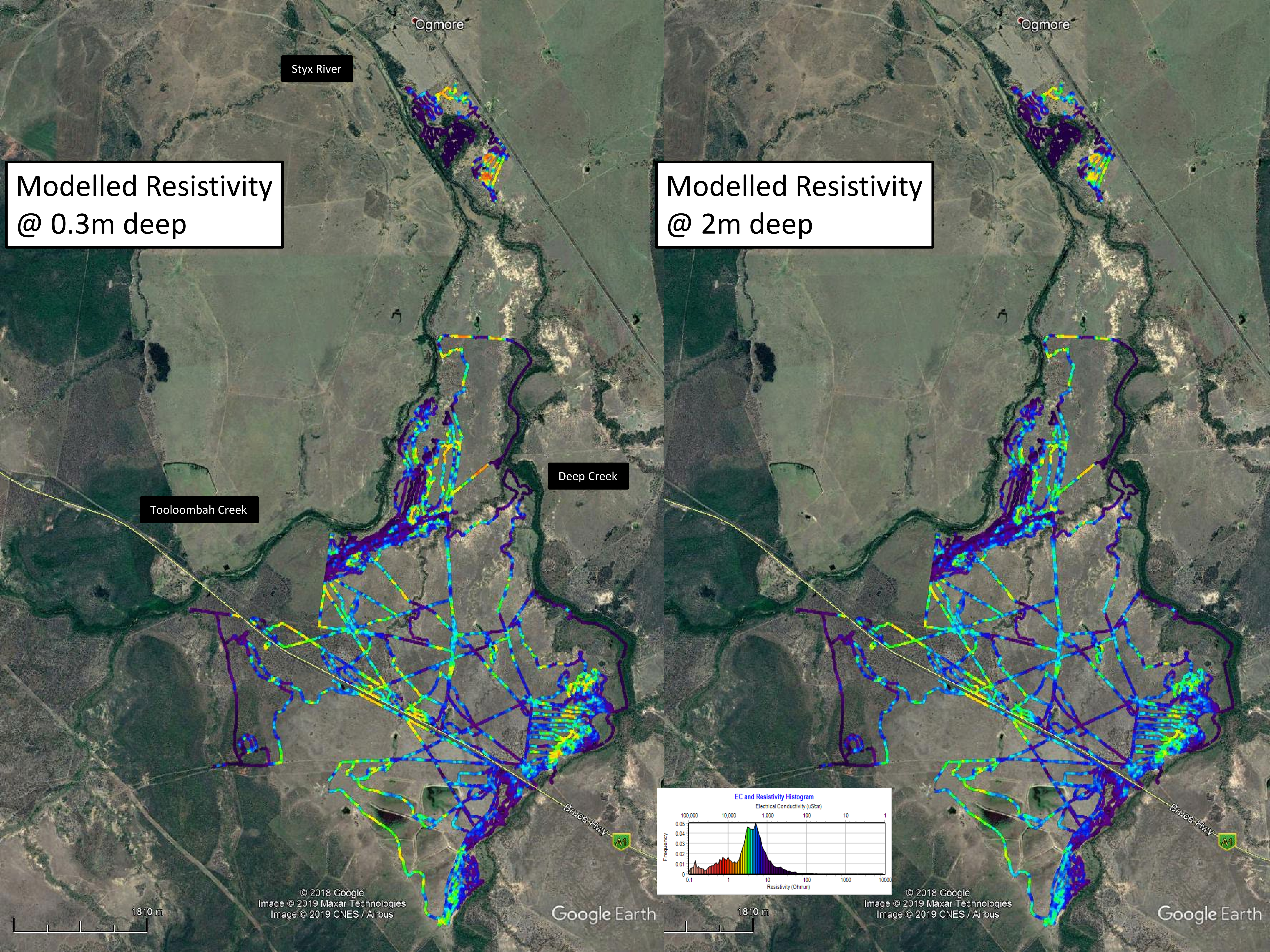
Full set of depth slices with common colour stretch

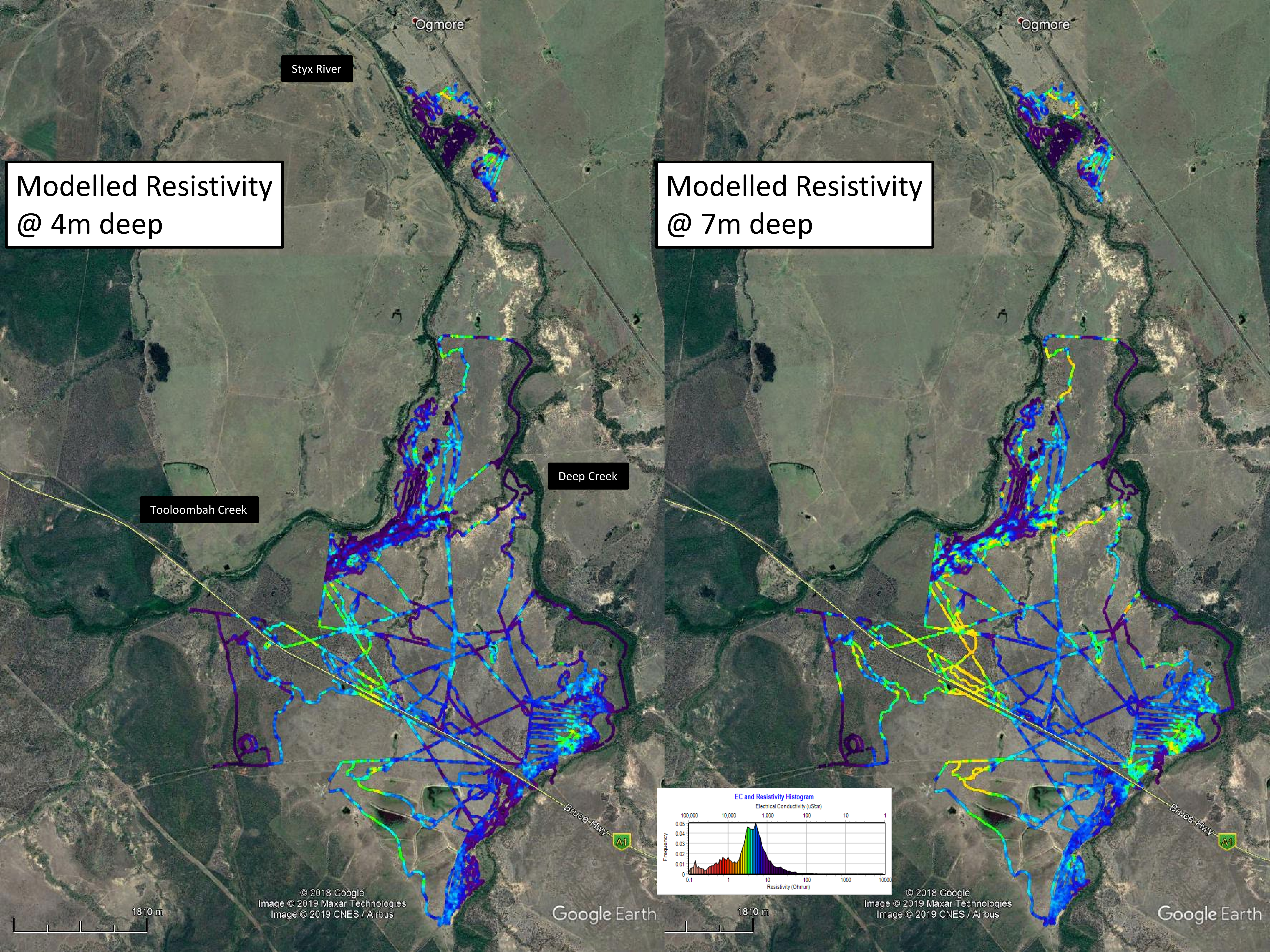


Ogmore
Styx River
CQC Ogmore background image
Deep Creek
Tooloombah Creek
Bruce Hwy
A1
1734 m
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
Google Earth

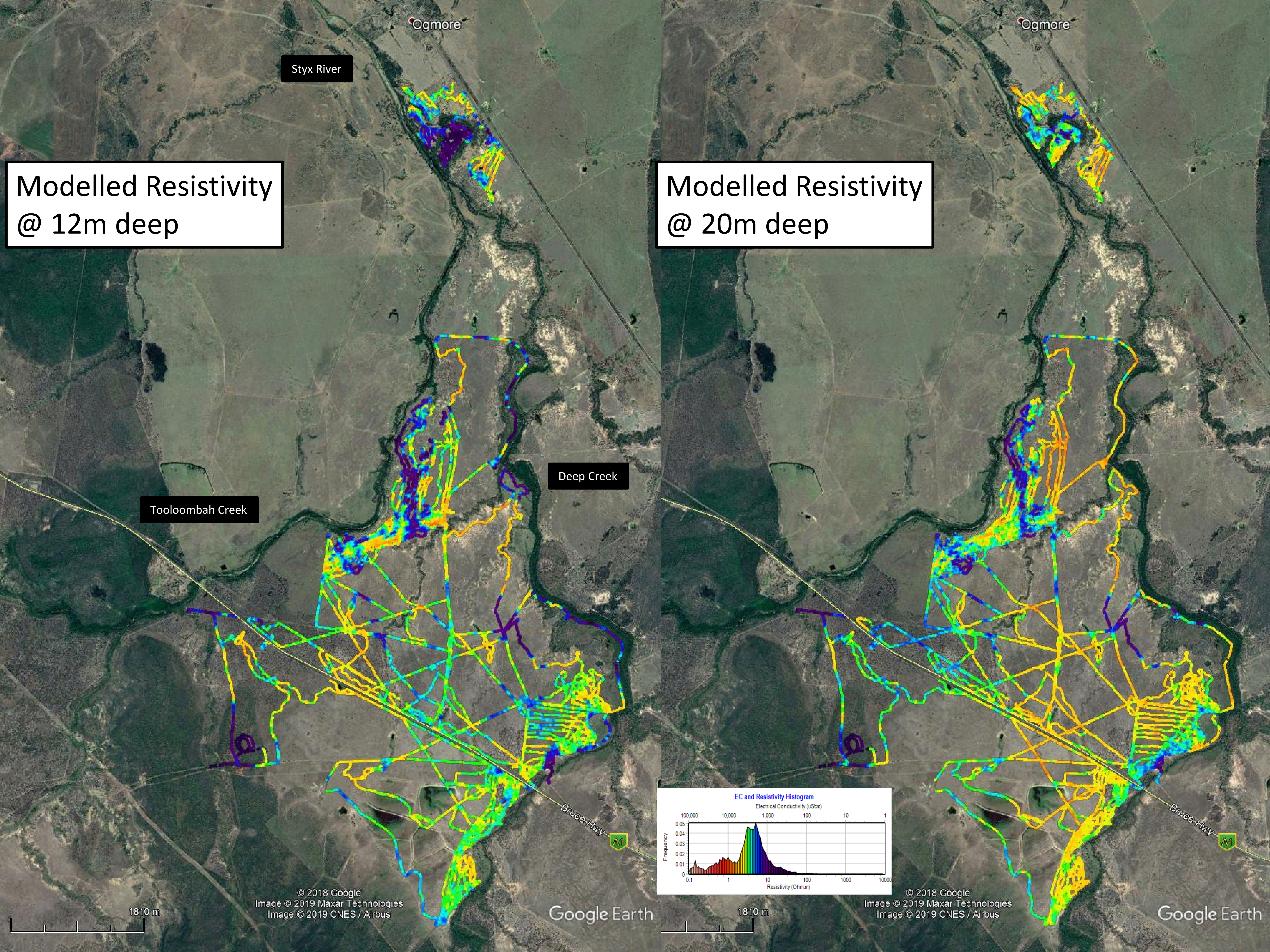


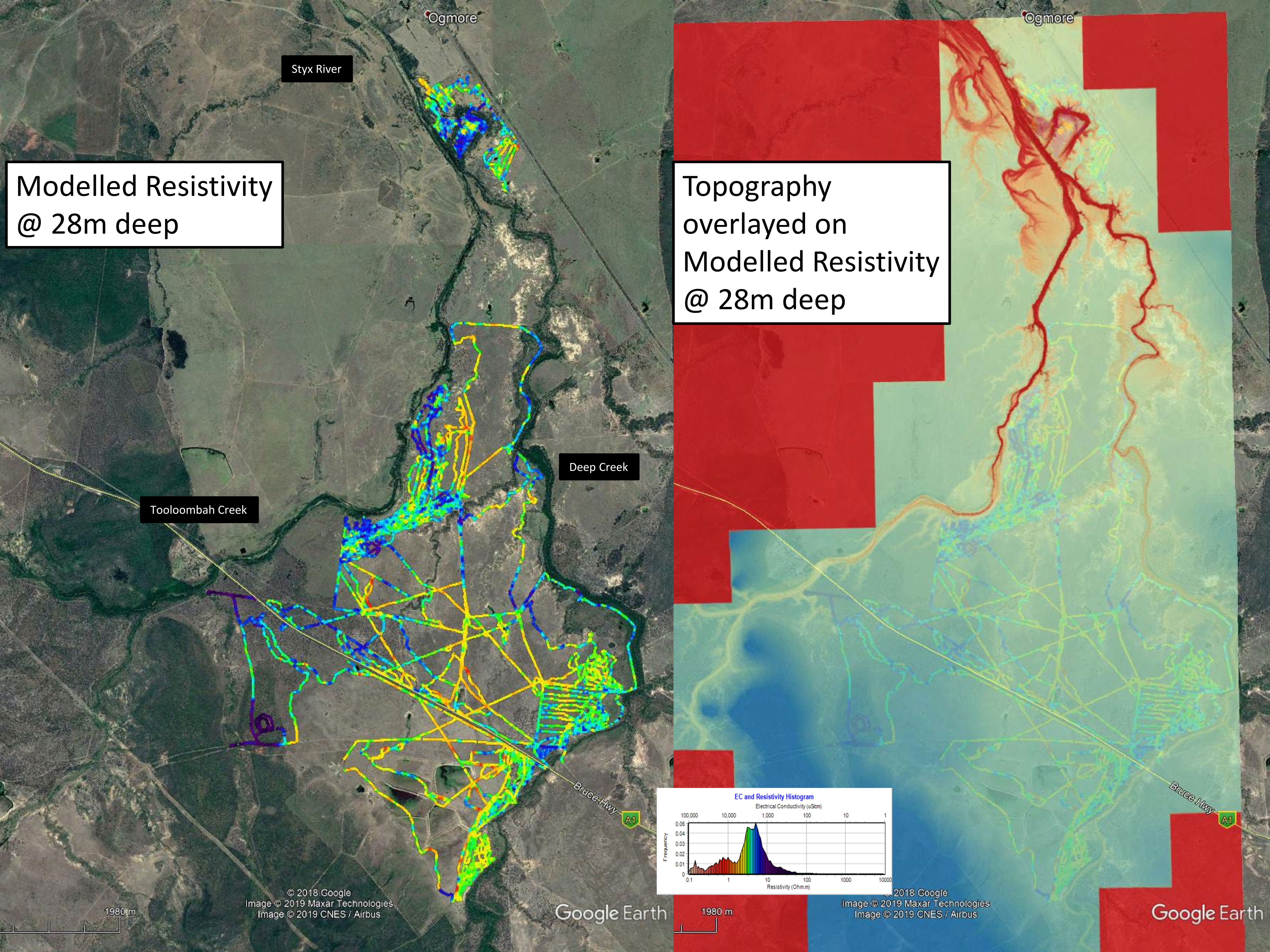
Ogmore
Maximum Modelled Resistivity between 0m and 80m deep
The most resistive features appear to be both sand/gravel and solid sandstone.
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
100,000
10,000
1,000
100
10
1
Frequency
0.05
0.04
0.03
0.02
0.01
0
0.1
1
10
100
1000
10000
Resistivity (Ohm.m)
Bruce Hwy
A1
1734 m
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
Google Earth

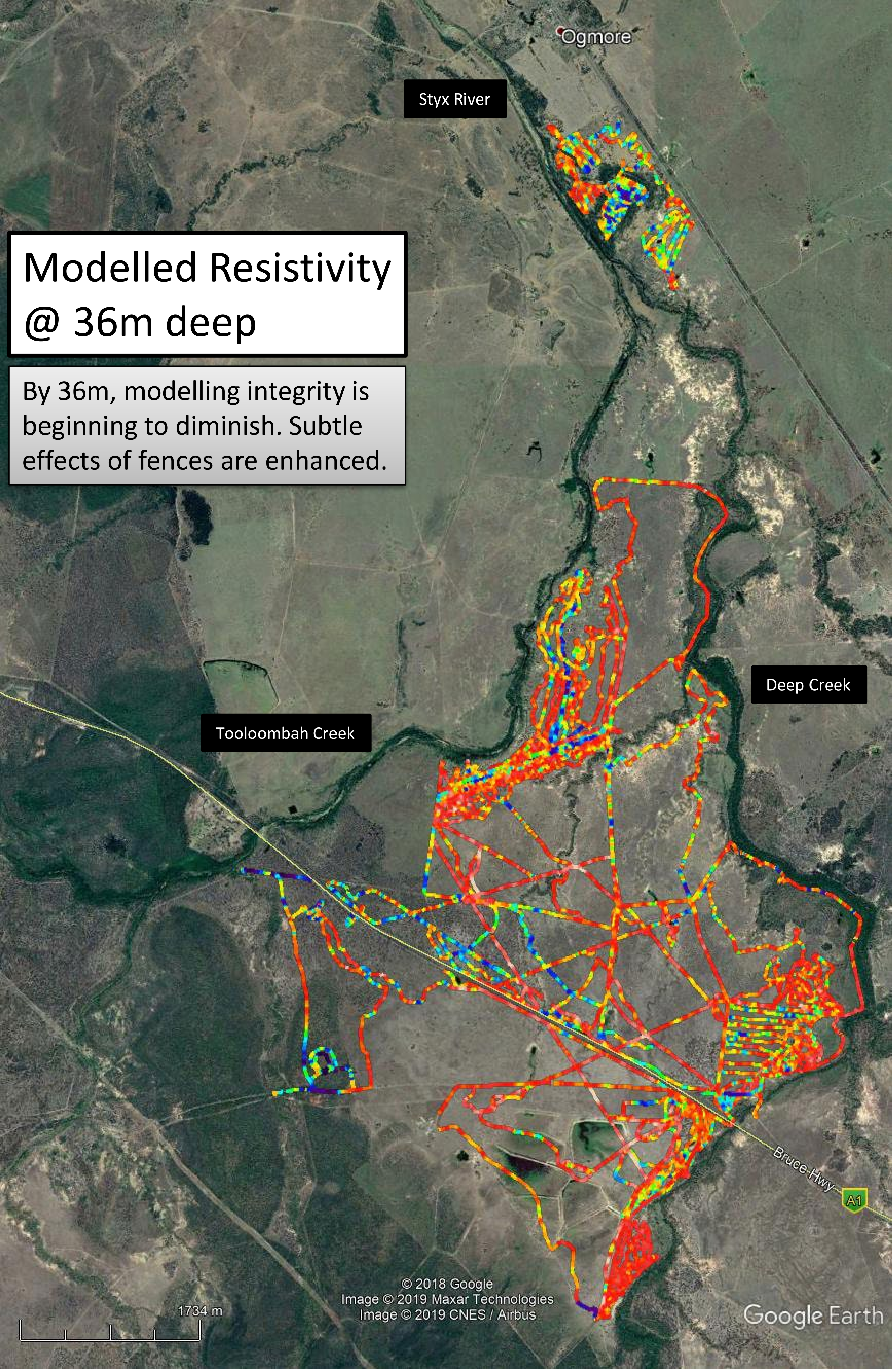

Ogmore
Styx River
Modelled Resistivity
@ 0.3m deep
Deep Creek
Tooloombah Creek
Bruce-Hwy
A1
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
1810 m
Google Earth
Ogmore
Modelled Resistivity
@ 2m deep
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
100,000
10,000
1,000
100
10
1
Frequency
0.05
0.04
0.03
0.02
0.01
0
0.1
1
10
100
1000
10000
Resistivity (Ohm.m)
Bruce-Hwy
A1
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
1810 m
Google Earth

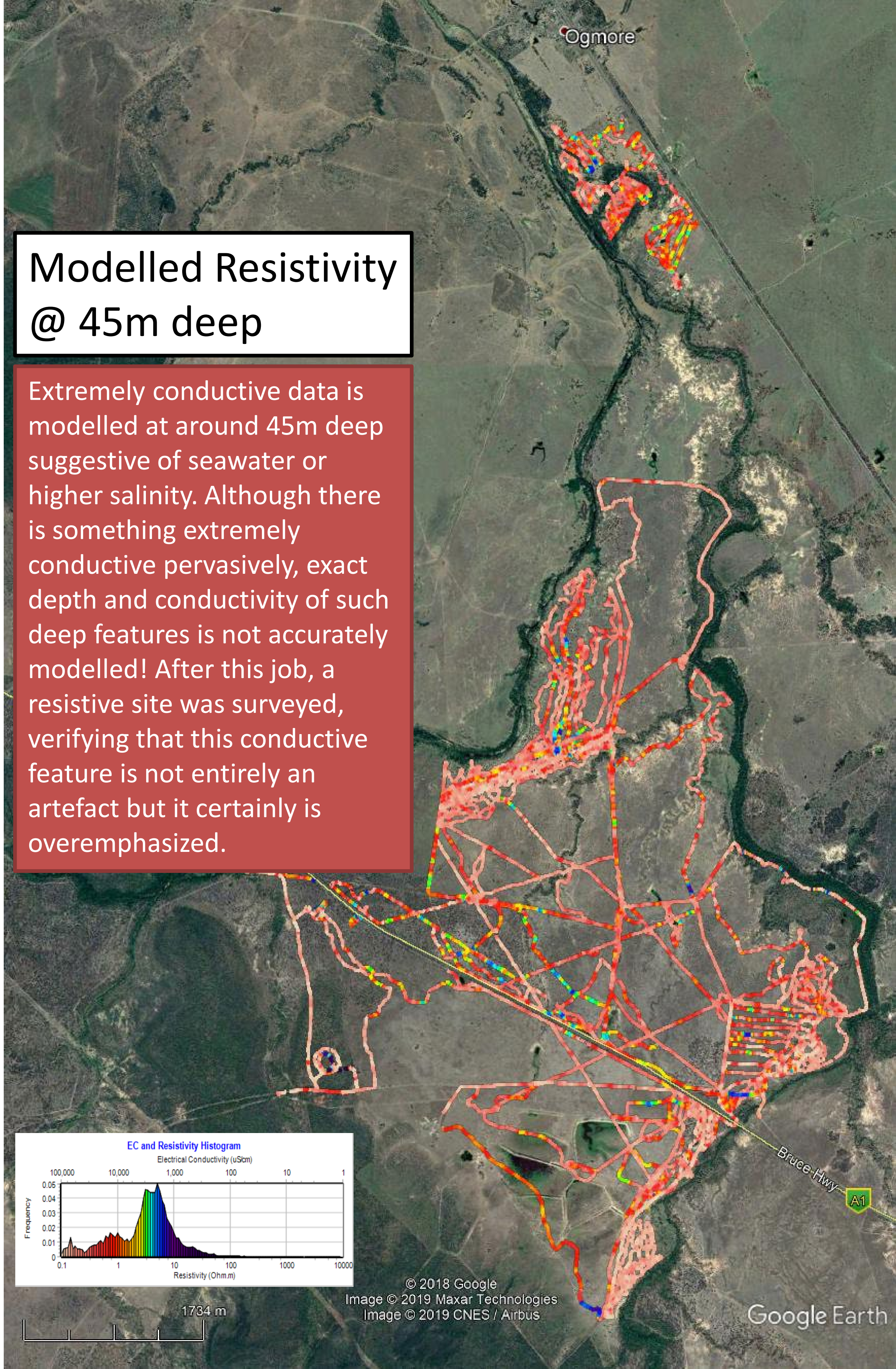


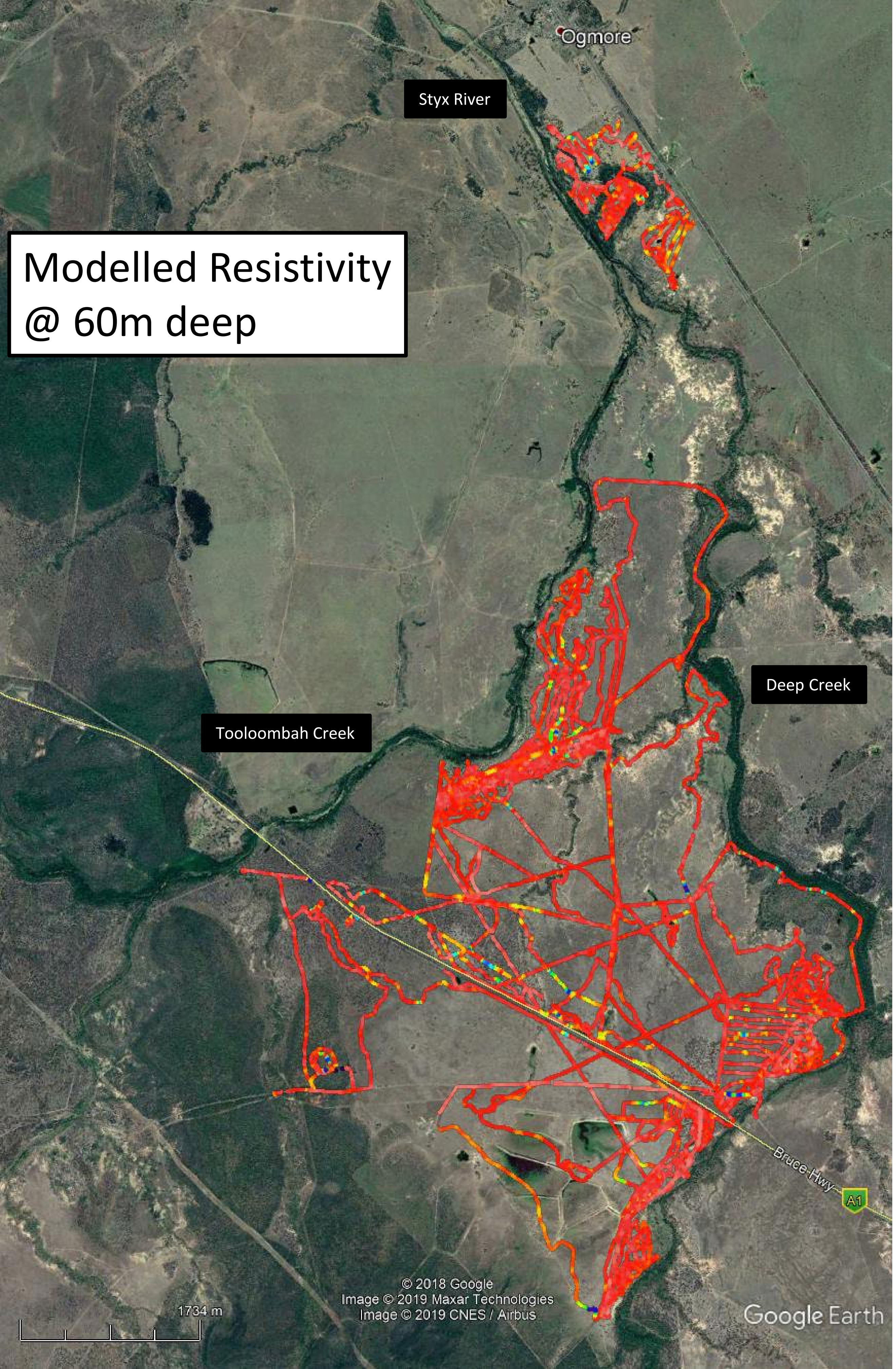
Ogmore
Styx River
Modelled Resistivity
@ 4m deep
Deep Creek
Tooloombah Creek
Bruce Hwy
A1
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
Google Earth
1810 m
Ogmore
Modelled Resistivity
@ 7m deep
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
100,000
10,000
1,000
100
10
1
Frequency
0.05
0.04
0.03
0.02
0.01
0
0.1
1
10
100
1000
10000
Resistivity (Ohm.m)
Bruce Hwy
A1
1810 m
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
Google Earth

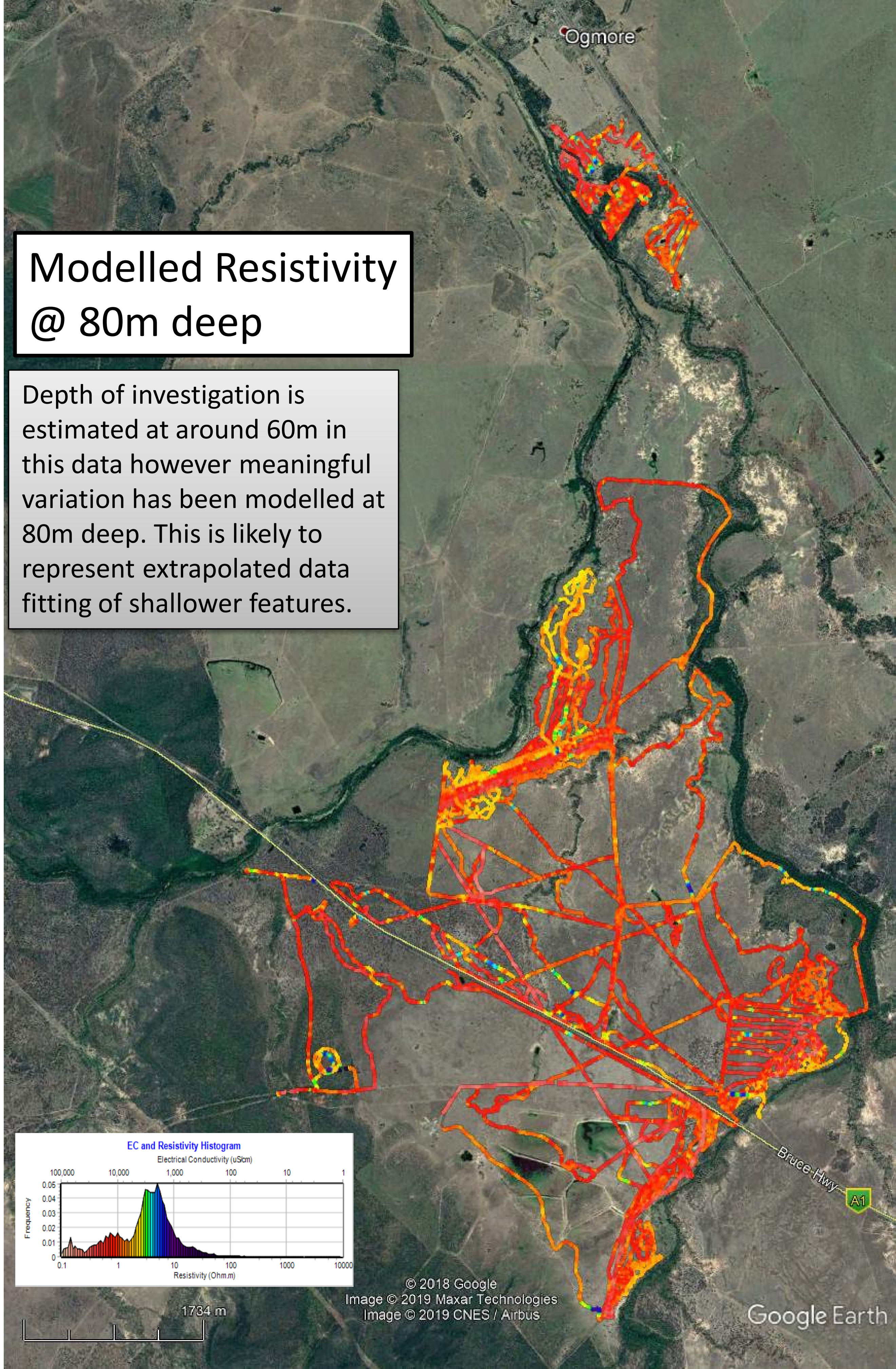

Ogmore
Styx River
Modelled Resistivity @ 12m deep
Deep Creek
Tooloombah Creek
Bruce Hwy
A1
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
1810 m
Google Earth
Ogmore
Modelled Resistivity @ 20m deep
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
100,000
10,000
1,000
100
10
1
Frequency
0.05
0.04
0.03
0.02
0.01
0
0.1
1
10
100
1000
10000
Resistivity (Ohm.m)
Bruce Hwy
A1
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
1810 m
Google Earth


Modelled Resistivity
@ 28m deep
Ogmore
Styx River
Deep Creek
Tooloombah Creek
Bruce Hwy
A1
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
1980 m
Google Earth
Topography
overlayed on
Modelled Resistivity
@ 28m deep
Ogmore
Bruce Hwy
A1
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
100,000
10,000
1,000
100
10
1
Frequency
0.05
0.04
0.03
0.02
0.01
0
0.1
1
10
100
1000
10000
Resistivity (Ohm.m)
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
1980 m
Google Earth

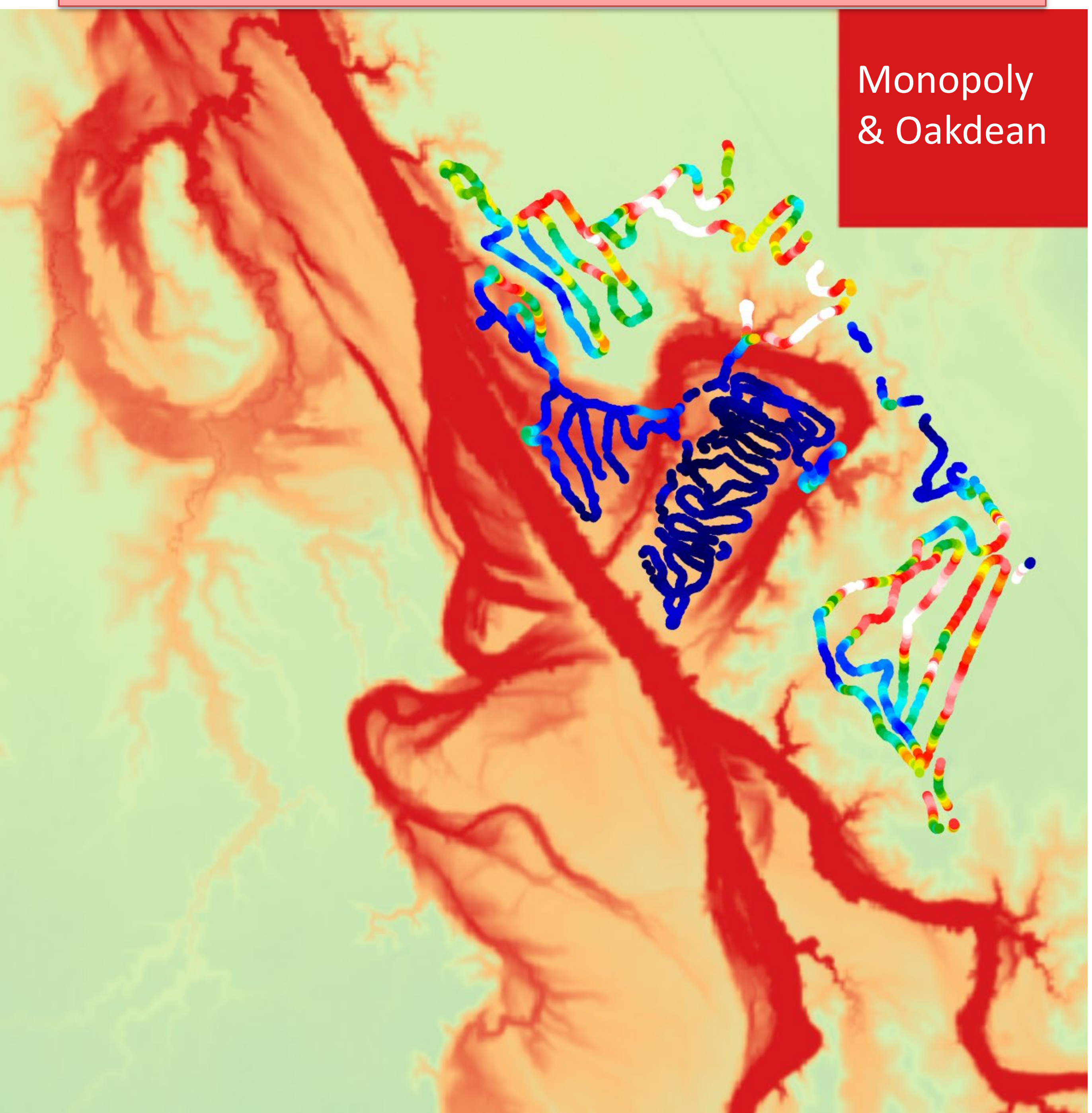

Ogmore
Styx River
Modelled Resistivity @ 36m deep
By 36m, modelling integrity is beginning to diminish. Subtle effects of fences are enhanced.
Deep Creek
Tooloombah Creek
Bruce Hwy
A1
1734 m
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
Google Earth

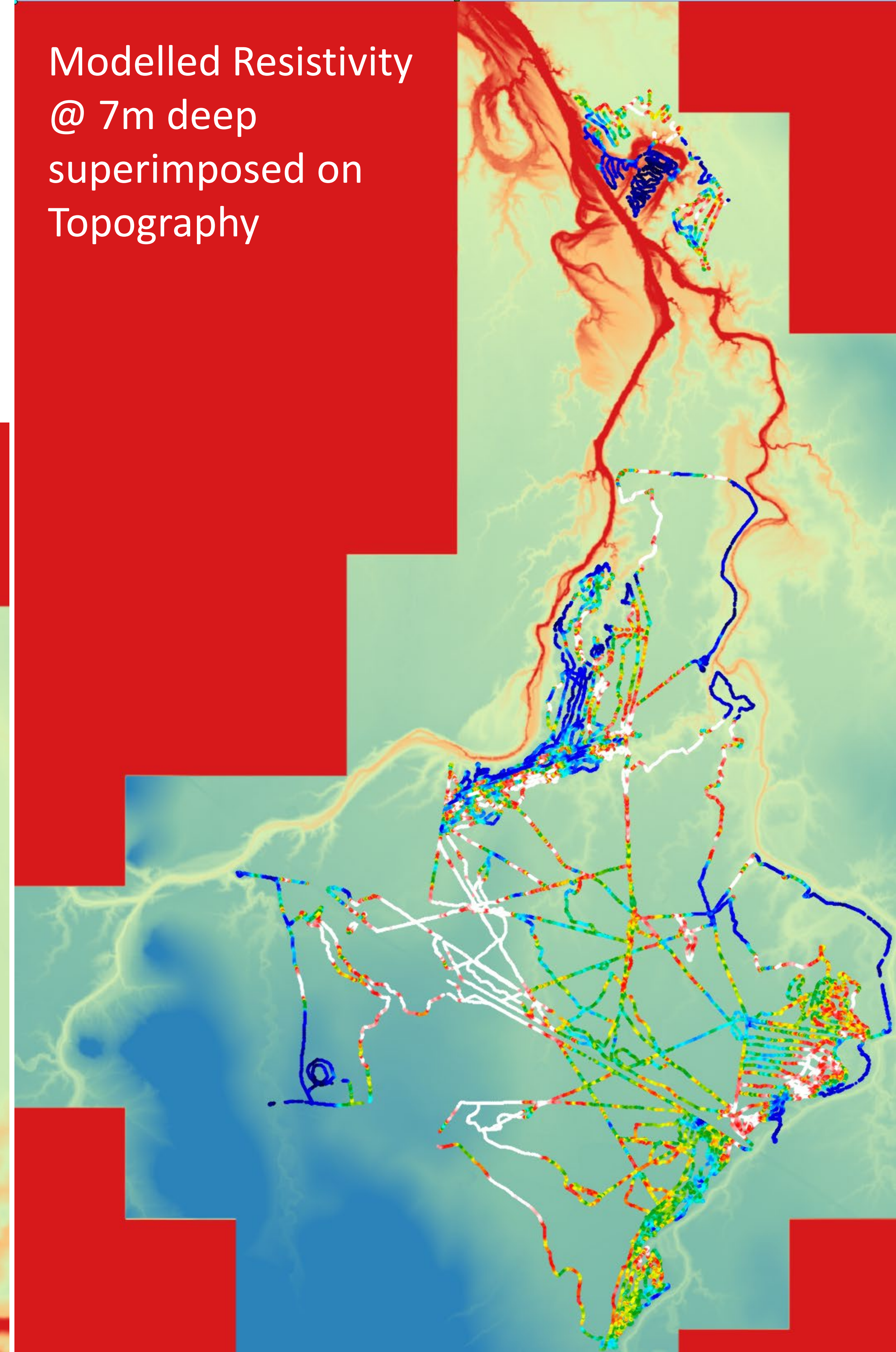

Ogmore
Modelled Resistivity @ 45m deep
Extremely conductive data is modelled at around 45m deep suggestive of seawater or higher salinity. Although there is something extremely conductive pervasively, exact depth and conductivity of such deep features is not accurately modelled! After this job, a resistive site was surveyed, verifying that this conductive feature is not entirely an artefact but it certainly is overemphasized.
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
Frequency
Resistivity (Ohm.m)
Bruce Hwy
A1
1734 m
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
Google Earth


Ogmore
Styx River
Modelled Resistivity
@ 60m deep
Deep Creek
Tooloombah Creek
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
1734 m
Google Earth


Ogmore
Modelled Resistivity
@ 80m deep
Depth of investigation is estimated at around 60m in this data however meaningful variation has been modelled at 80m deep. This is likely to represent extrapolated data fitting of shallower features.
Bruce Hwy
A1
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
Frequency
Resistivity (Ohm.m)
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
1734 m
Google Earth

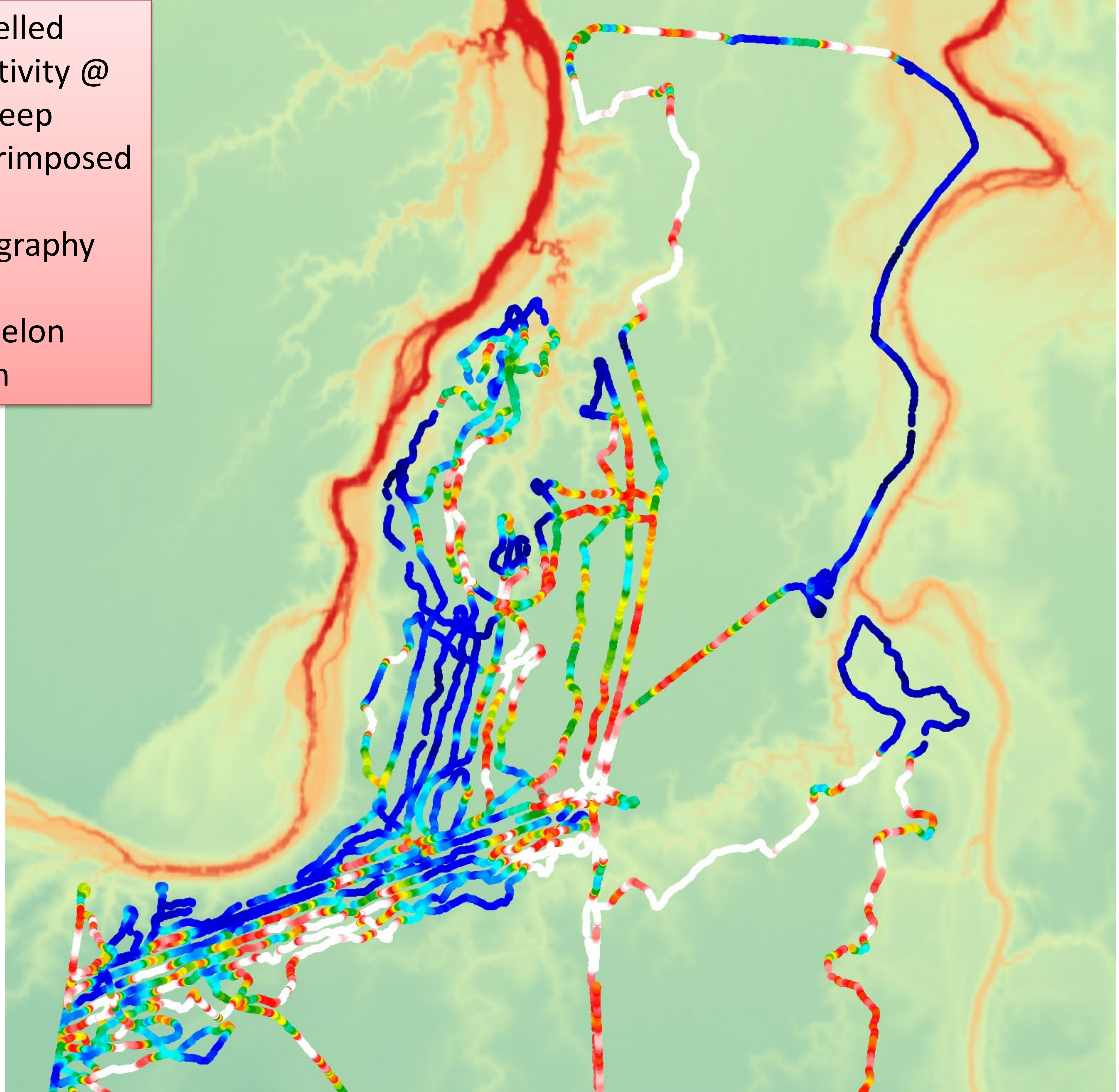
Comparison of topography with modelled resistivity at various depths reveals that some resistive features are associated with incised creeks, some are suggestive of infilled incised creeks and some cross-cut or are otherwise unrelated to the creeks. The unrelated ones seem to be thick sandstone.

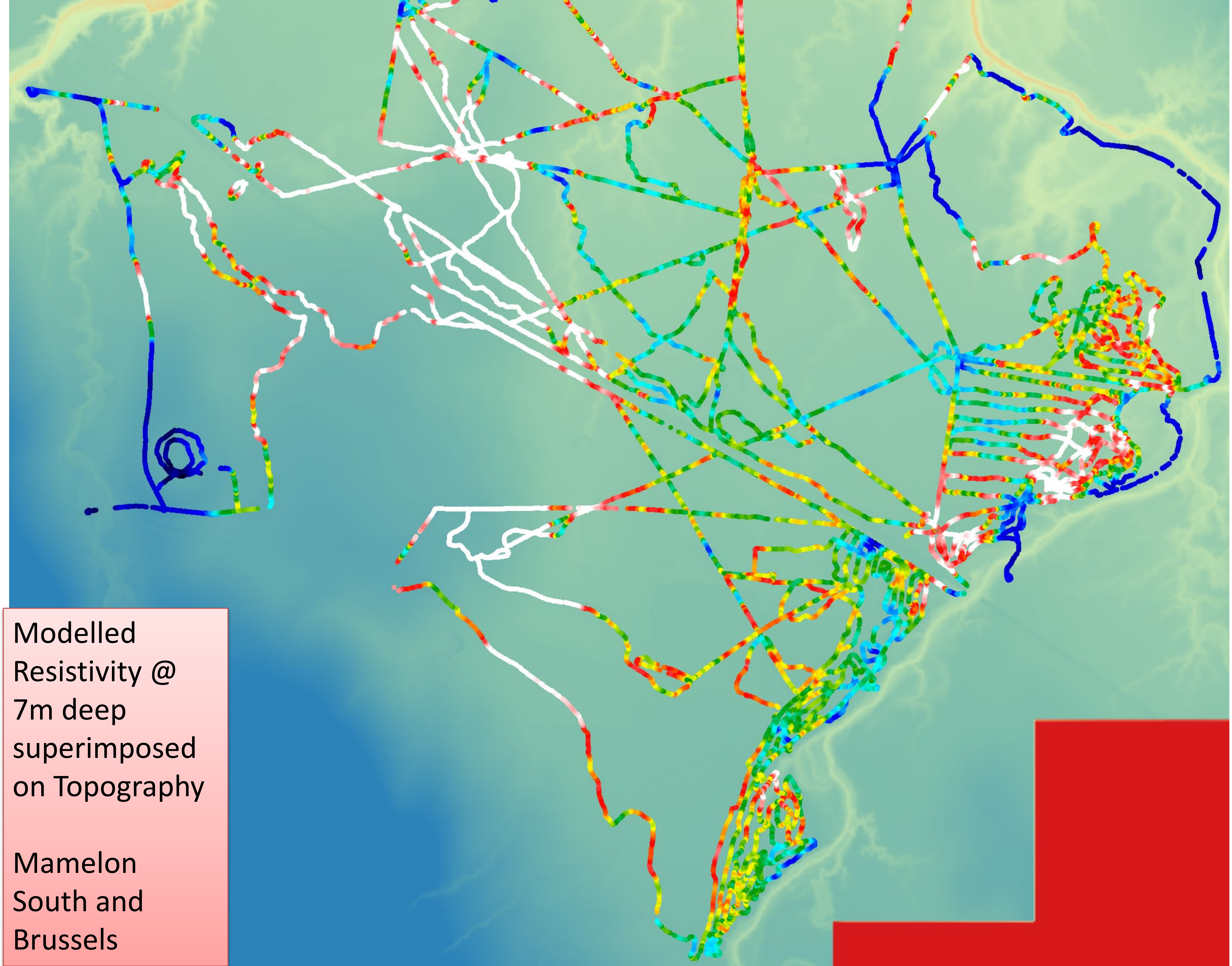




Modelled Resistivity @ 7m deep superimposed on Topography

Mamelon North

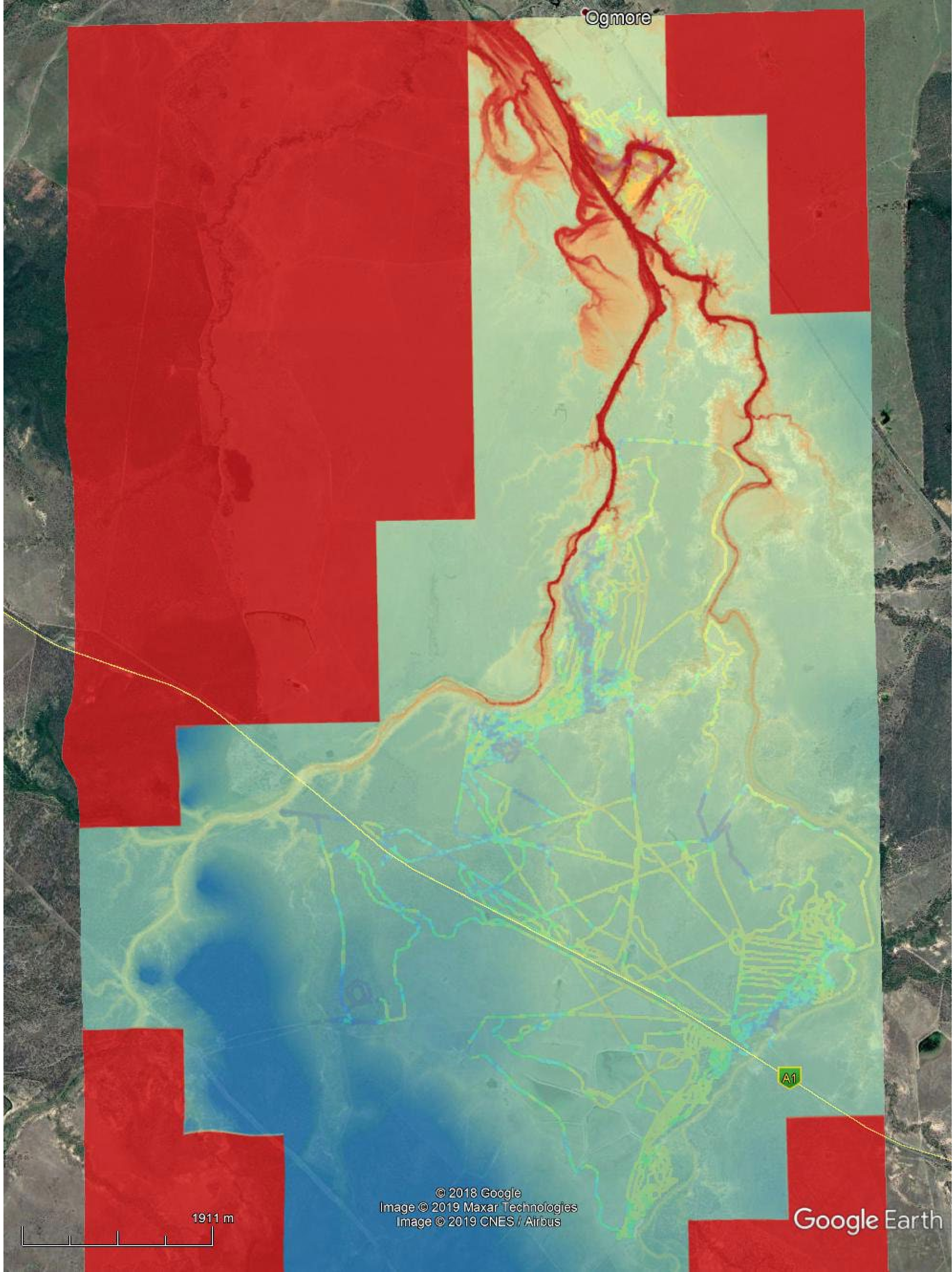




Modelled Resistivity @ 7m deep superimposed on Topography

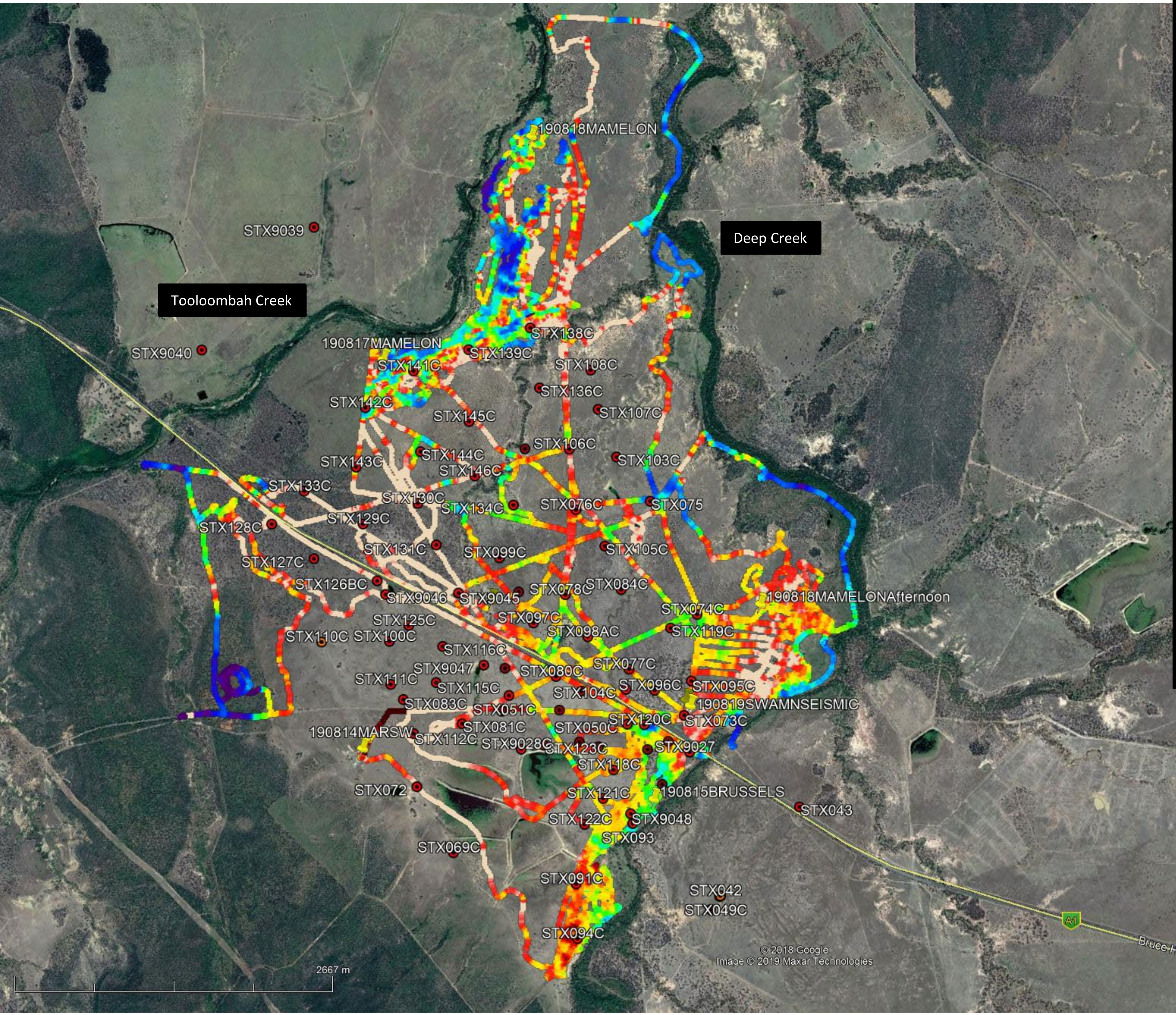
Mamelon South and Brussels

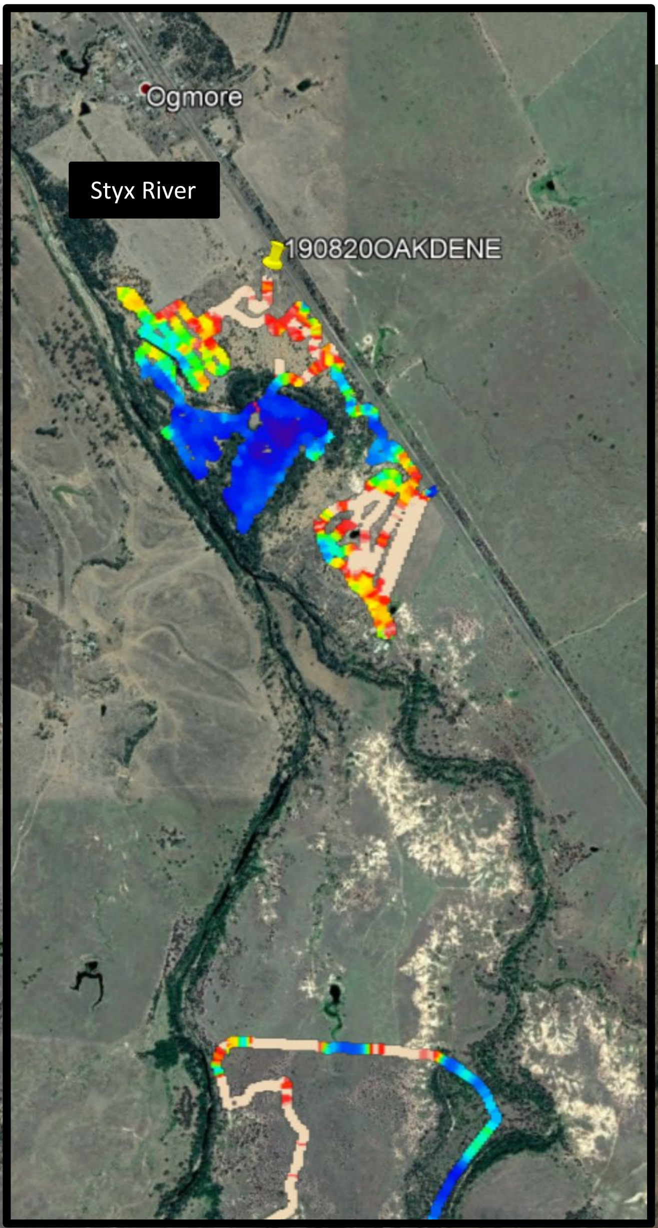
Topography superimposed on Modelled Resistivity @ 20m deep and background image.

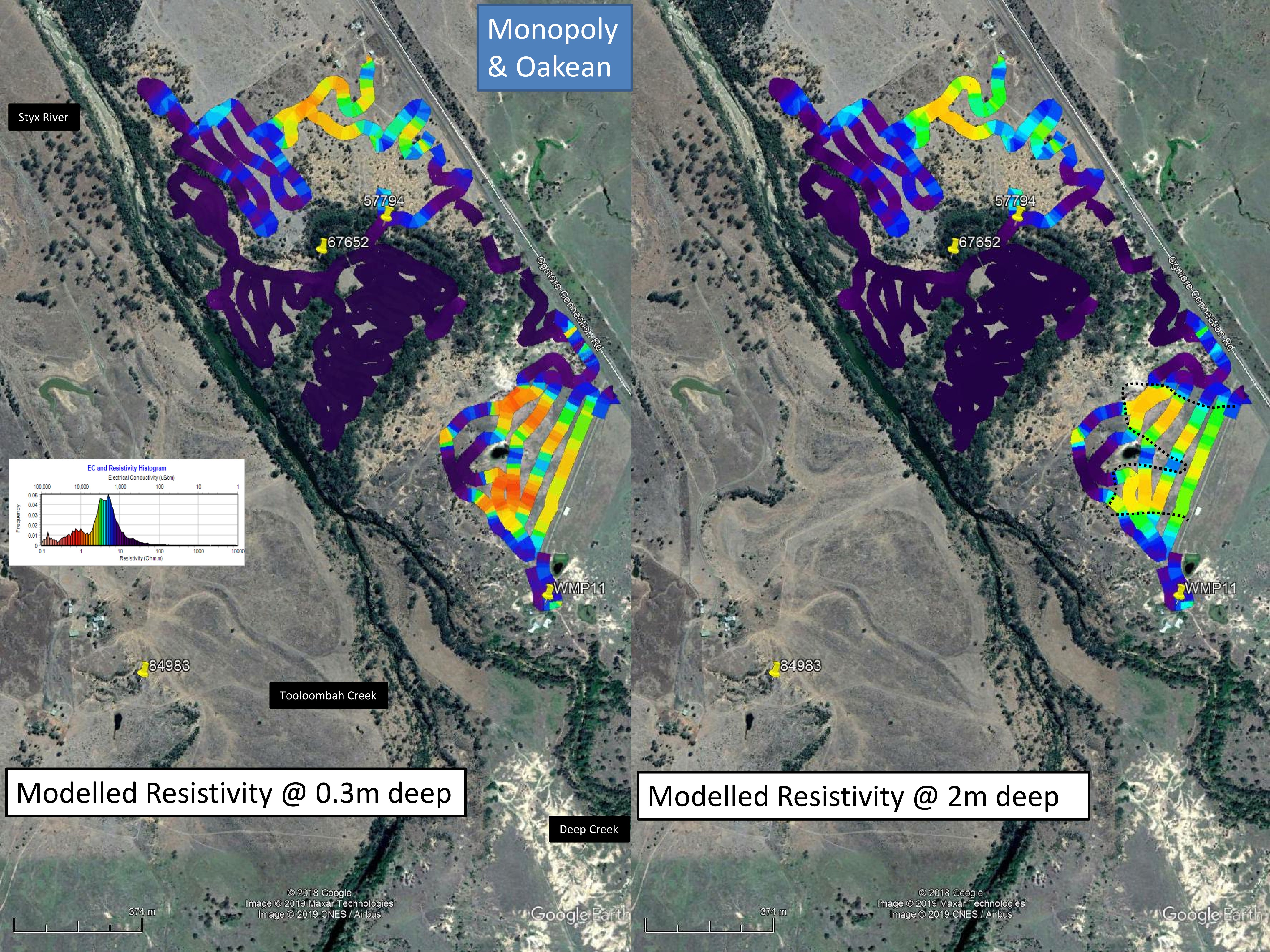


Raw Voltage Data gate 22

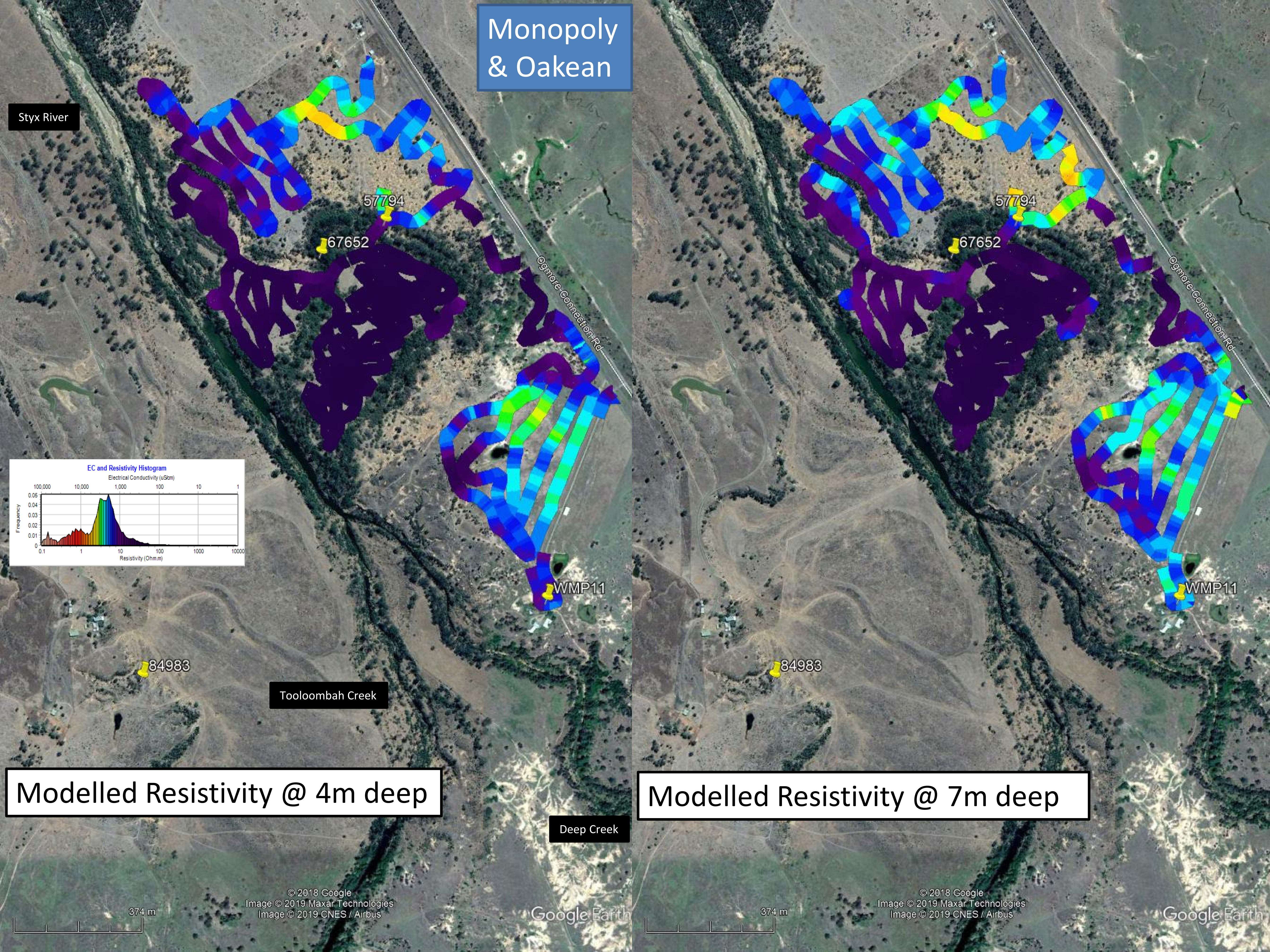
Raw voltage images are good at distinguishing depth to the shallowest non-resistive layer but generally mask anything beneath that layer



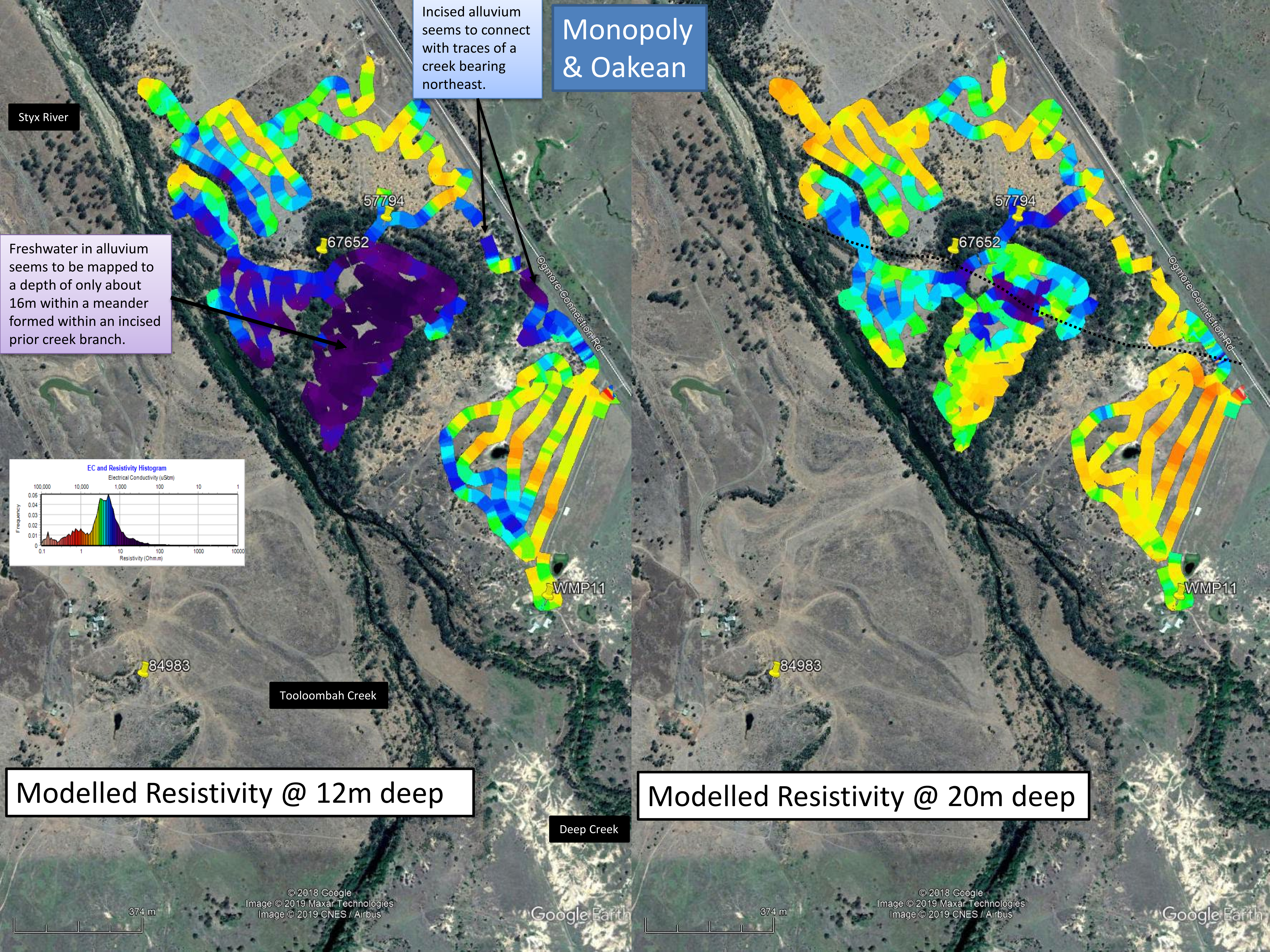




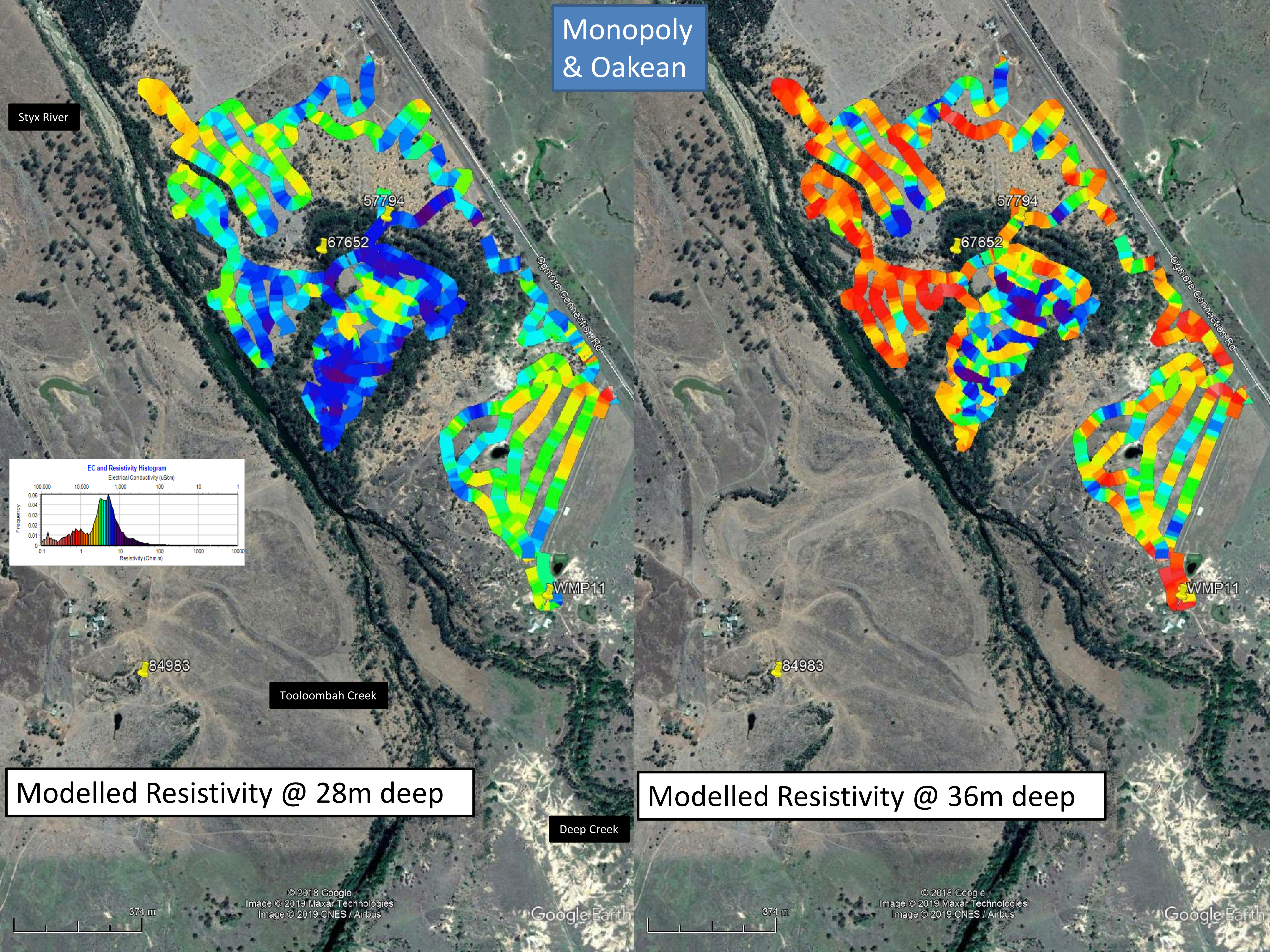
Monopoly & Oakean
Styx River
57794
67652
Ogmore Connection Rd
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
100,000
10,000
1,000
100
10
1
Frequency
0.05
0.04
0.03
0.02
0.01
0
0.1
1
10
100
1000
10000
Resistivity (Ohm.m)
WMP11
84983
Tooloombah Creek
Modelled Resistivity @ 0.3m deep
Deep Creek
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
374 m
Google Earth
Modelled Resistivity @ 2m deep

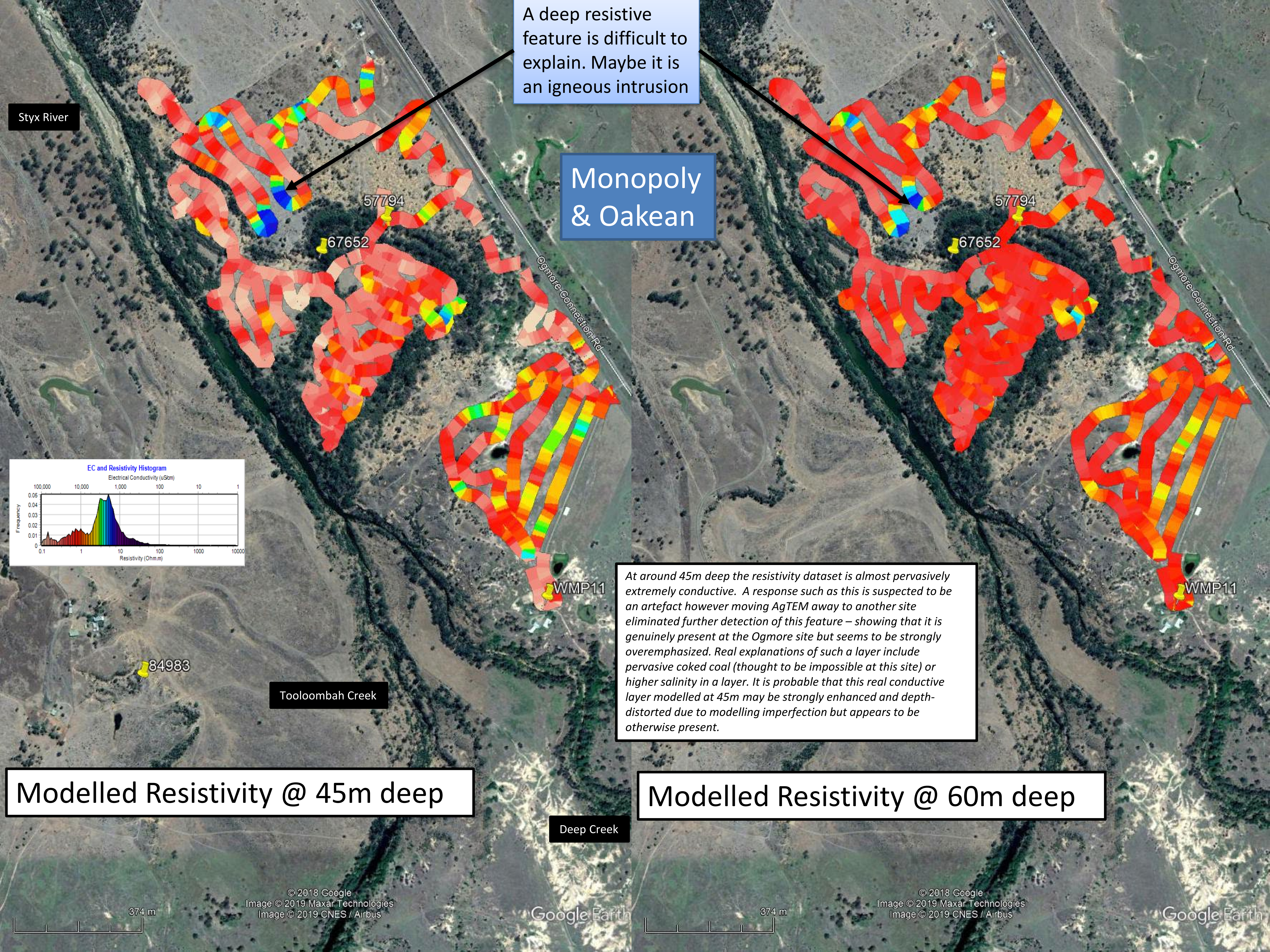


Monopoly & Oakean
Styx River
57794
67652
Ogmore Connection Rd
WMP11
84983
Tooloombah Creek
Deep Creek
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
100,000 10,000 1,000 100 10 1
Frequency
0.06 0.05 0.04 0.03 0.02 0.01 0
0.1 1 10 100 1000 10000
Resistivity (Ohm.m)
Modelled Resistivity @ 4m deep
Modelled Resistivity @ 7m deep
374 m
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
Google Earth

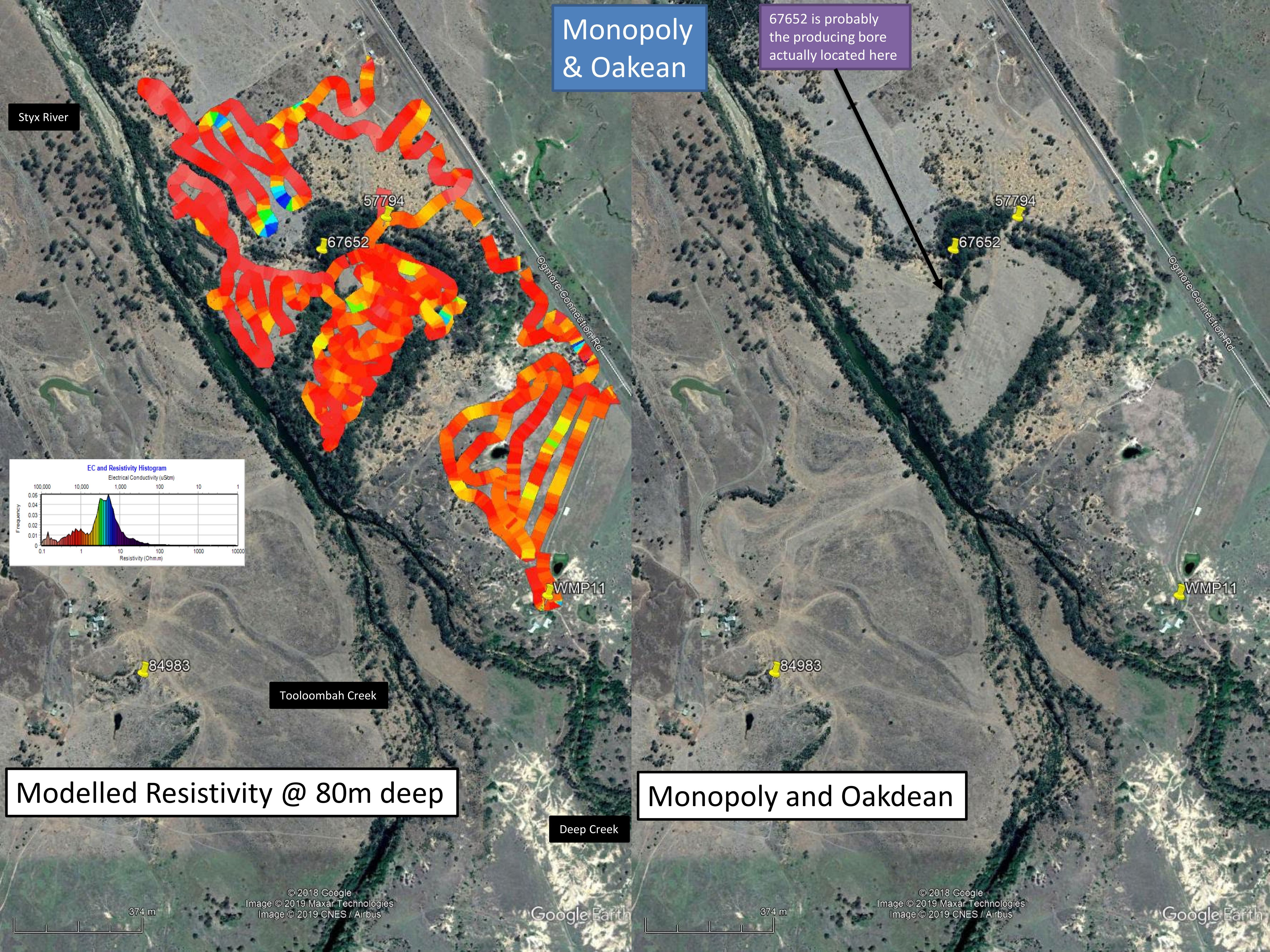


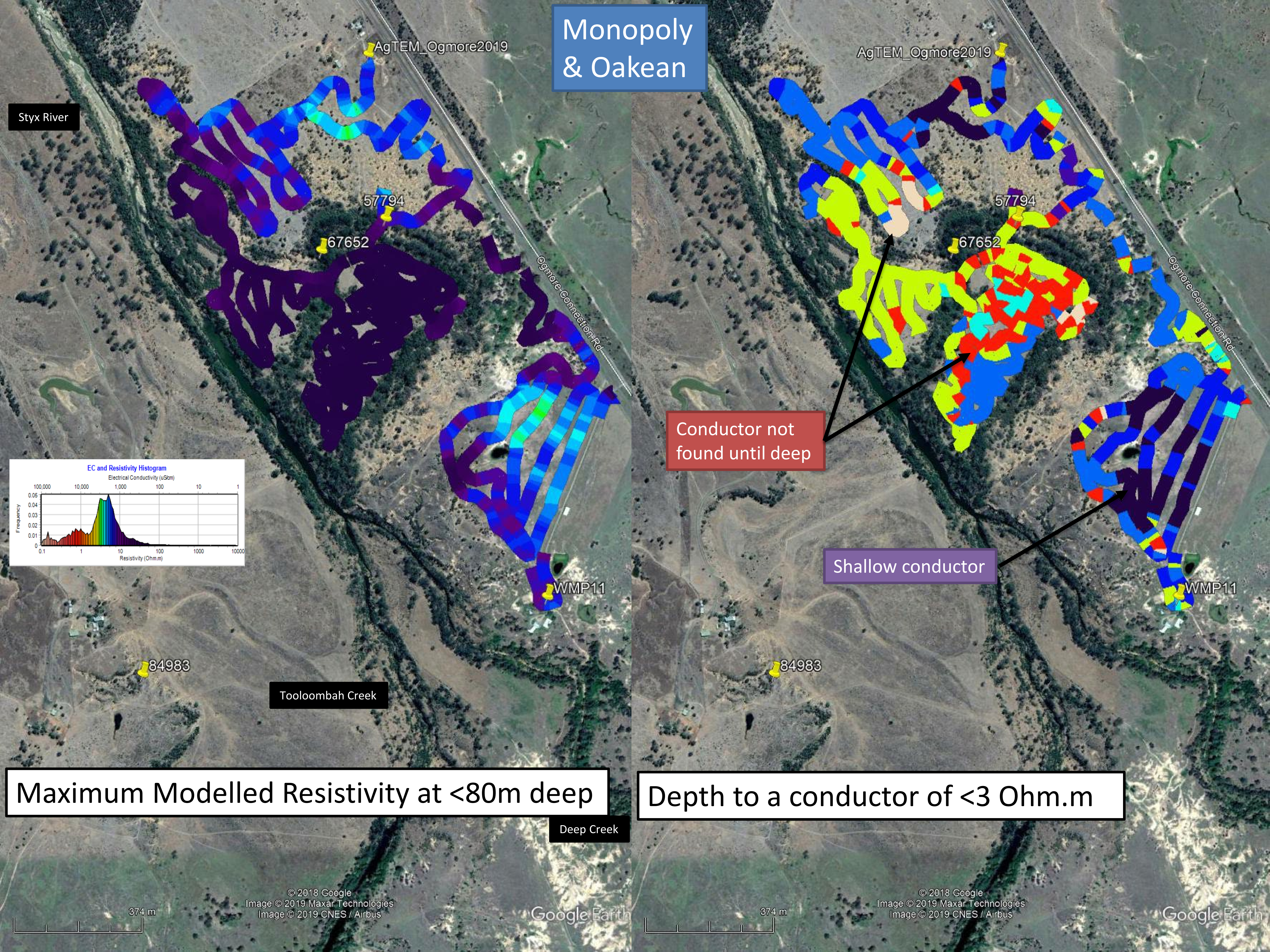
Monopoly & Oakean
Incised alluvium seems to connect with traces of a creek bearing northeast.
Freshwater in alluvium seems to be mapped to a depth of only about 16m within a meander formed within an incised prior creek branch.
Styx River
Tooloombah Creek
Deep Creek
Ogmore Connection Rd
57794
67652
WMP11
84983
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
Frequency
Resistivity (Ohm.m)
Modelled Resistivity @ 12m deep
Modelled Resistivity @ 20m deep
374 m
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
Google Earth


Monopoly & Oakean
Styx River
57794
67652
Ogmore Connection Rd
WMP11
84983
Tooloombah Creek
Deep Creek
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
Frequency
Resistivity (Ohm.m)
Modelled Resistivity @ 28m deep
Modelled Resistivity @ 36m deep
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
374 m
Google Earth

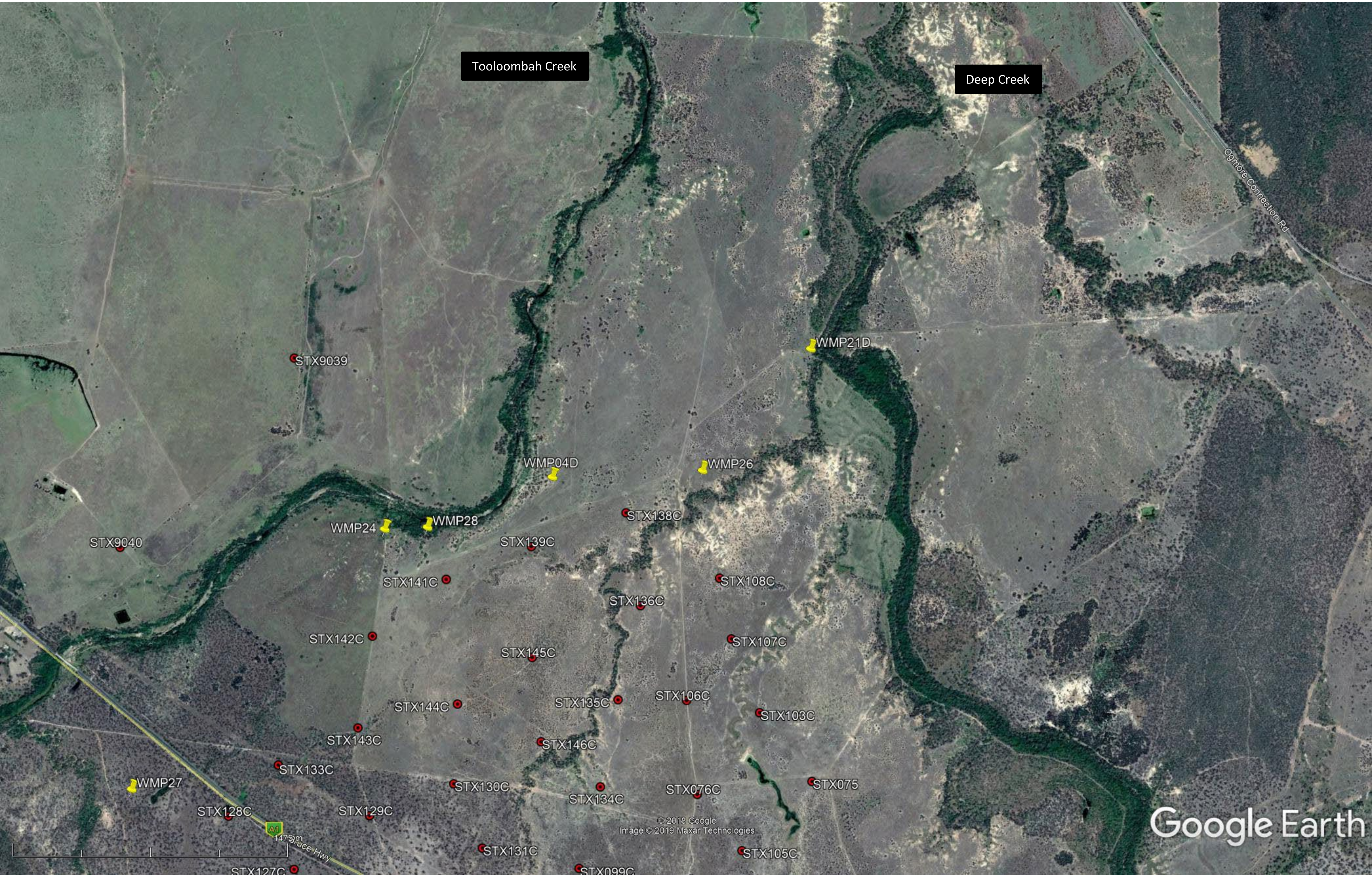


A deep resistive feature is difficult to explain. Maybe it is an igneous intrusion
Monopoly & Oakean
Styx River
57794
67652
Ogmore Connection Rd
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
Frequency
Resistivity (Ohm.m)
WMP11
84983
Tooloombah Creek
Deep Creek
At around 45m deep the resistivity dataset is almost pervasively extremely conductive. A response such as this is suspected to be an artefact however moving AgTEM away to another site eliminated further detection of this feature – showing that it is genuinely present at the Ogmore site but seems to be strongly overemphasized. Real explanations of such a layer include pervasive coked coal (thought to be impossible at this site) or higher salinity in a layer. It is probable that this real conductive layer modelled at 45m may be strongly enhanced and depth-distorted due to modelling imperfection but appears to be otherwise present.
Modelled Resistivity @ 45m deep
Modelled Resistivity @ 60m deep
374 m
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
Google Earth

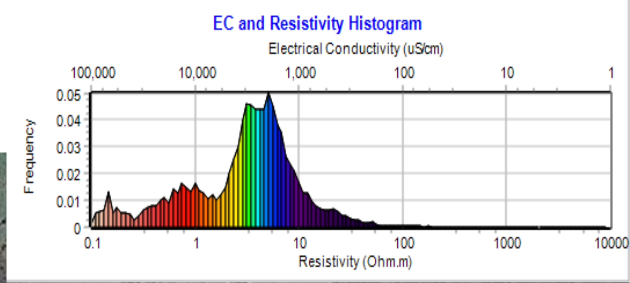

Monopoly & Oakean
67652 is probably the producing bore actually located here
Styx River
57794
67652
Ogmore Connection Rd
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
Frequency
Resistivity (Ohm.m)
WMP11
84983
Tooloombah Creek
Modelled Resistivity @ 80m deep
Deep Creek
Monopoly and Oakdean
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
374 m
Google Earth

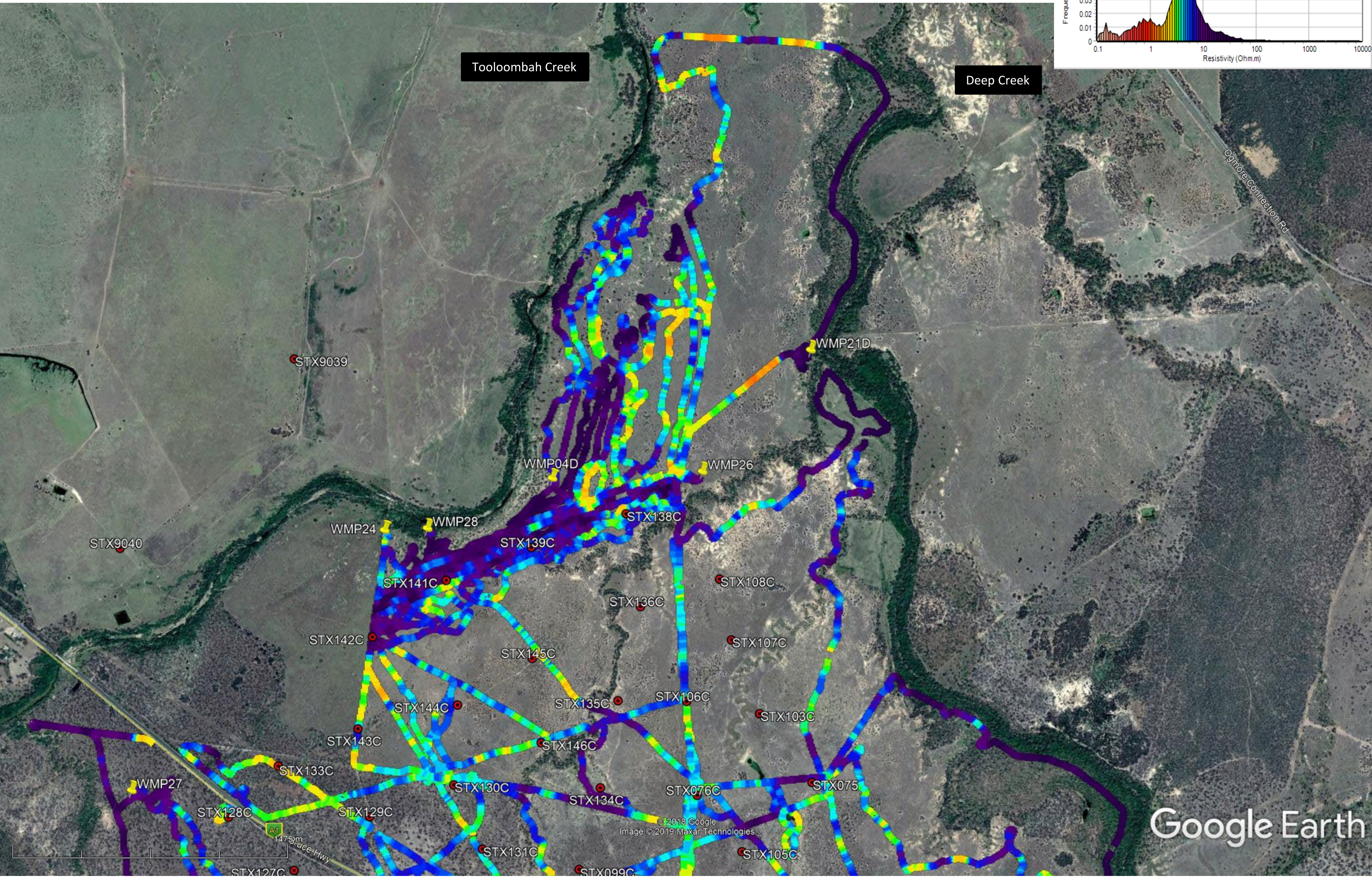

Monopoly & Oakean
Styx River
AgTEM_Ogmore2019
57794
67652
Ogmore Connection Rd
WMP11
84983
Tooloombah Creek
Deep Creek
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
100,000
10,000
1,000
100
10
1
Frequency
0.05
0.04
0.03
0.02
0.01
0
0.1
1
10
100
1000
10000
Resistivity (Ohm.m)
Maximum Modelled Resistivity at <80m deep
AgTEM_Ogmore2019
57794
67652
Ogmore Connection Rd
WMP11
84983
Conductor not found until deep
Shallow conductor
Depth to a conductor of <3 Ohm.m
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
374 m
Google Earth

Mamelon North and Bar-H Background Image

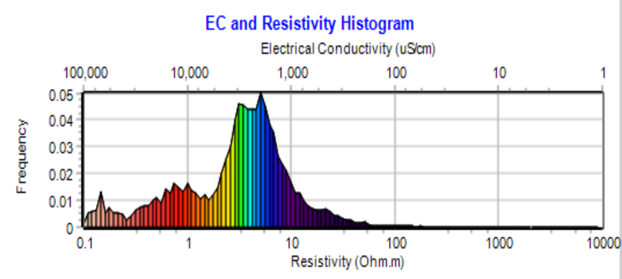


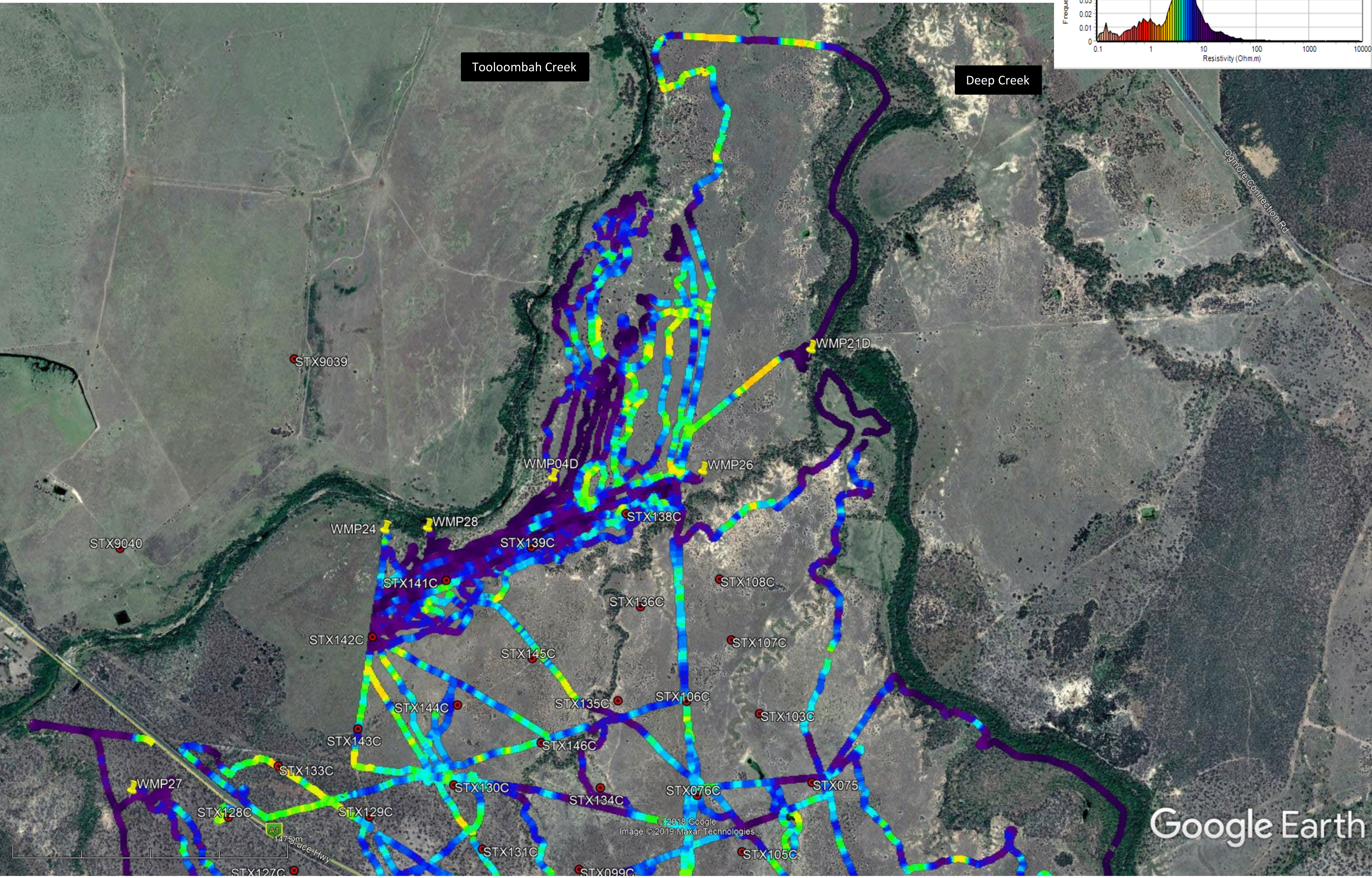
Modelled Resistivity @ 0.3m deep



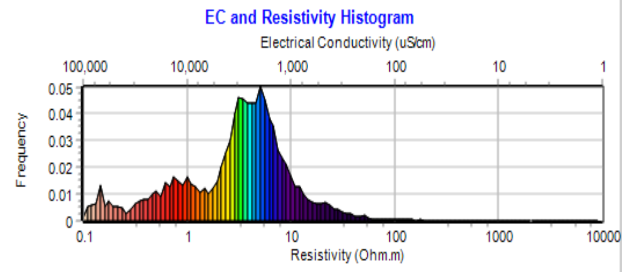


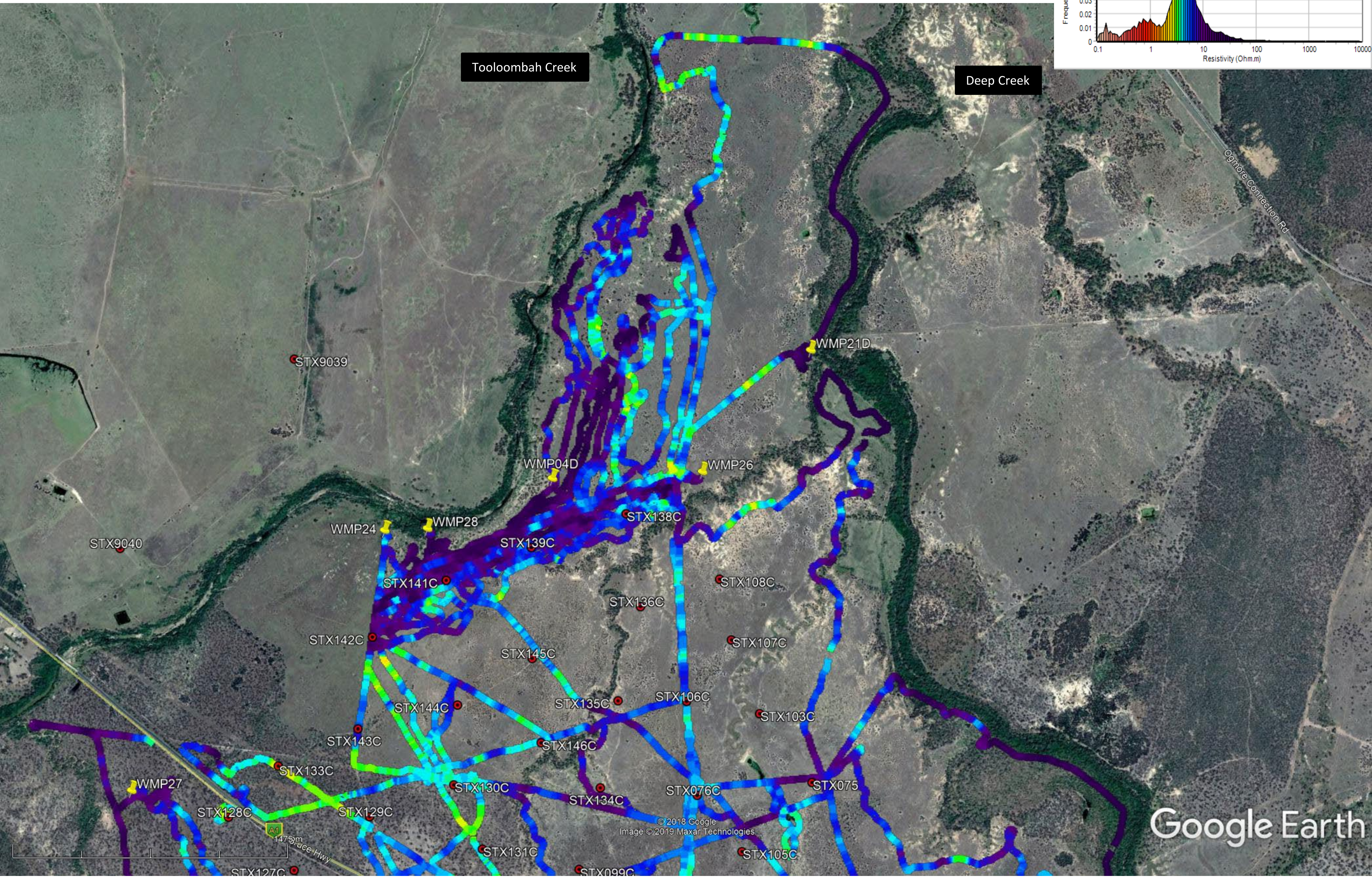
Modelled Resistivity @ 2m deep



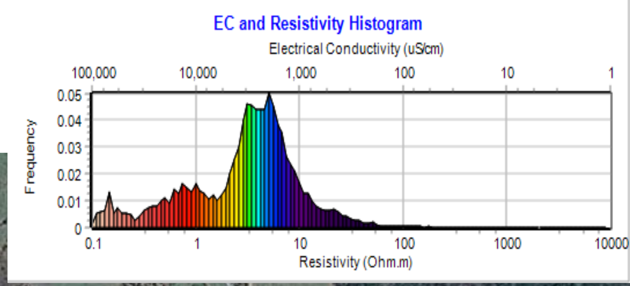


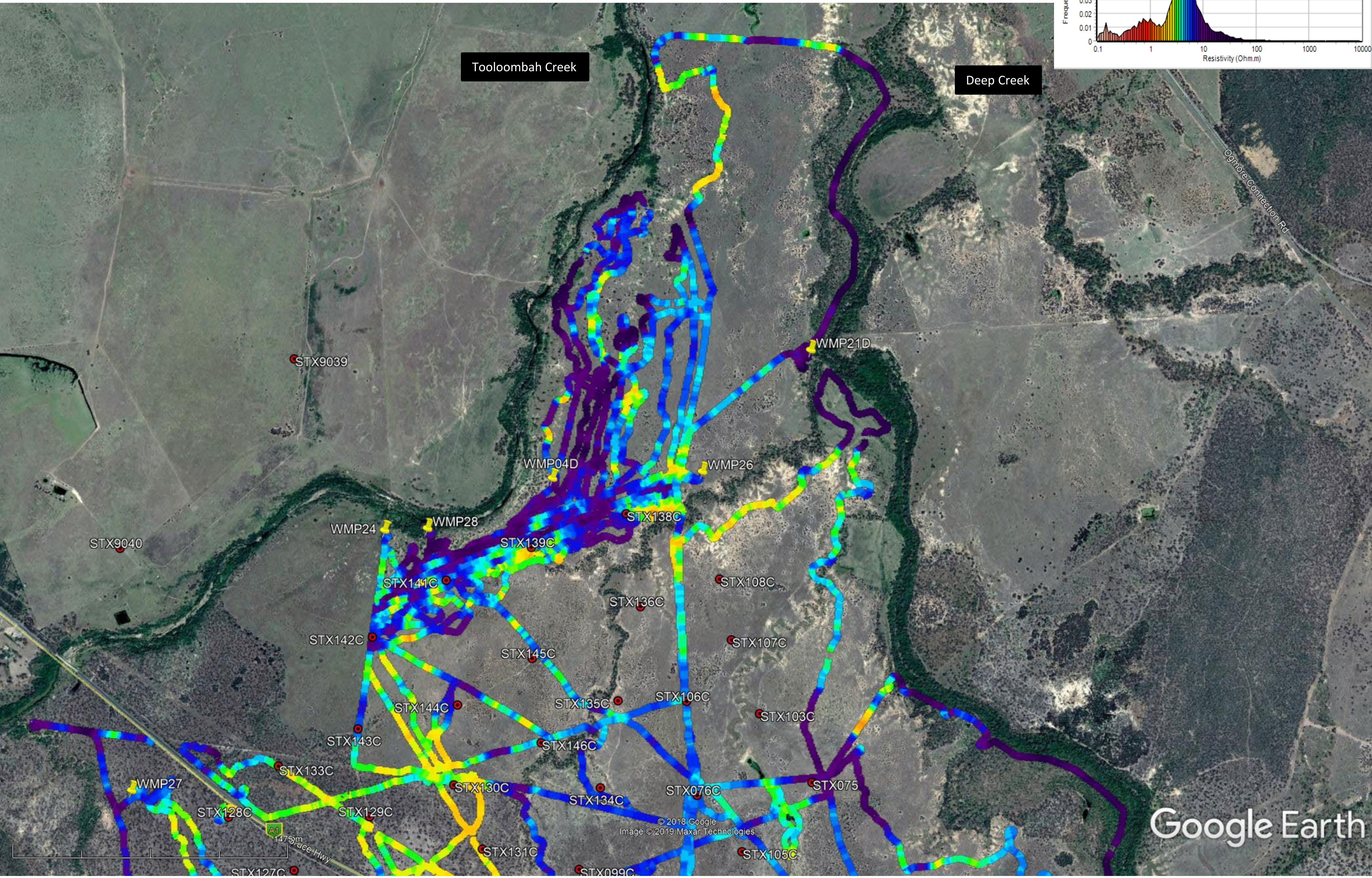
Modelled Resistivity @ 4m deep



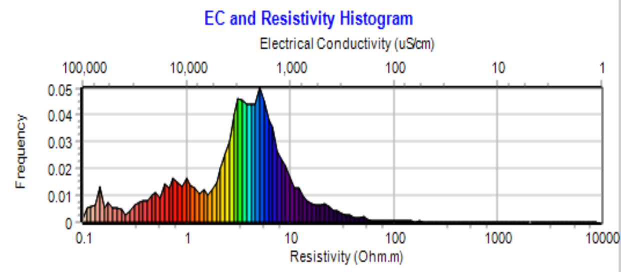


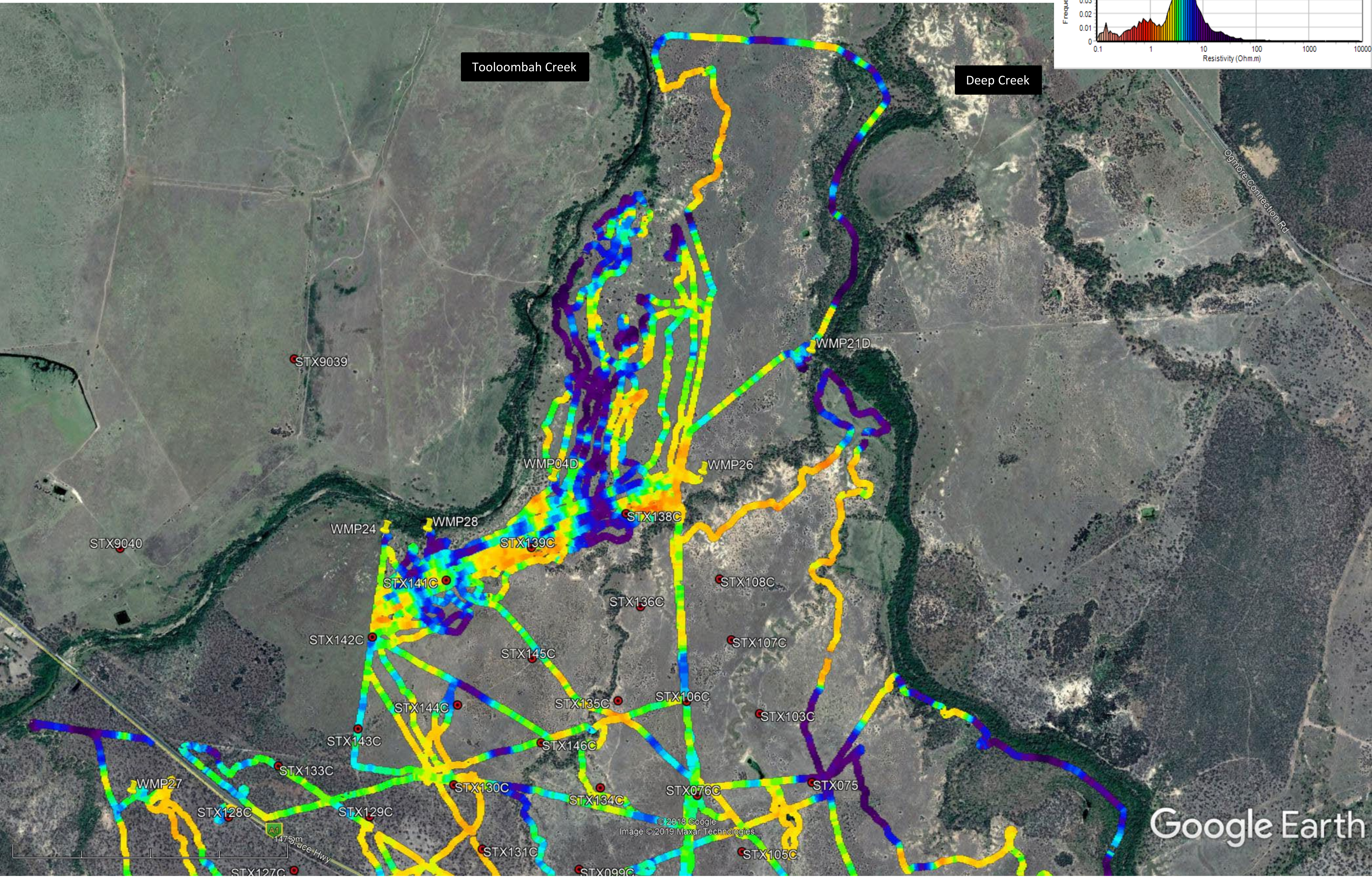
Modelled Resistivity @ 7m deep



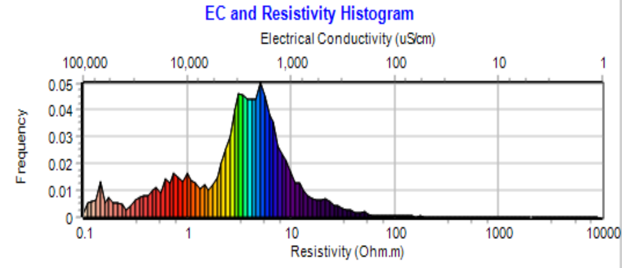


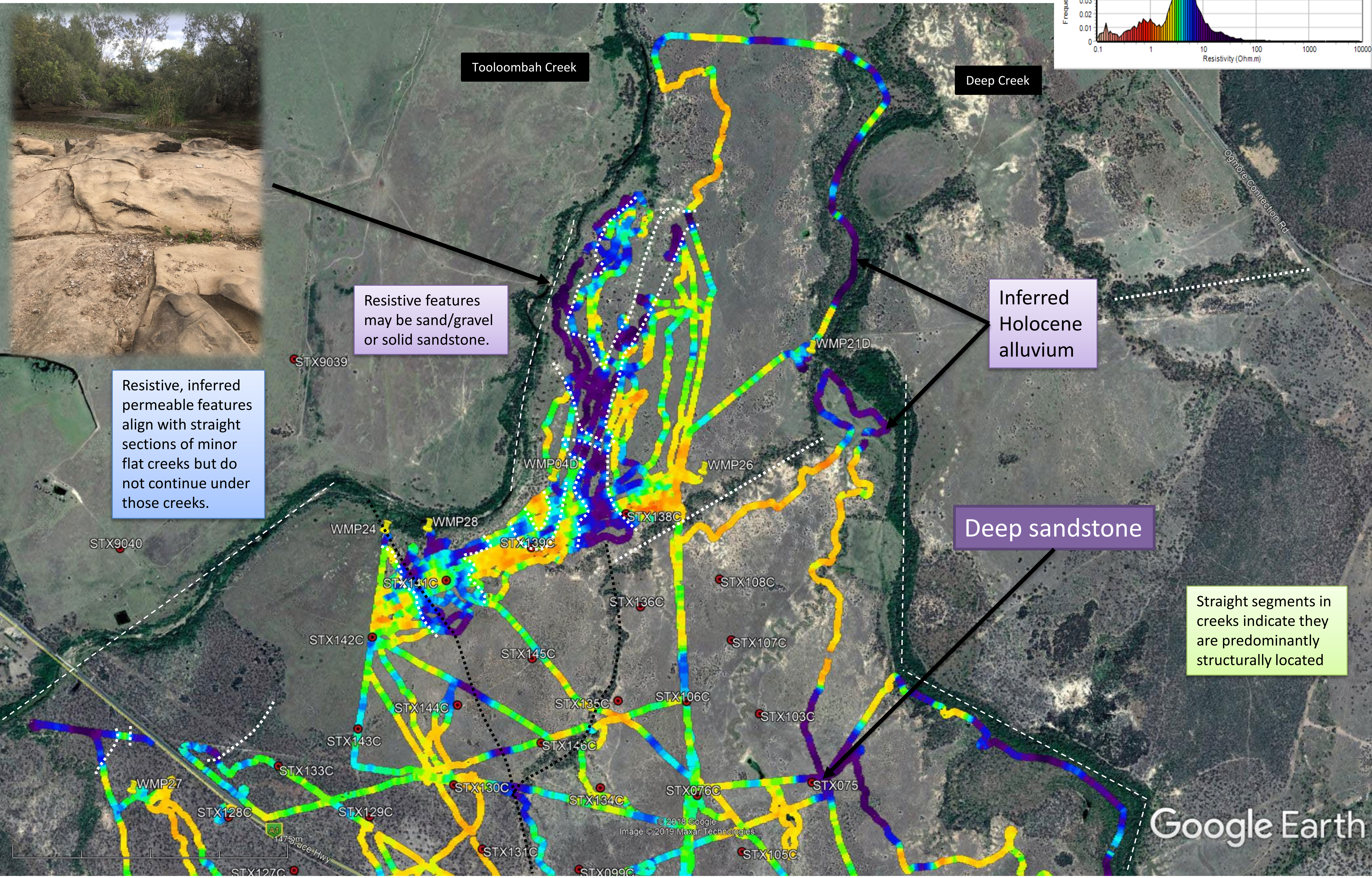
Modelled Resistivity @ 12m deep



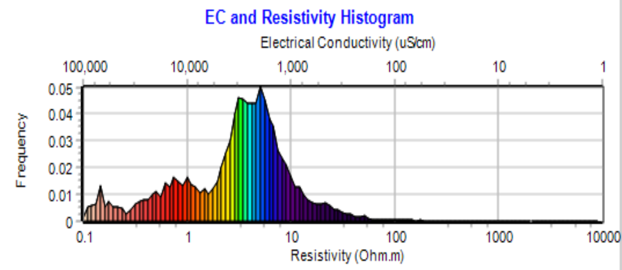


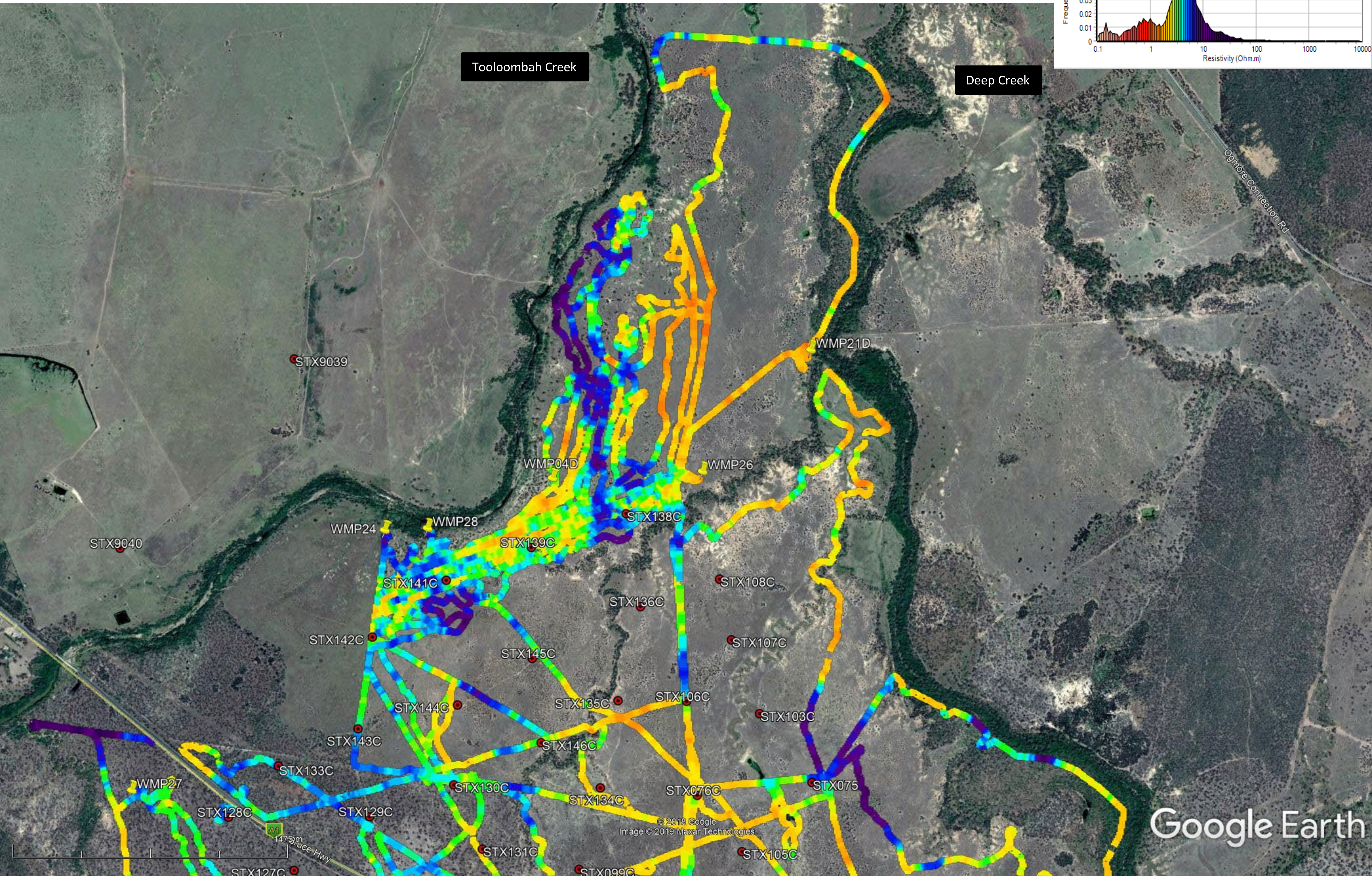
Modelled Resistivity @ 12m deep + Interpretation



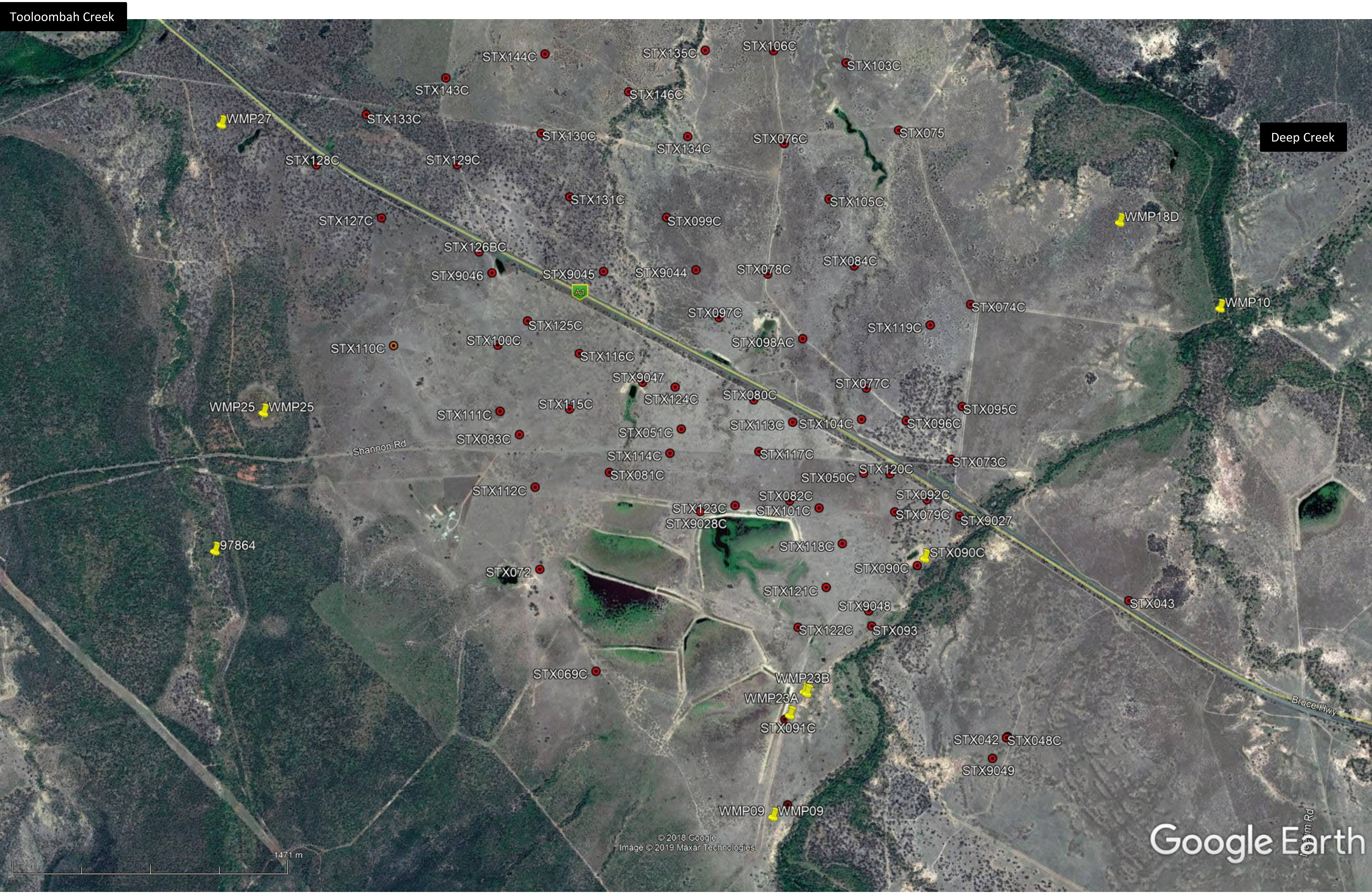


Modelled Resistivity @ 20m deep

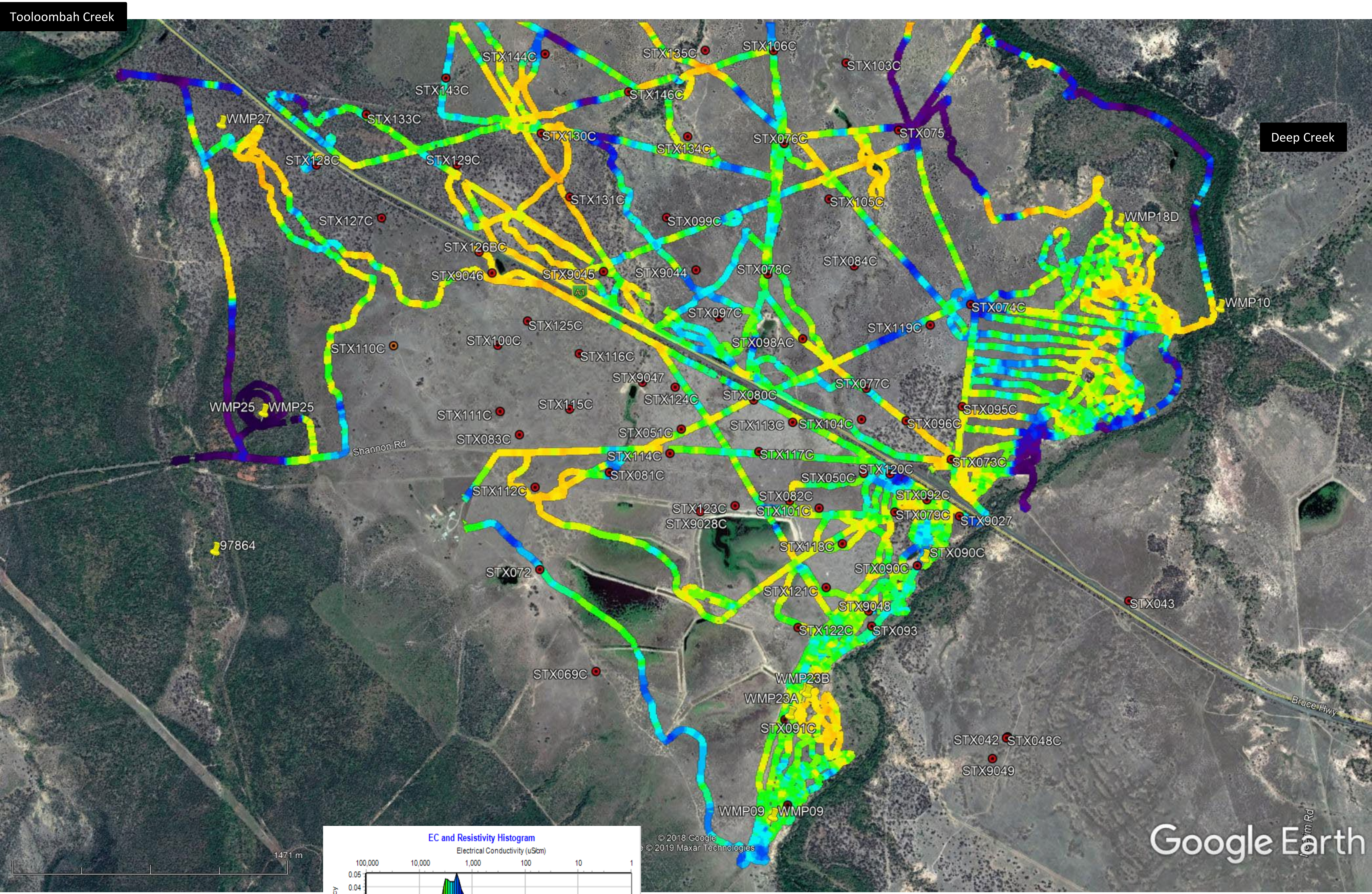


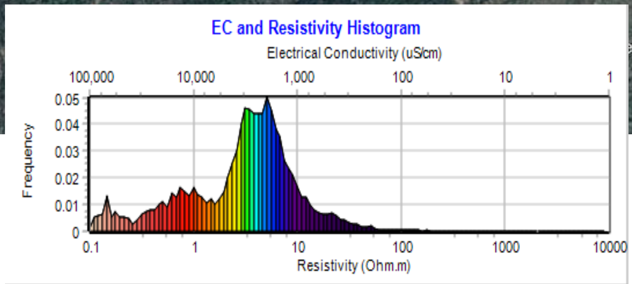


Mamelon South and Brussels Background Image

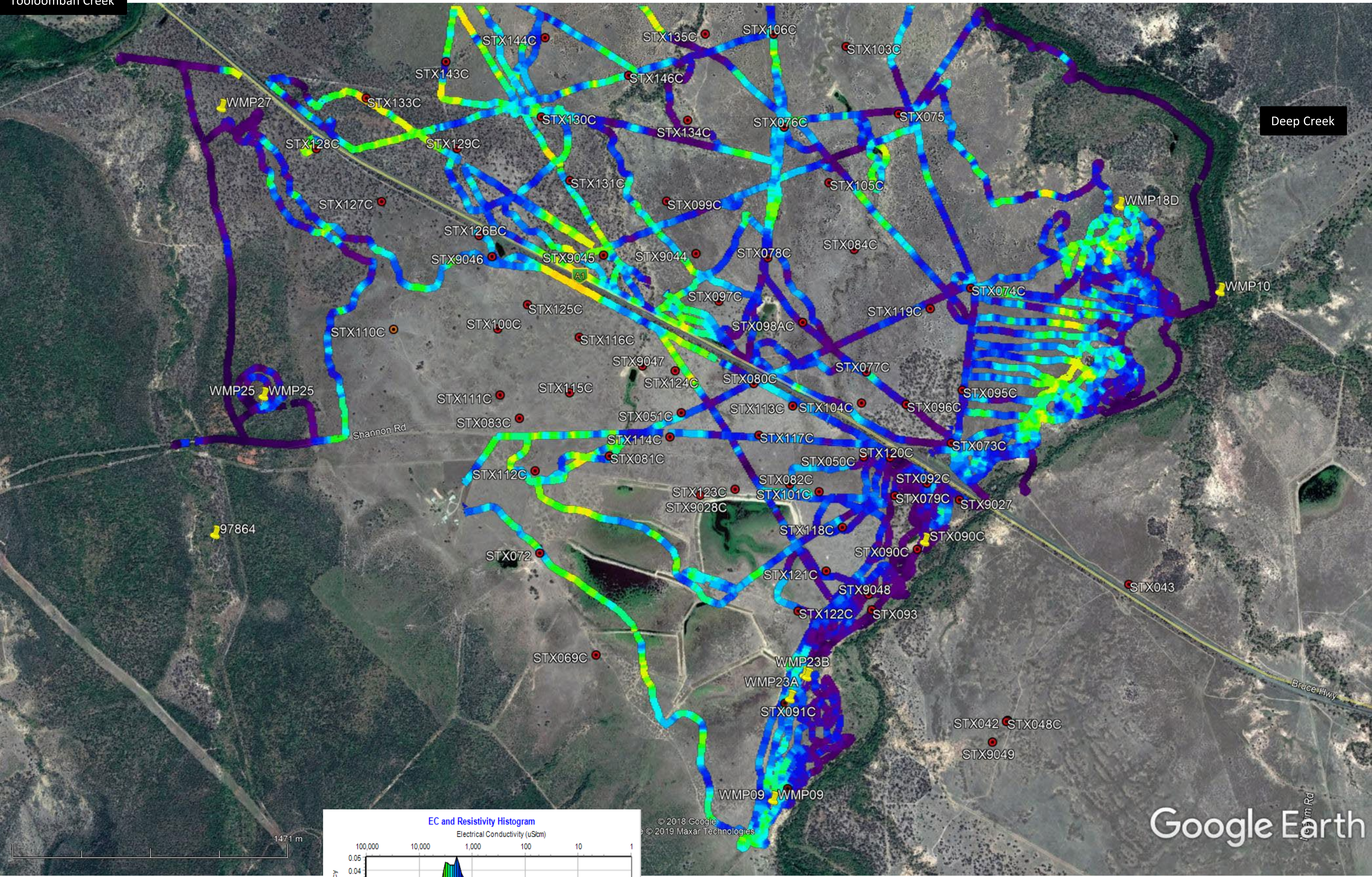


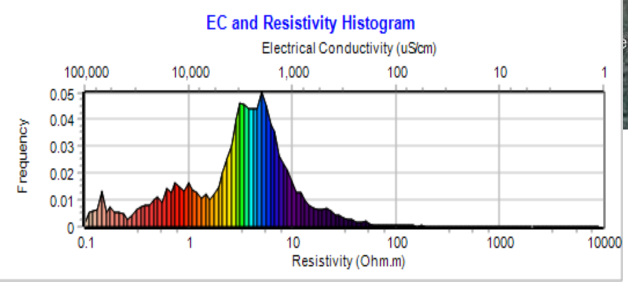
Modelled Resistivity @ 0.3m deep



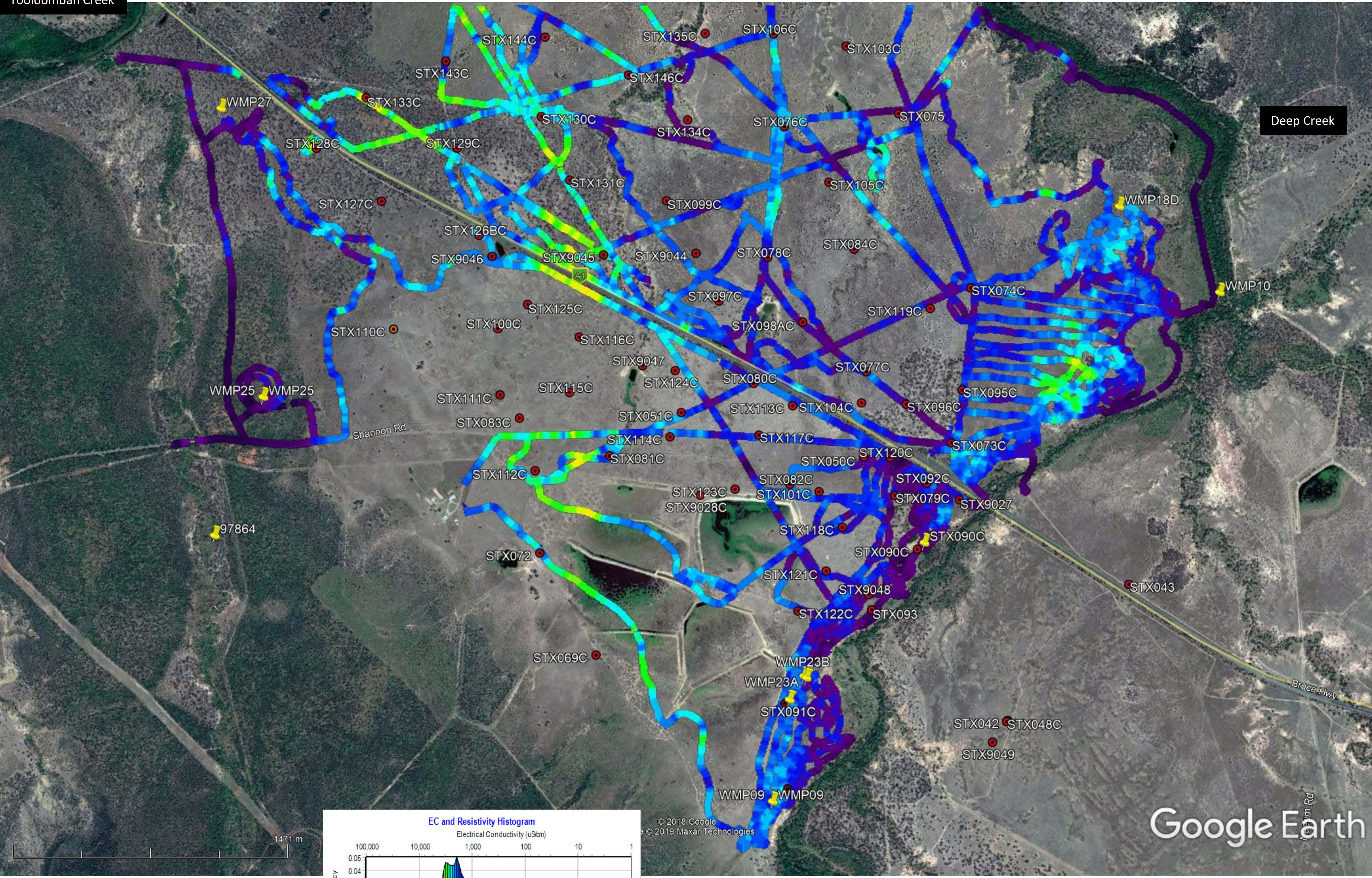


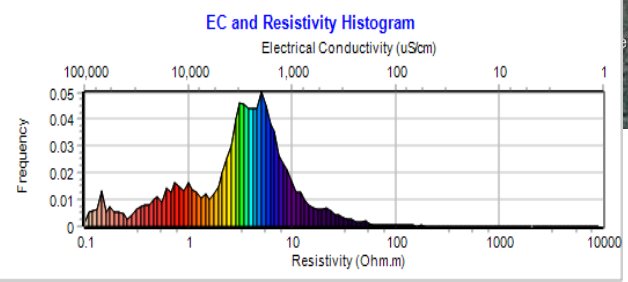
Modelled Resistivity @ 2m deep



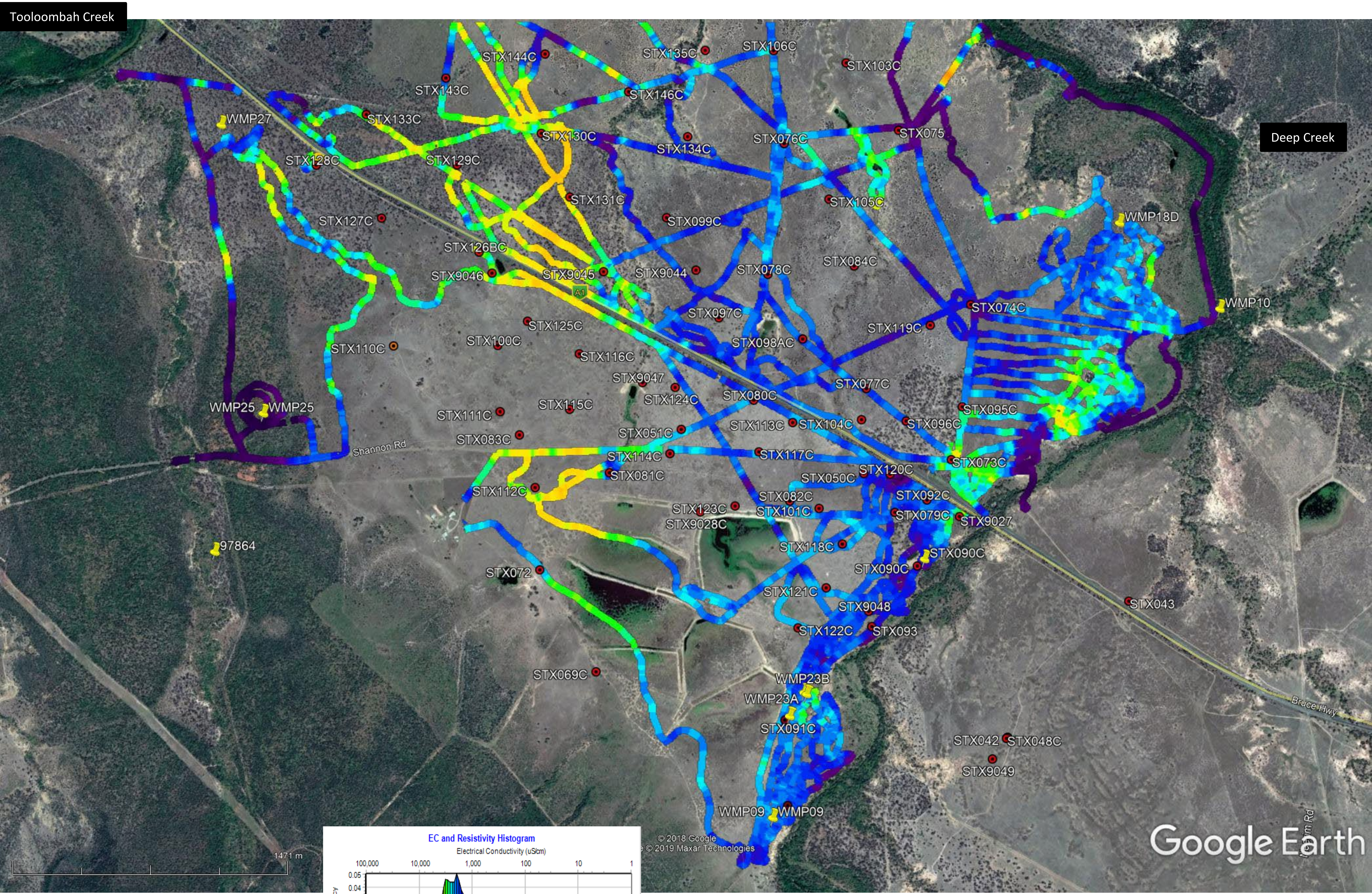


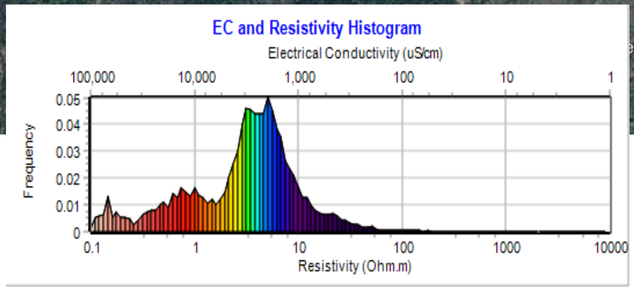
Modelled Resistivity @ 4m deep



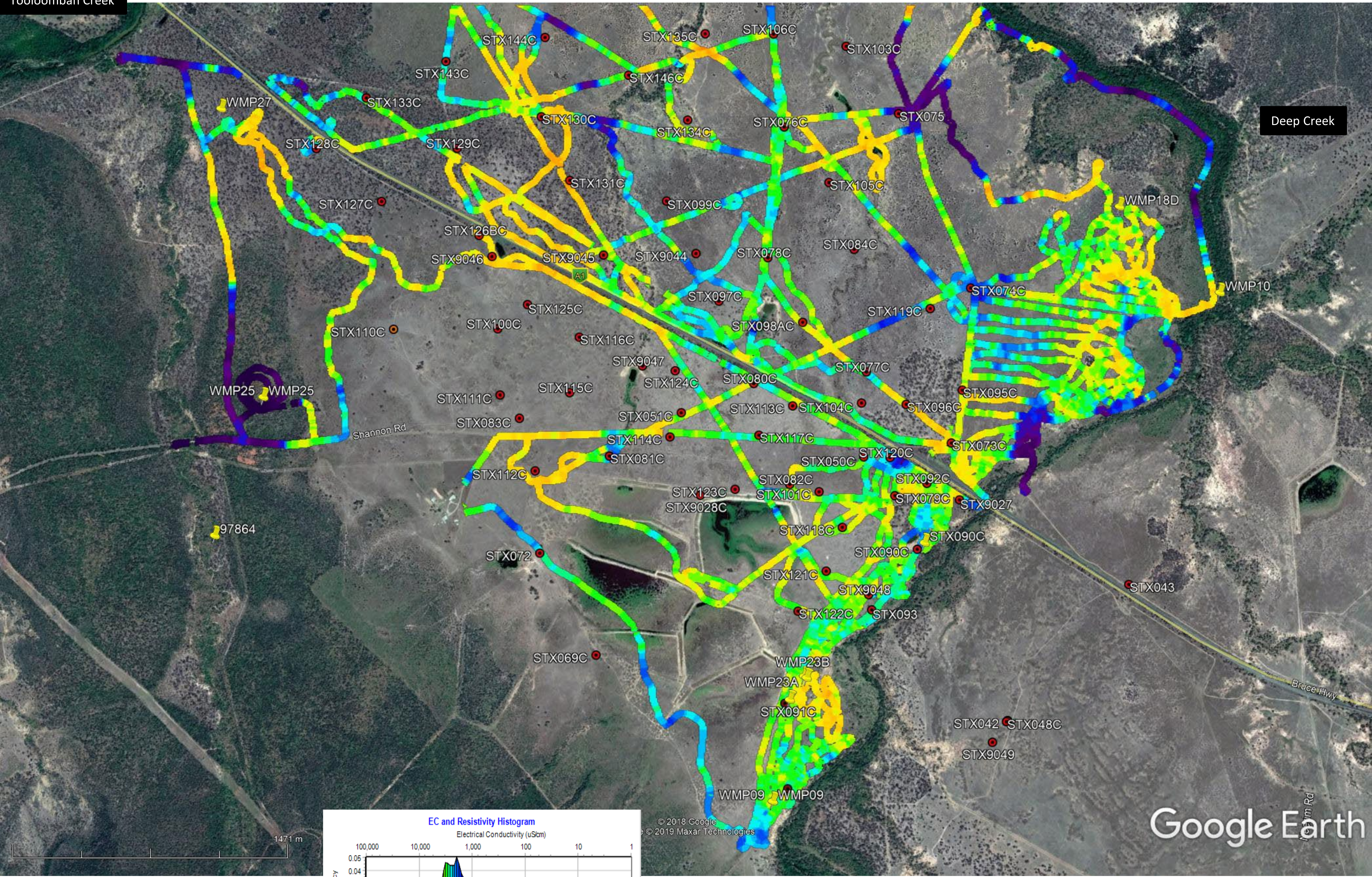


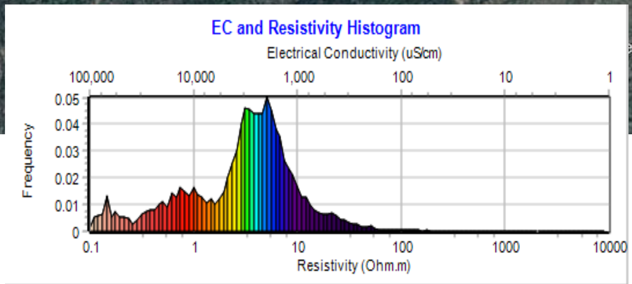
Modelled Resistivity @ 7m deep



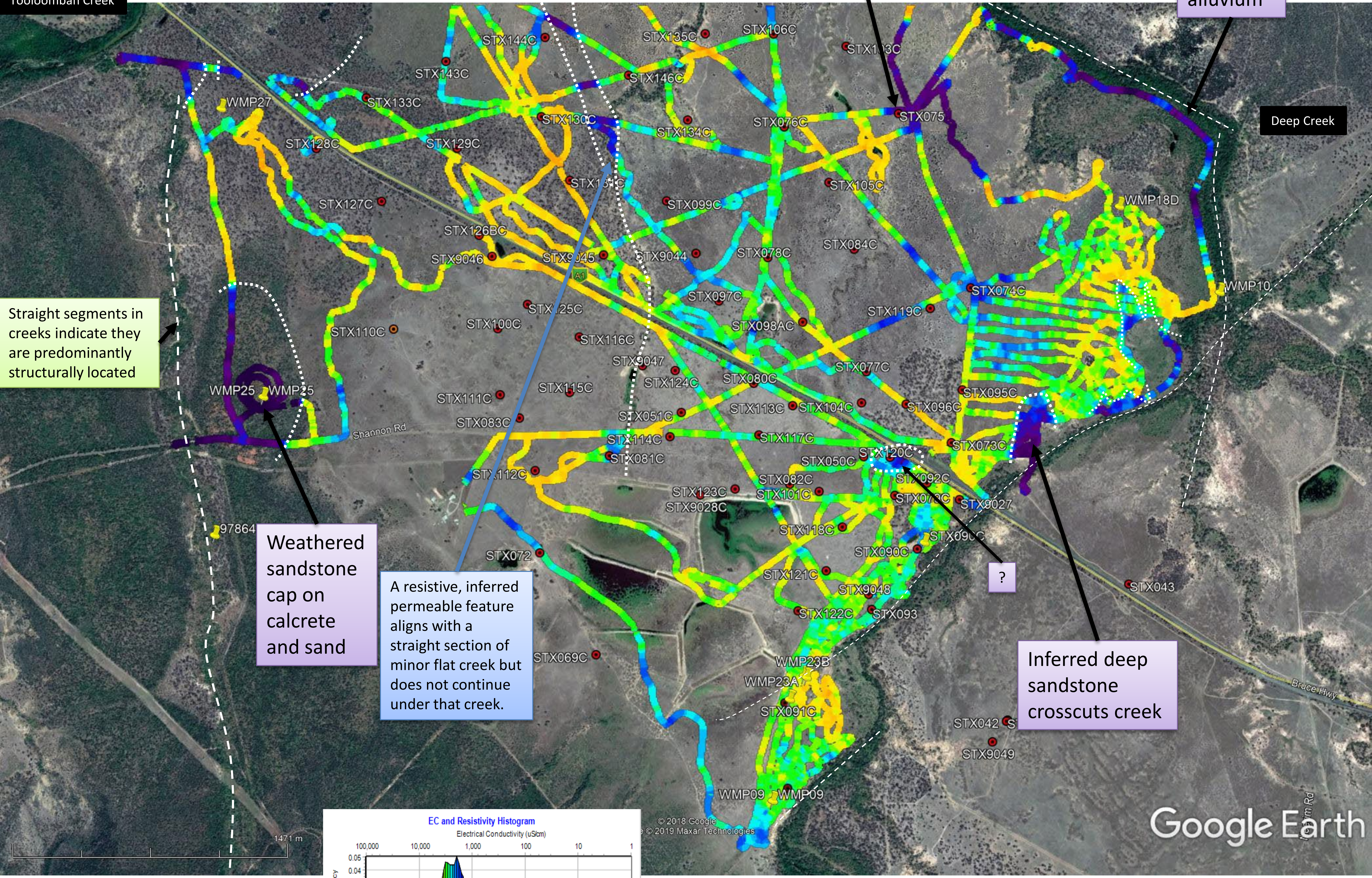


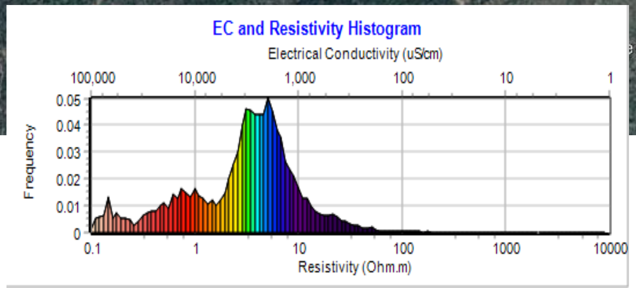
Modelled Resistivity @ 12m deep



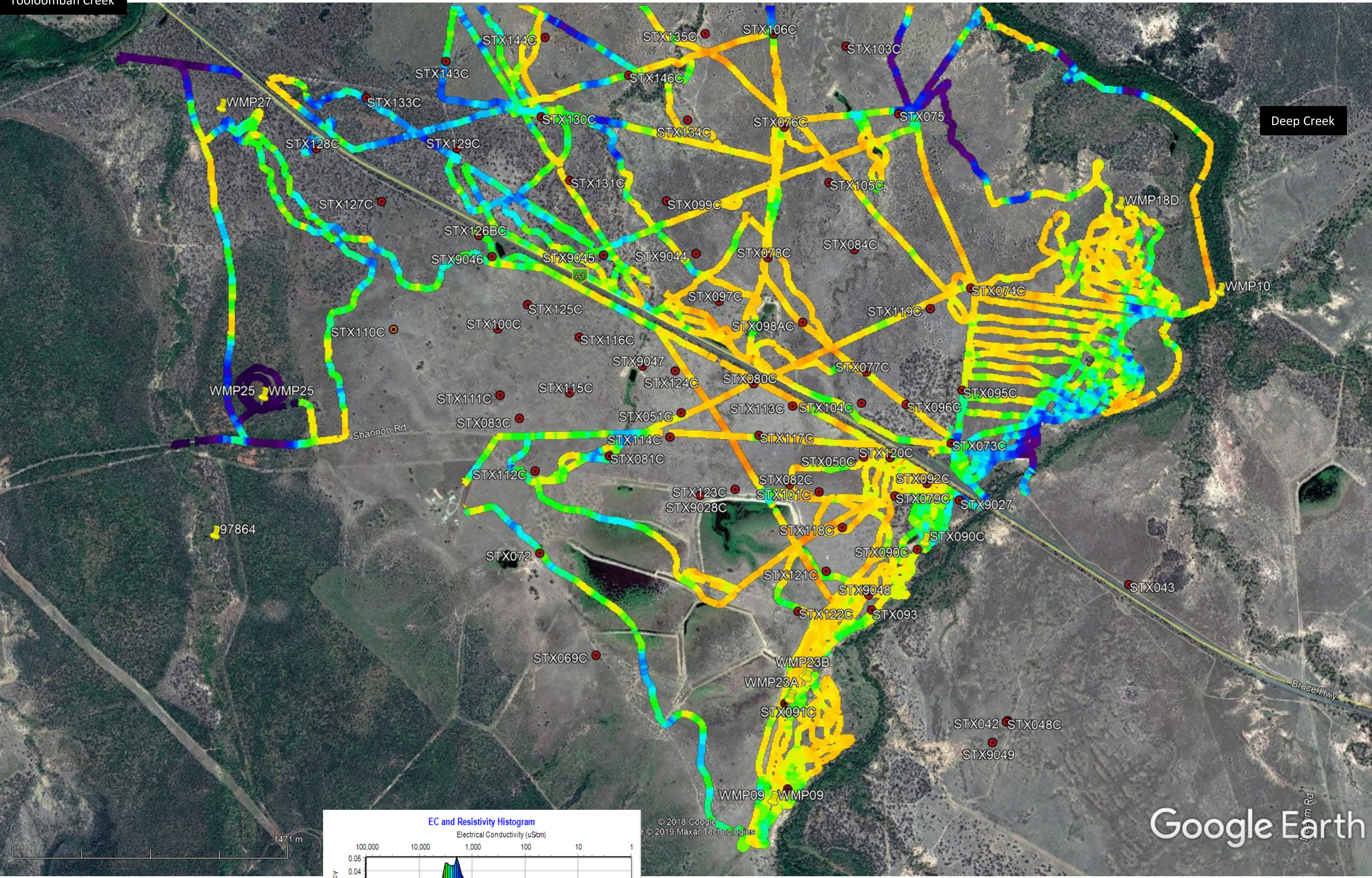


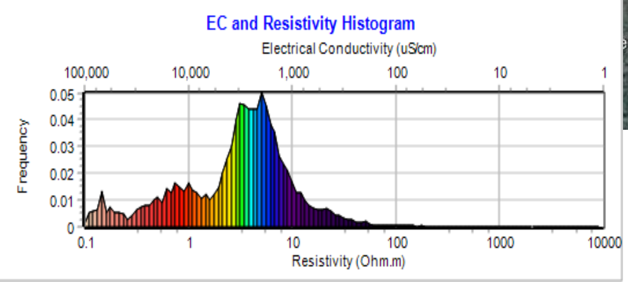
Modelled Resistivity @ 12m deep + Interpretation





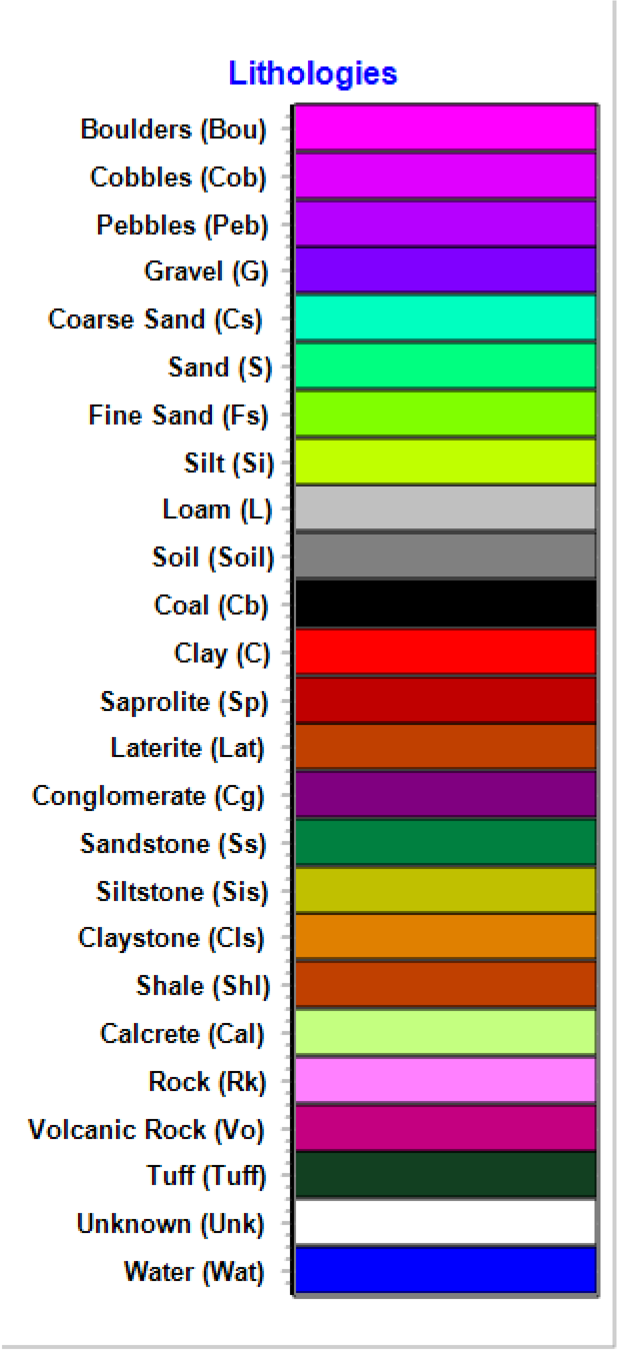
Modelled Resistivity @ 20m deep

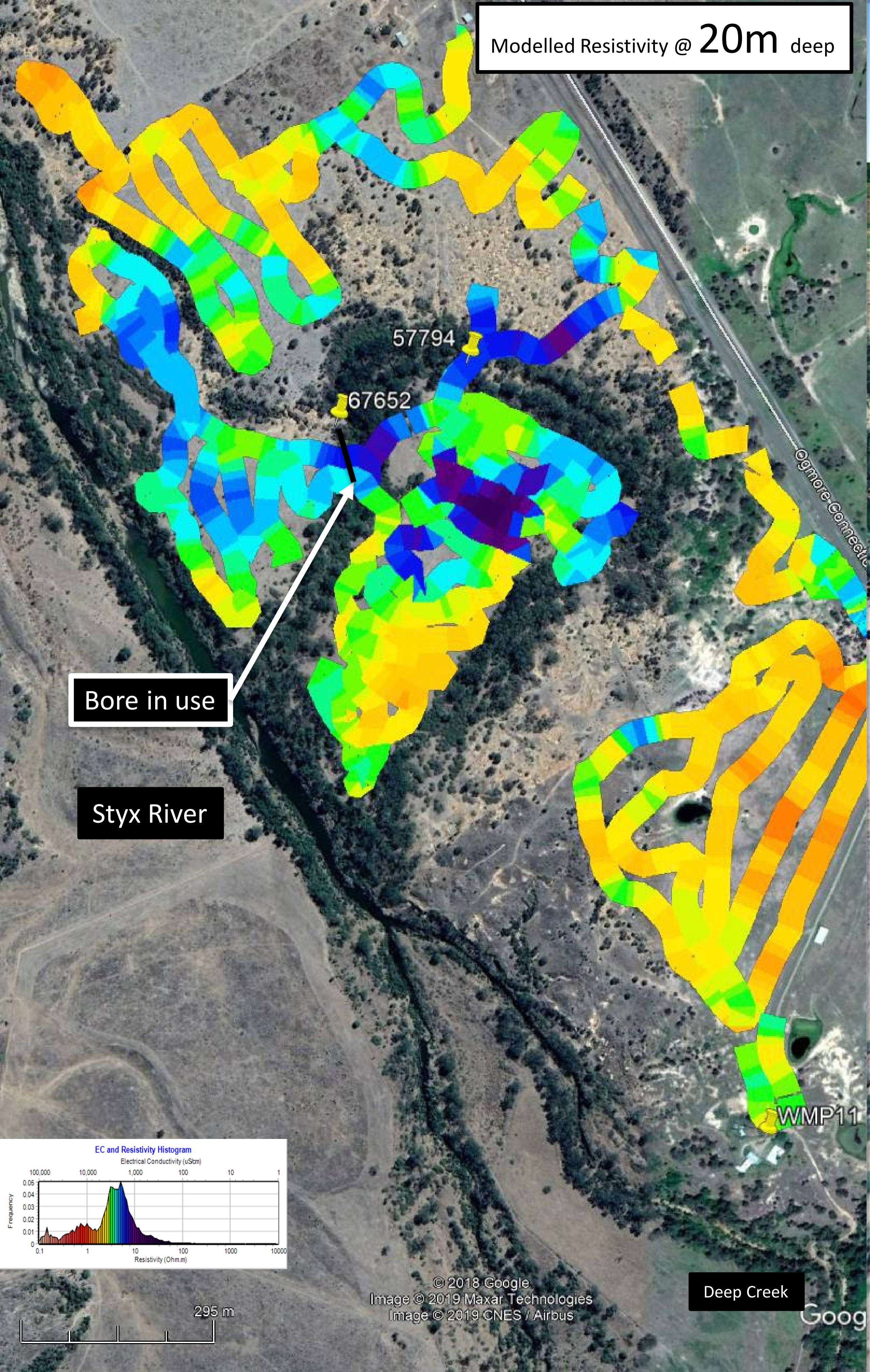




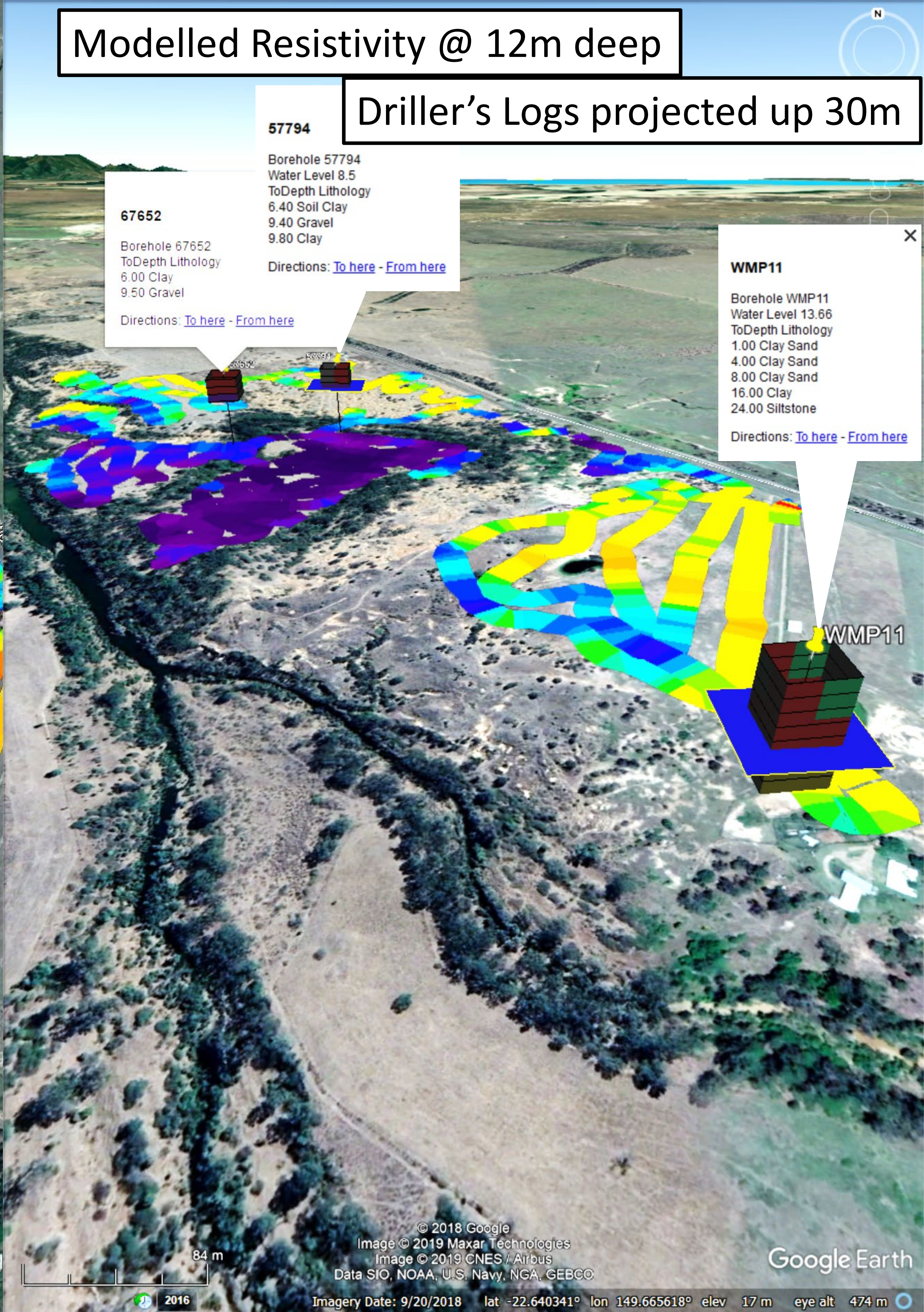
Three dimensional presentation

- In order to understand the TEM data, it has been plotted in 3D. This helps with observation of the geometry of features in vertical transects.
- The curtain images are simply projected 50m up from the Google Earth DEM. The data is plotted against depth but draped over the Google Earth DEM.
- Bores are projected with 4x vertical exaggeration.
- First, Bore Lithologies are projected over a draped depth slice.
- Next, Resistivity Depth curtains are presented from North to south.





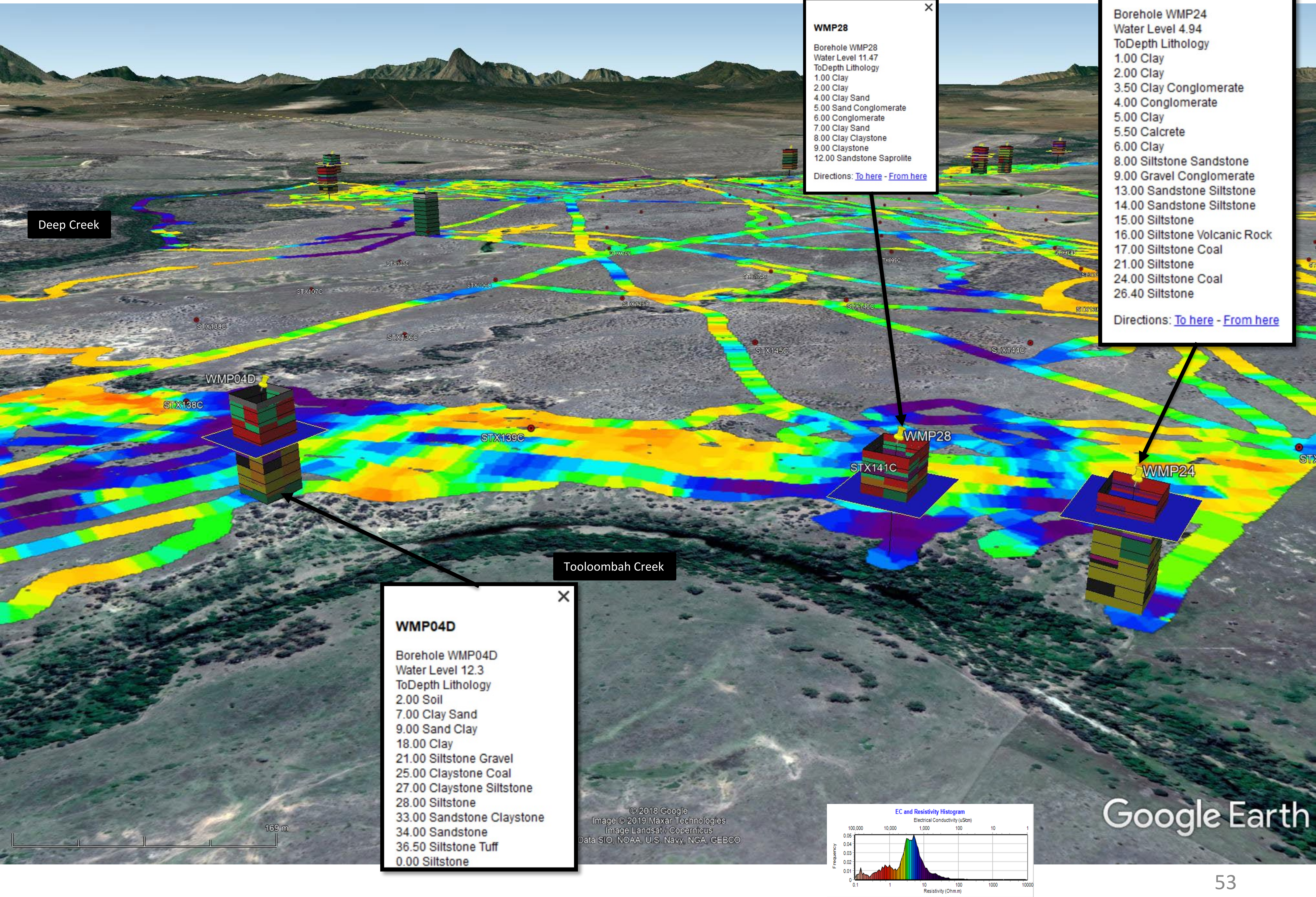
Modelled Resistivity @ 20m deep
57794
67652
Bore in use
Styx River
Ogmore Connection
WMP11
Deep Creek
EC and Resistivity Histogram
Electrical Conductivity (uS/m)
Frequency
Resistivity (Ohm.m)
295 m
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus



Modelled Resistivity @ 12m deep
Driller's Logs projected up 30m
57794
Borehole 57794
Water Level 8.5
ToDepth Lithology
6.40 Soil Clay
9.40 Gravel
9.80 Clay
Directions: To here - From here
67652
Borehole 67652
ToDepth Lithology
6.00 Clay
9.50 Gravel
Directions: To here - From here
WMP11
Borehole WMP11
Water Level 13.66
ToDepth Lithology
1.00 Clay Sand
4.00 Clay Sand
8.00 Clay Sand
16.00 Clay
24.00 Siltstone
Directions: To here - From here
WMP11
84 m
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google Earth
2016
Imagery Date: 9/20/2018 lat -22.640341° lon 149.665618° elev 17 m eye alt 474 m

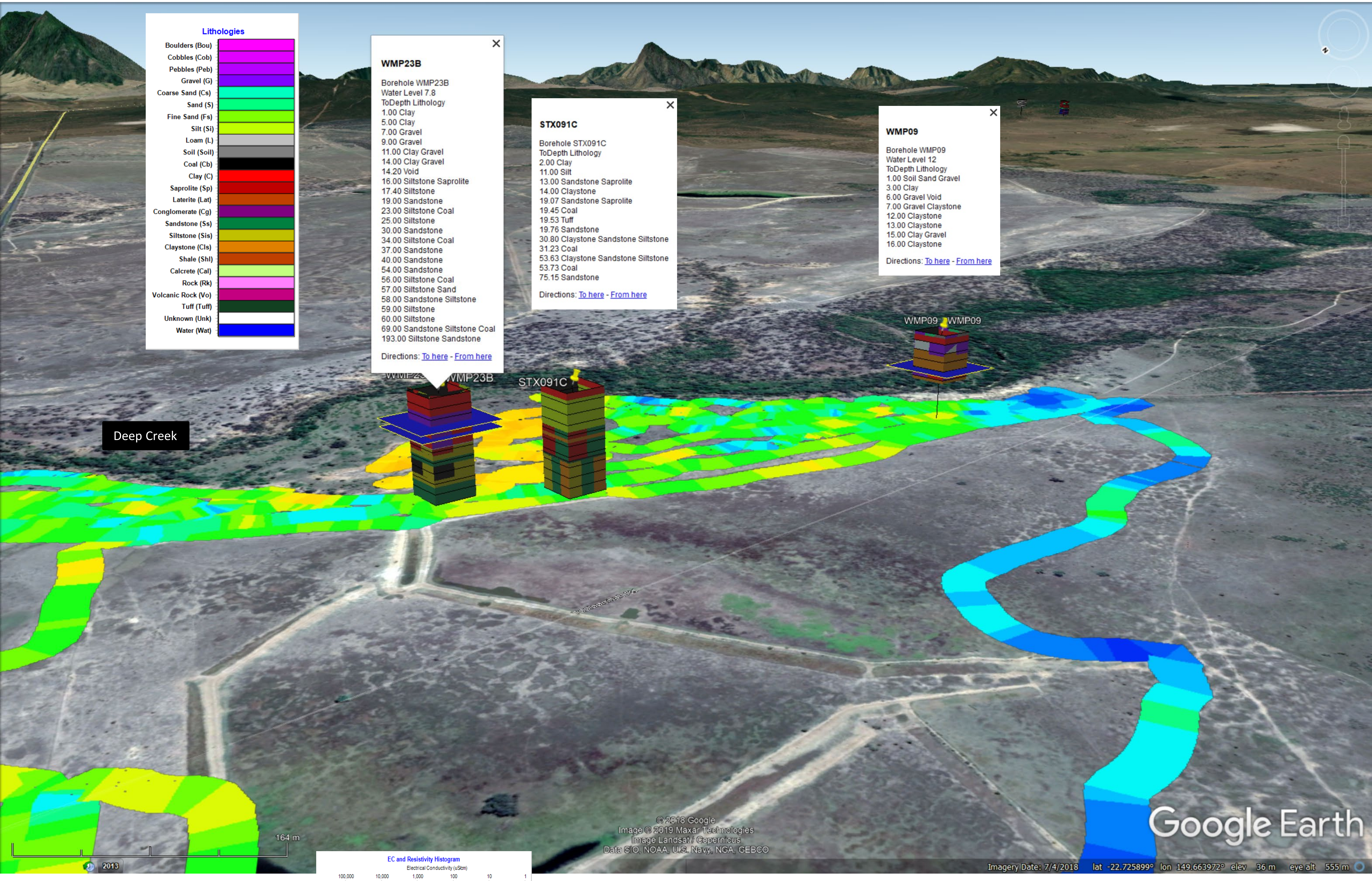
Modelled Resistivity @ 12m deep

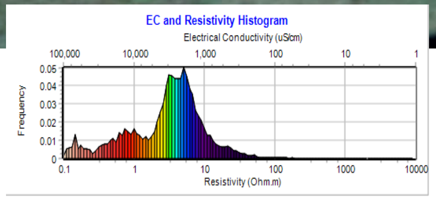
Driller's Logs projected up 30m



Modelled Resistivity @ 12m deep

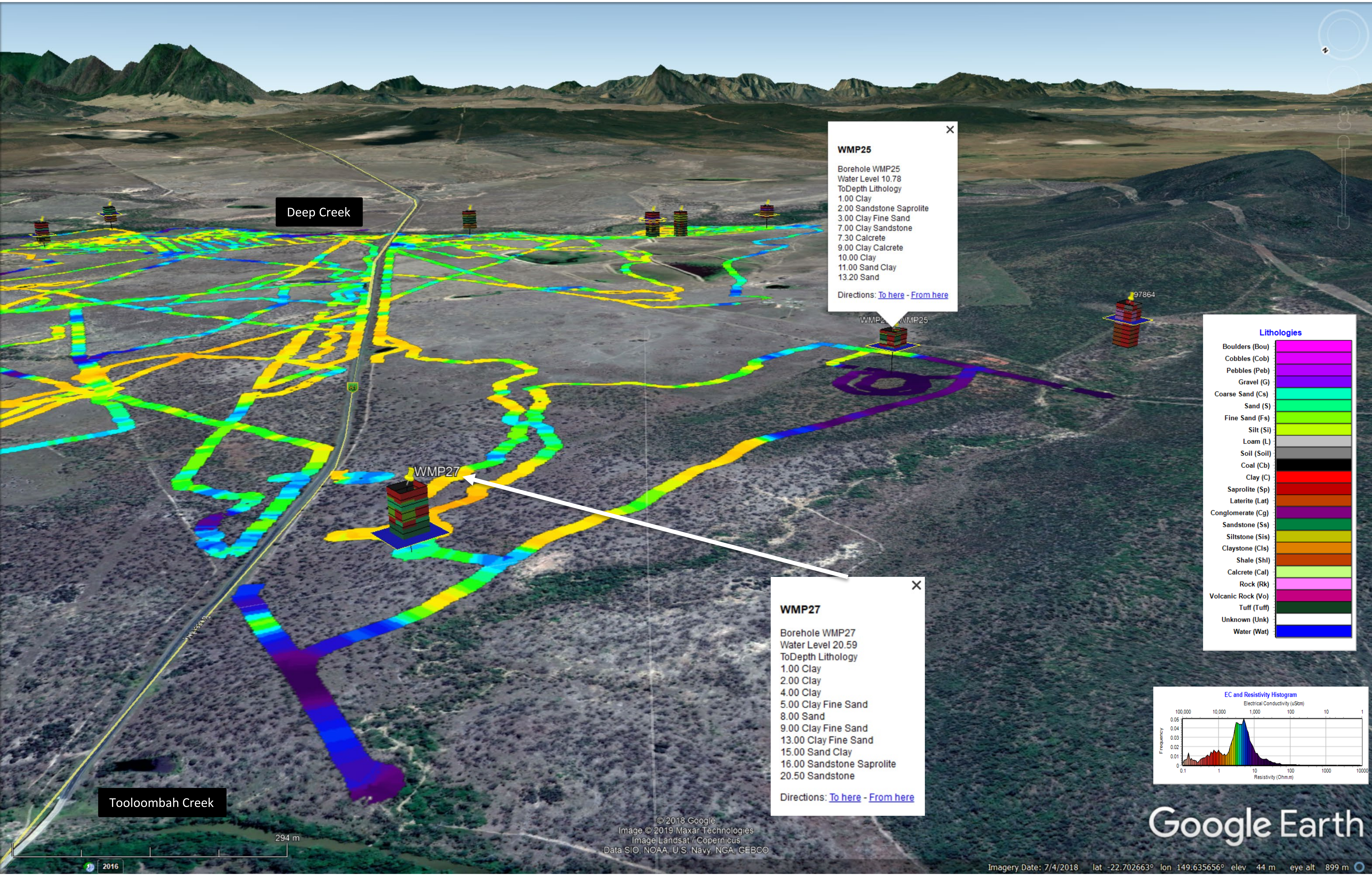
Driller’s Logs projected up 30m





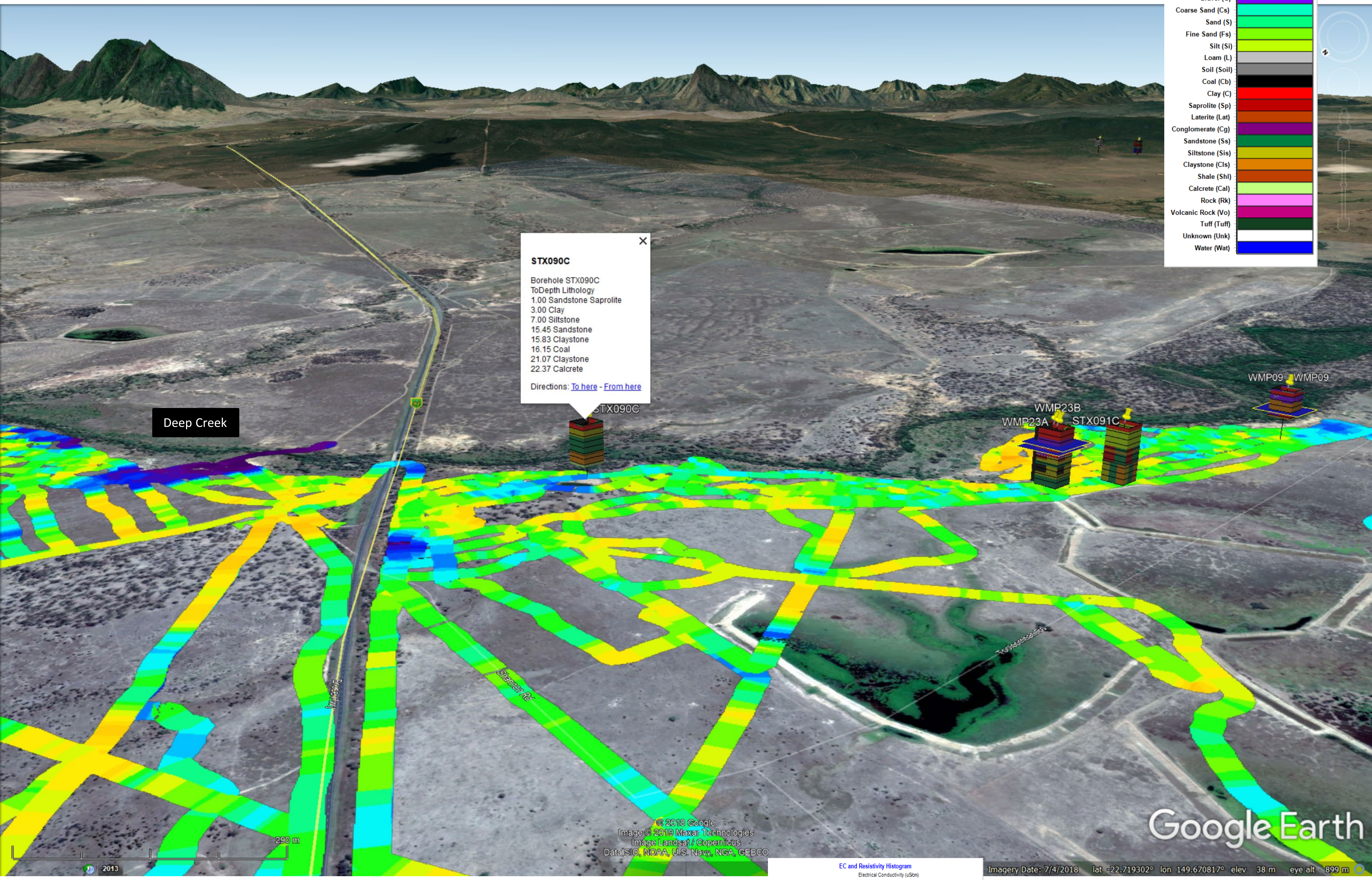
Modelled Resistivity @ 12m deep

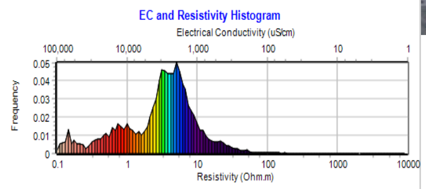
Driller's Logs projected up 30m



Modelled Resistivity @ 12m deep

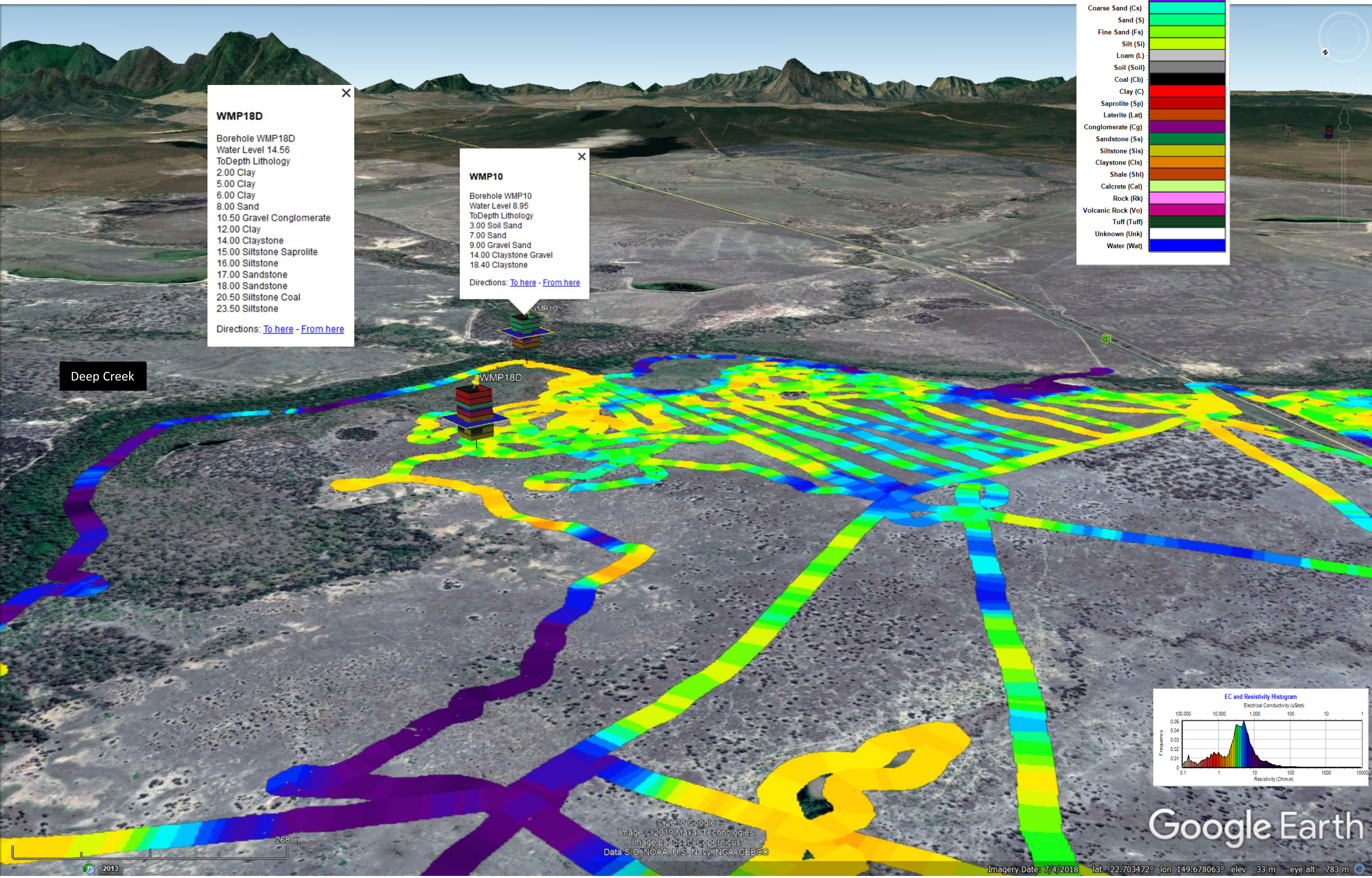
Driller's Logs projected up 30m





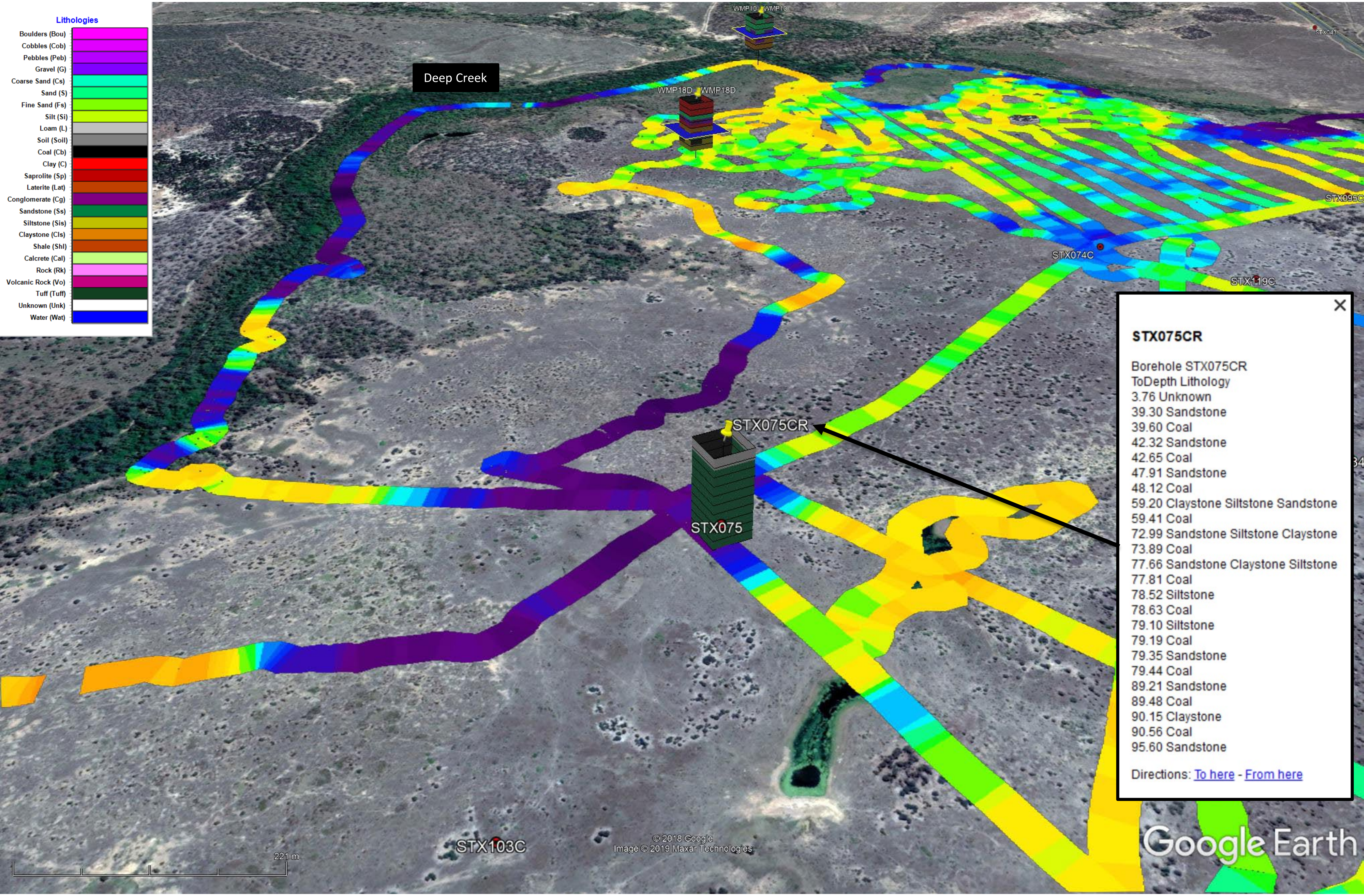
Modelled Resistivity @ 12m deep

Driller's Logs projected up 30m



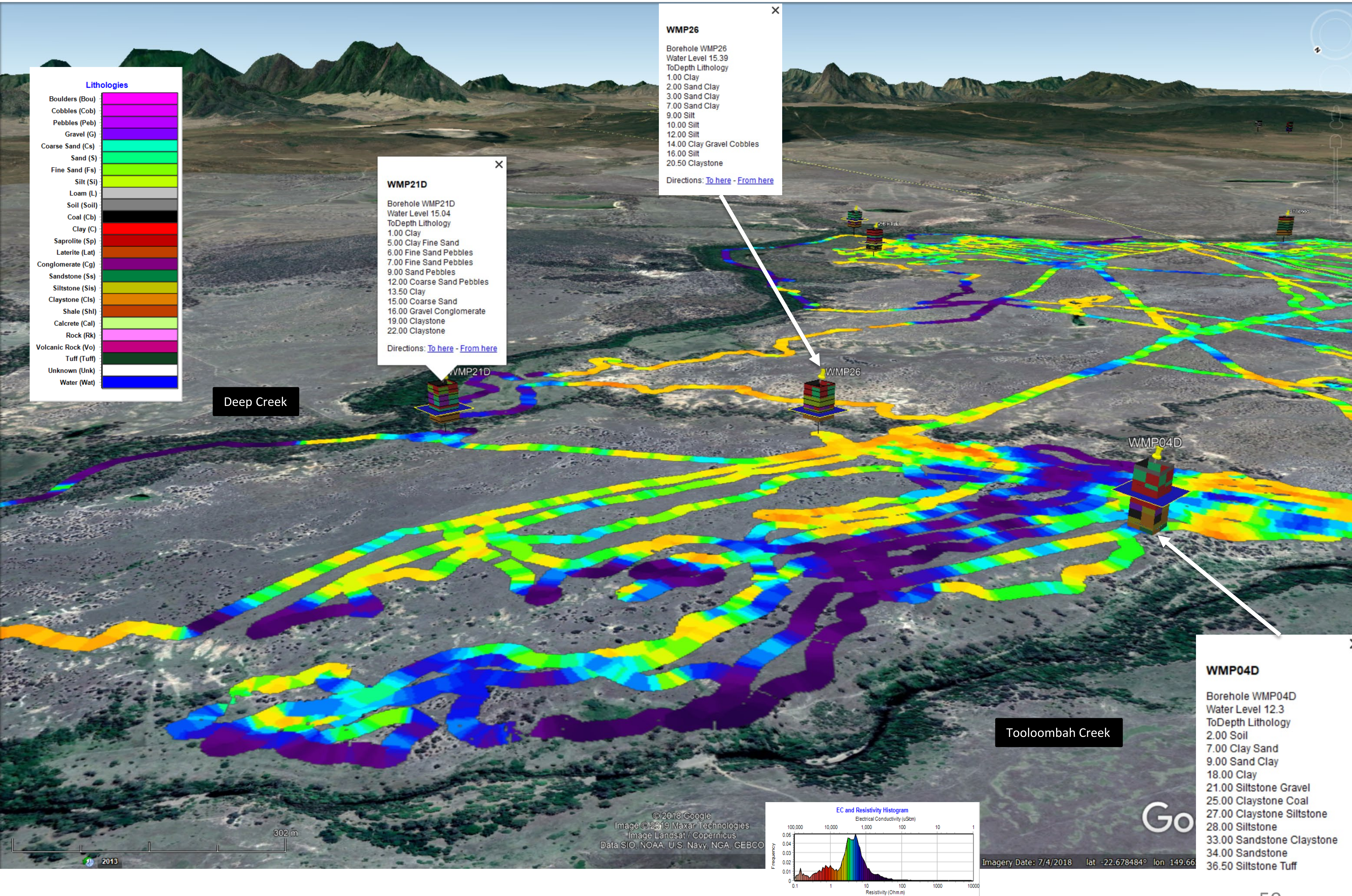
Modelled Resistivity @ 12m deep

Driller's Logs projected up 30m



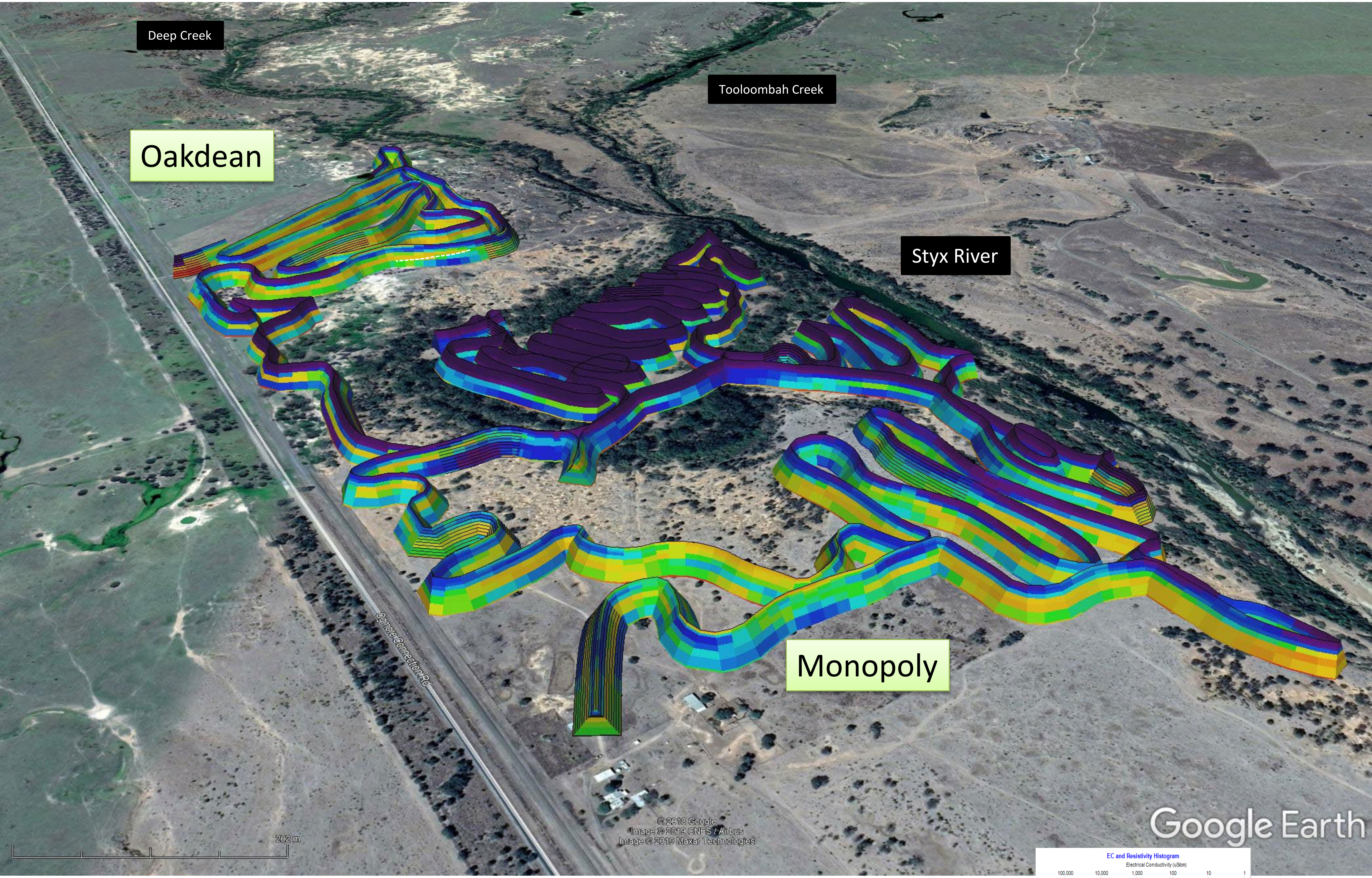
Modelled Resistivity @ 12m deep

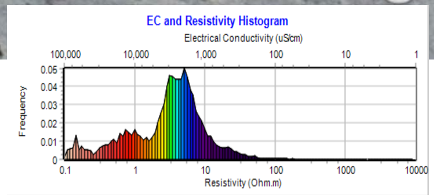
Driller's Logs projected up 30m



Modelled Resistivity projected up 30m

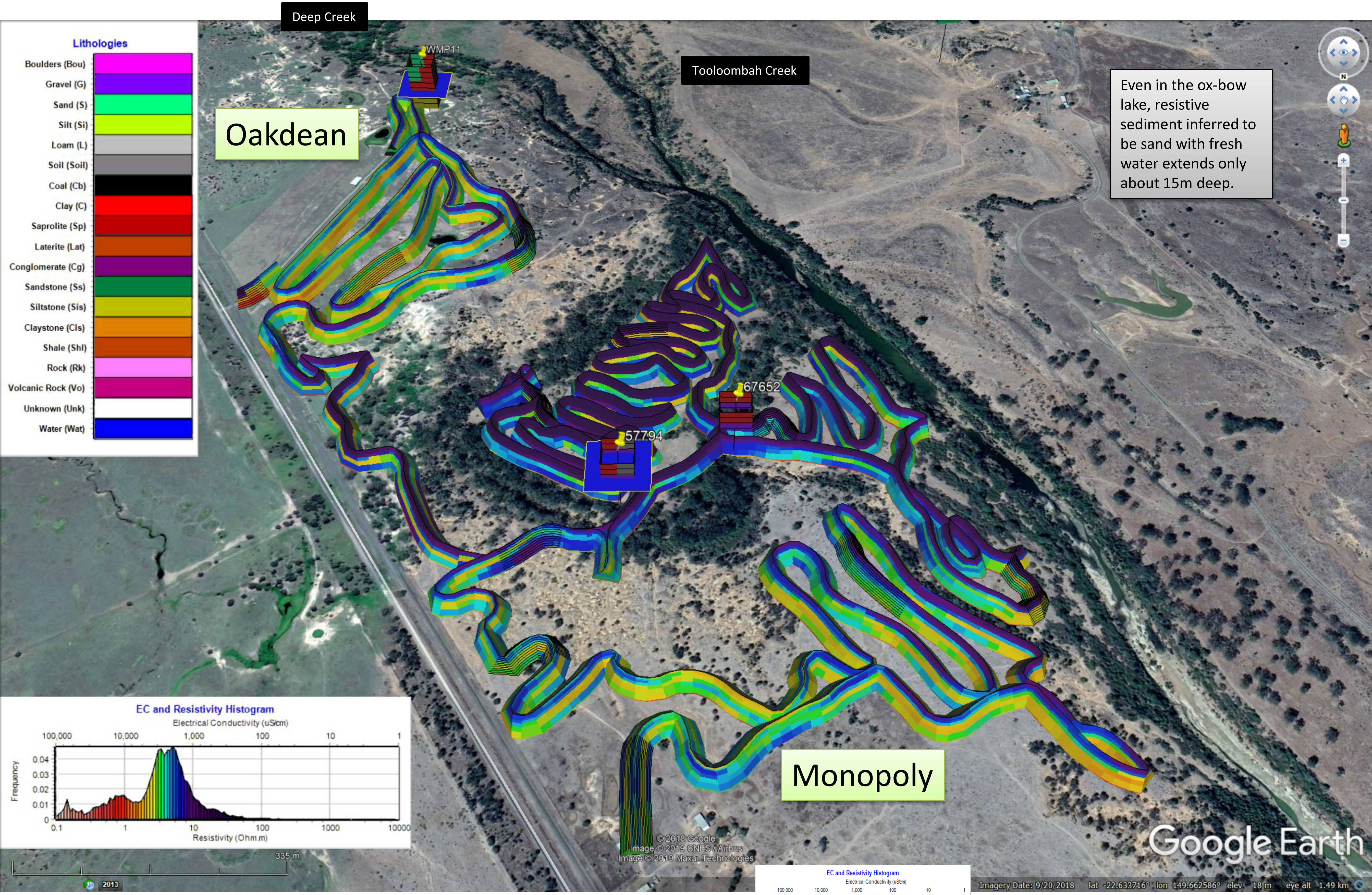
Looking south – Data segment 1 of 7

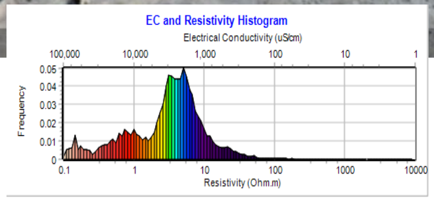




Modelled Resistivity projected up 30m

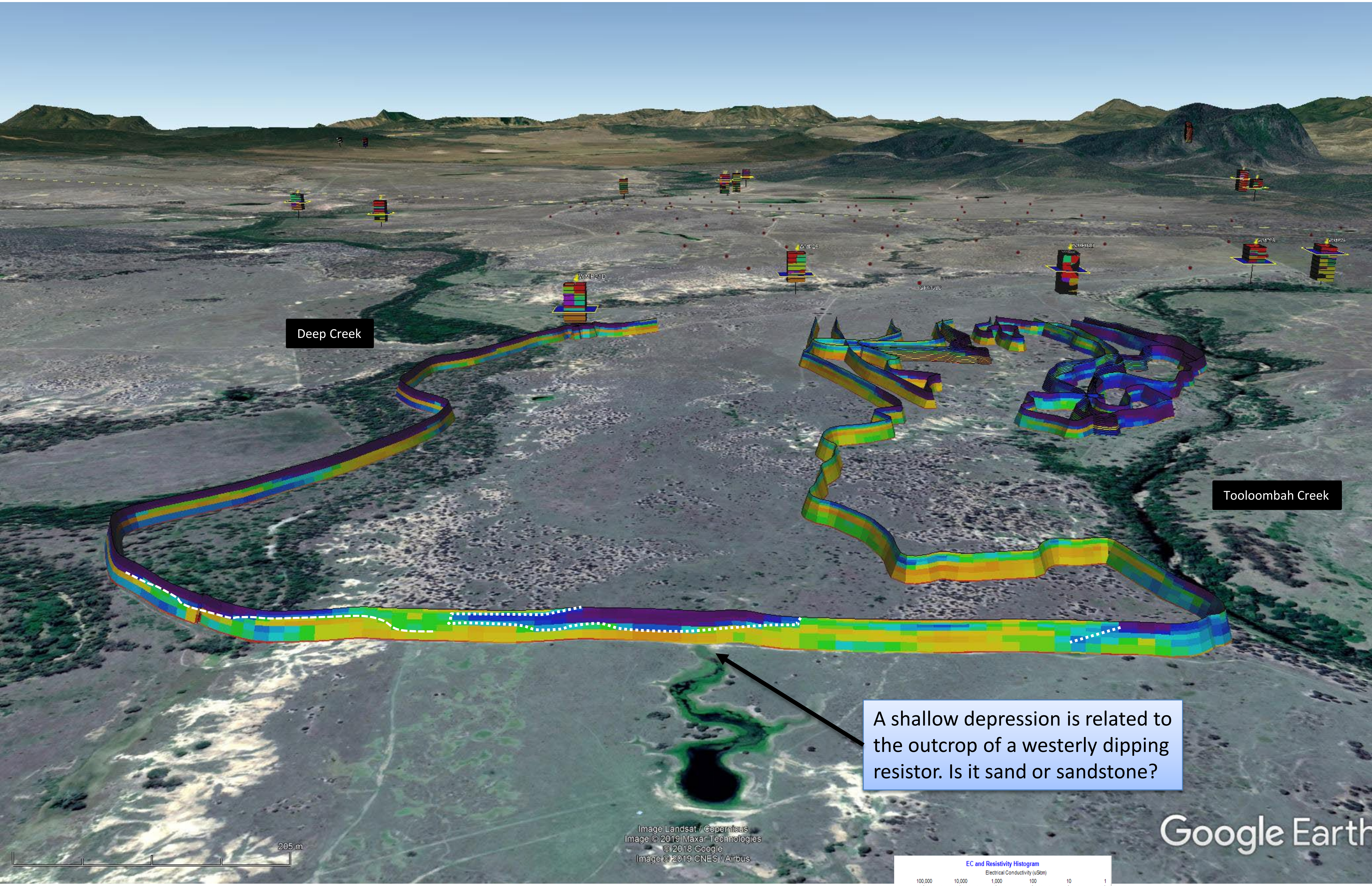
Looking south

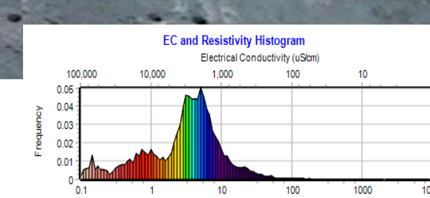




Modelled Resistivity projected up 30m

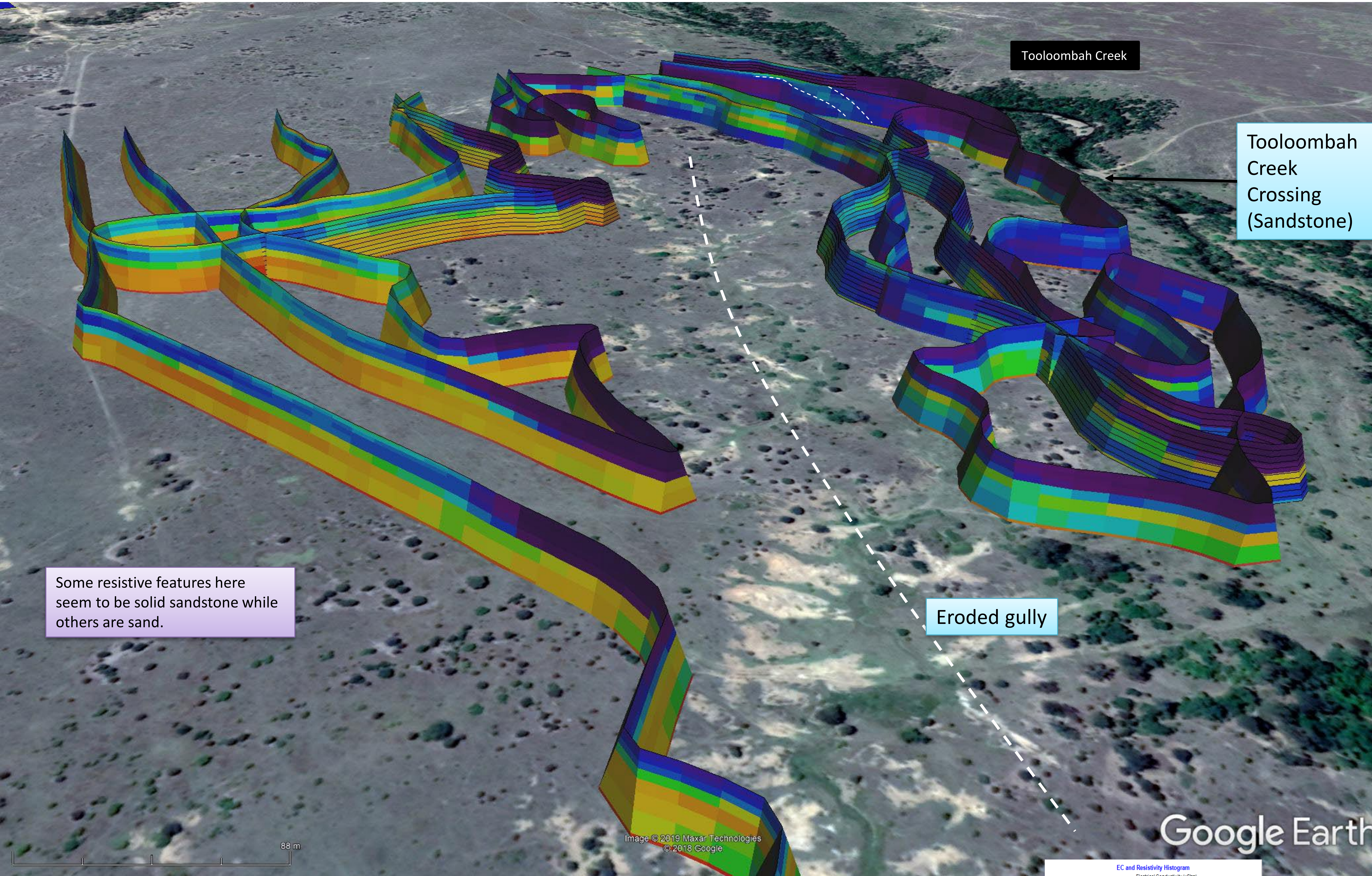
Mamelon North - Looking South – Data segment 2/7

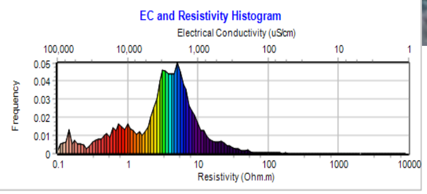




Modelled Resistivity projected up 30m

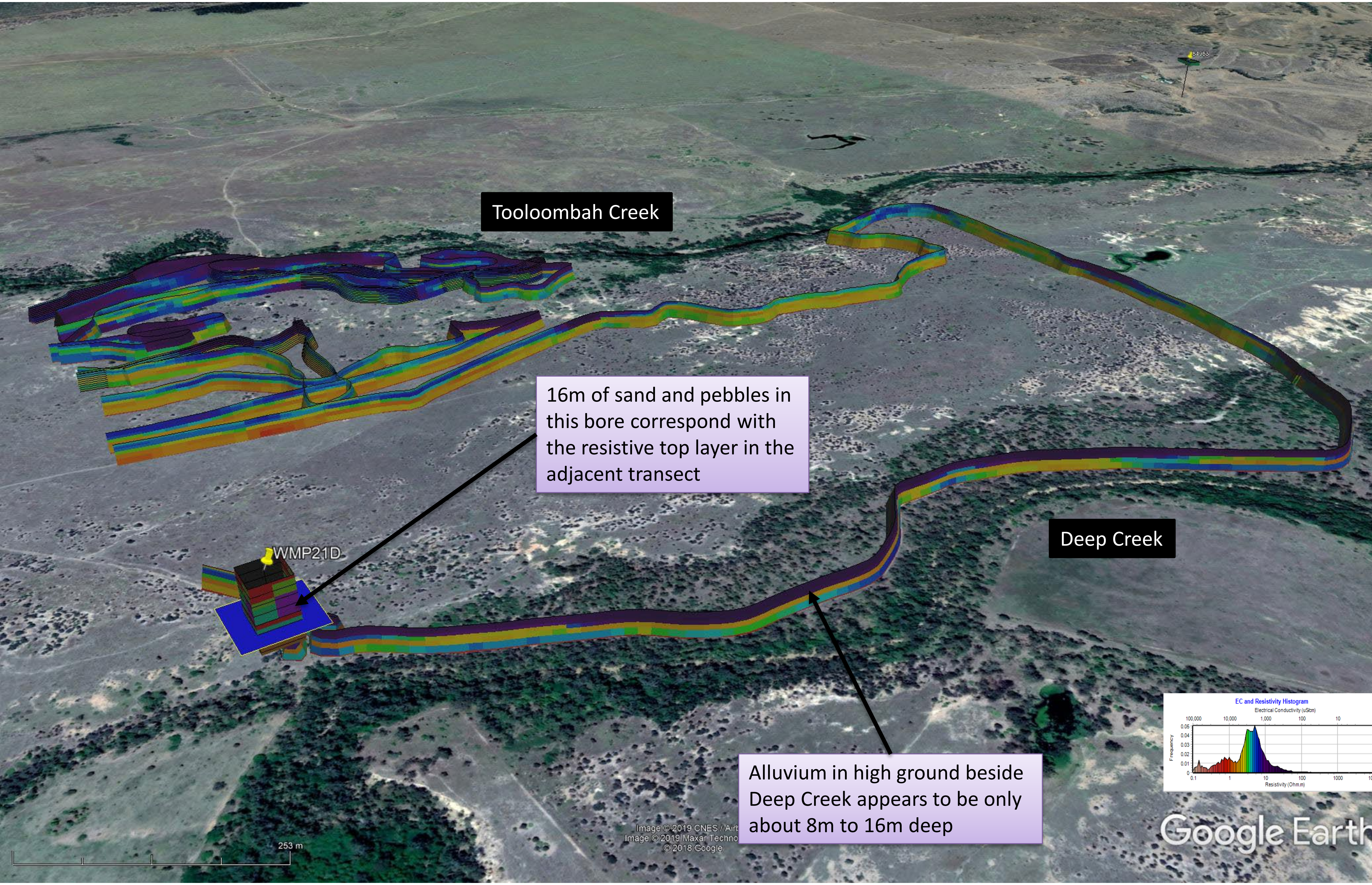
Tooloombah Creek – Mamelon North - Looking South





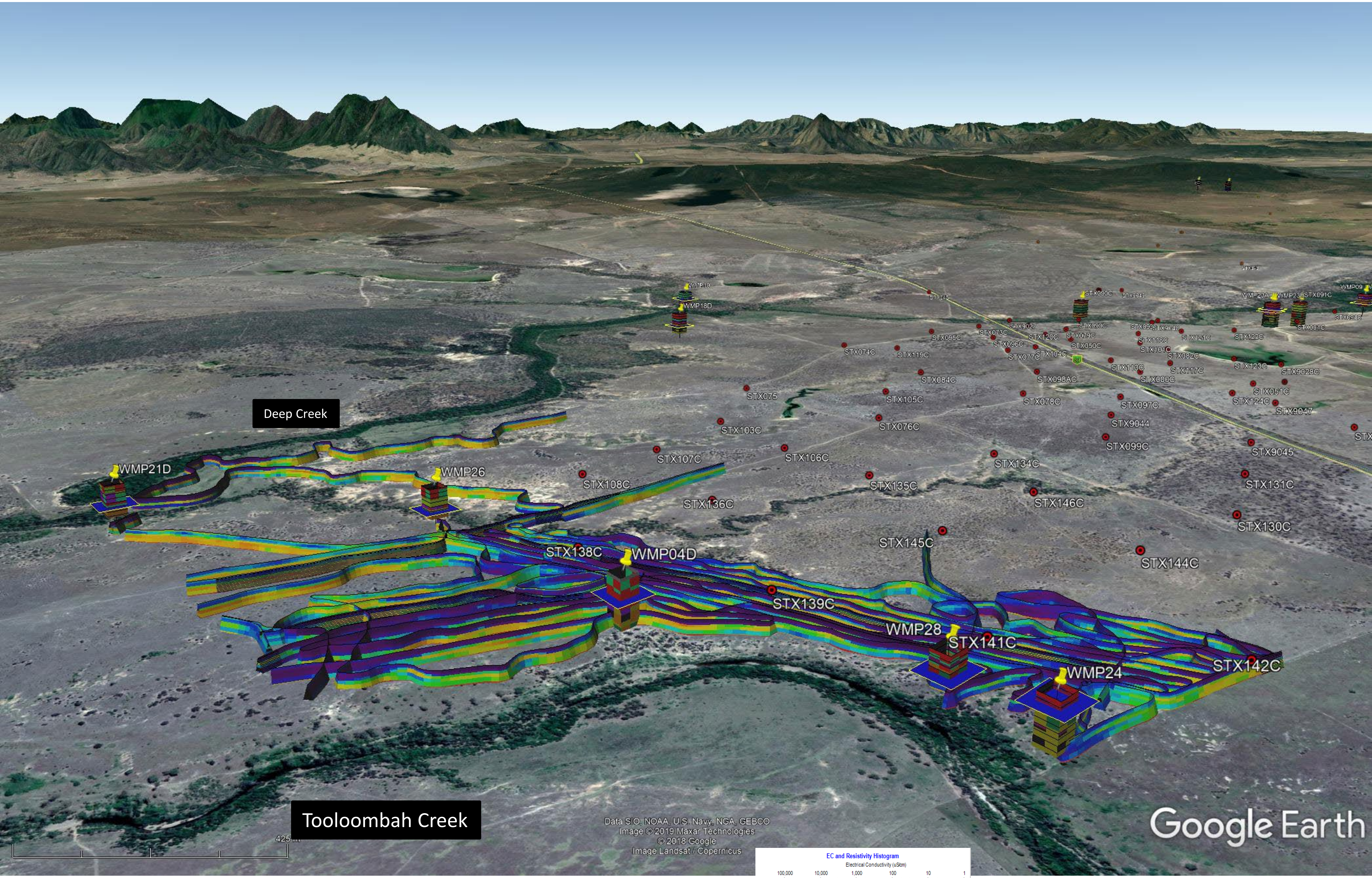
Modelled Resistivity projected up 30m

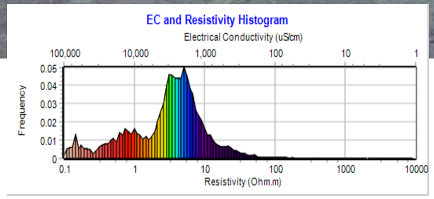
Mamelon North – Looking West



Modelled Resistivity projected up 30m

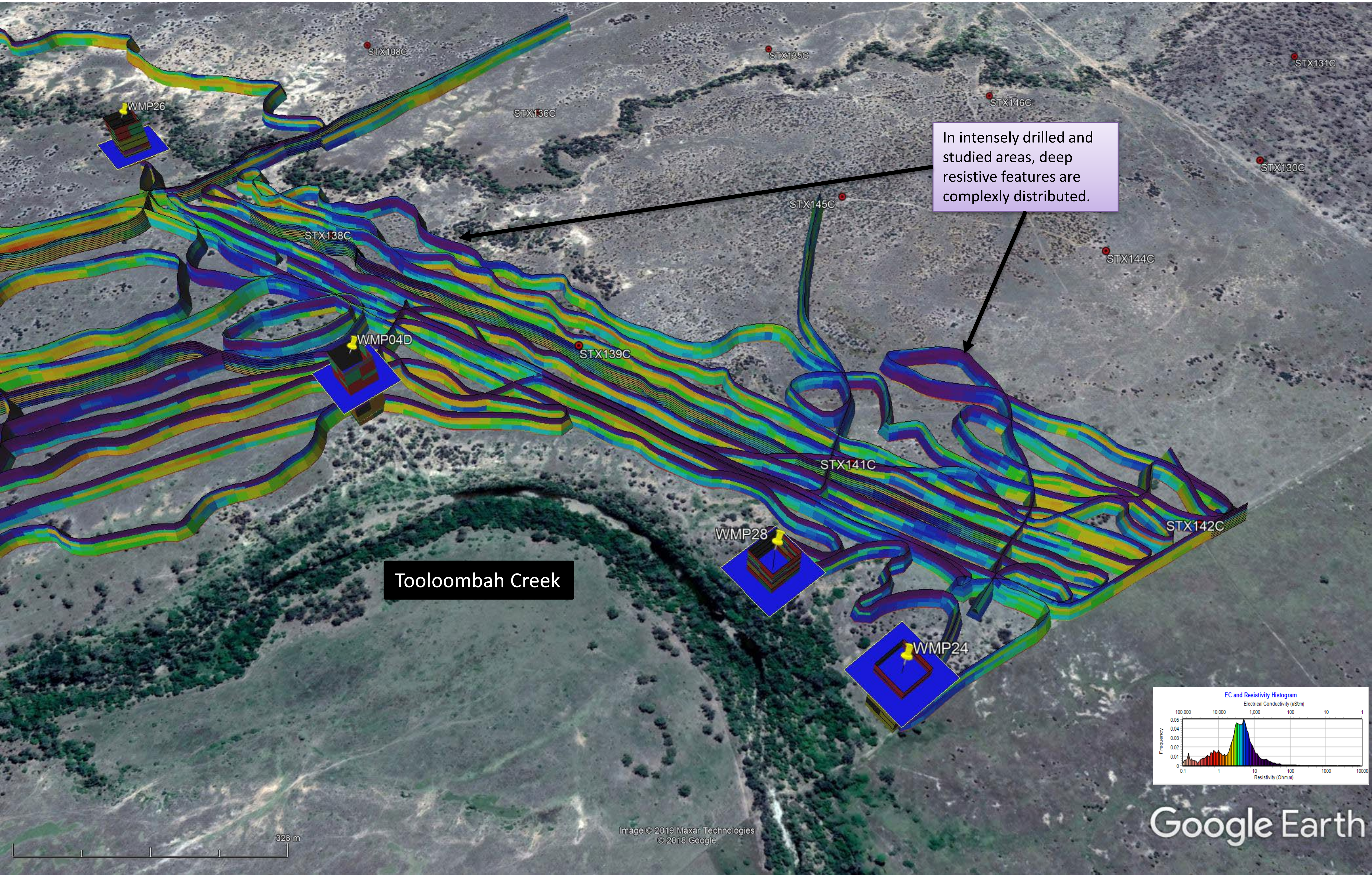
Mamelon – looking SE – Data segment 3 of 7





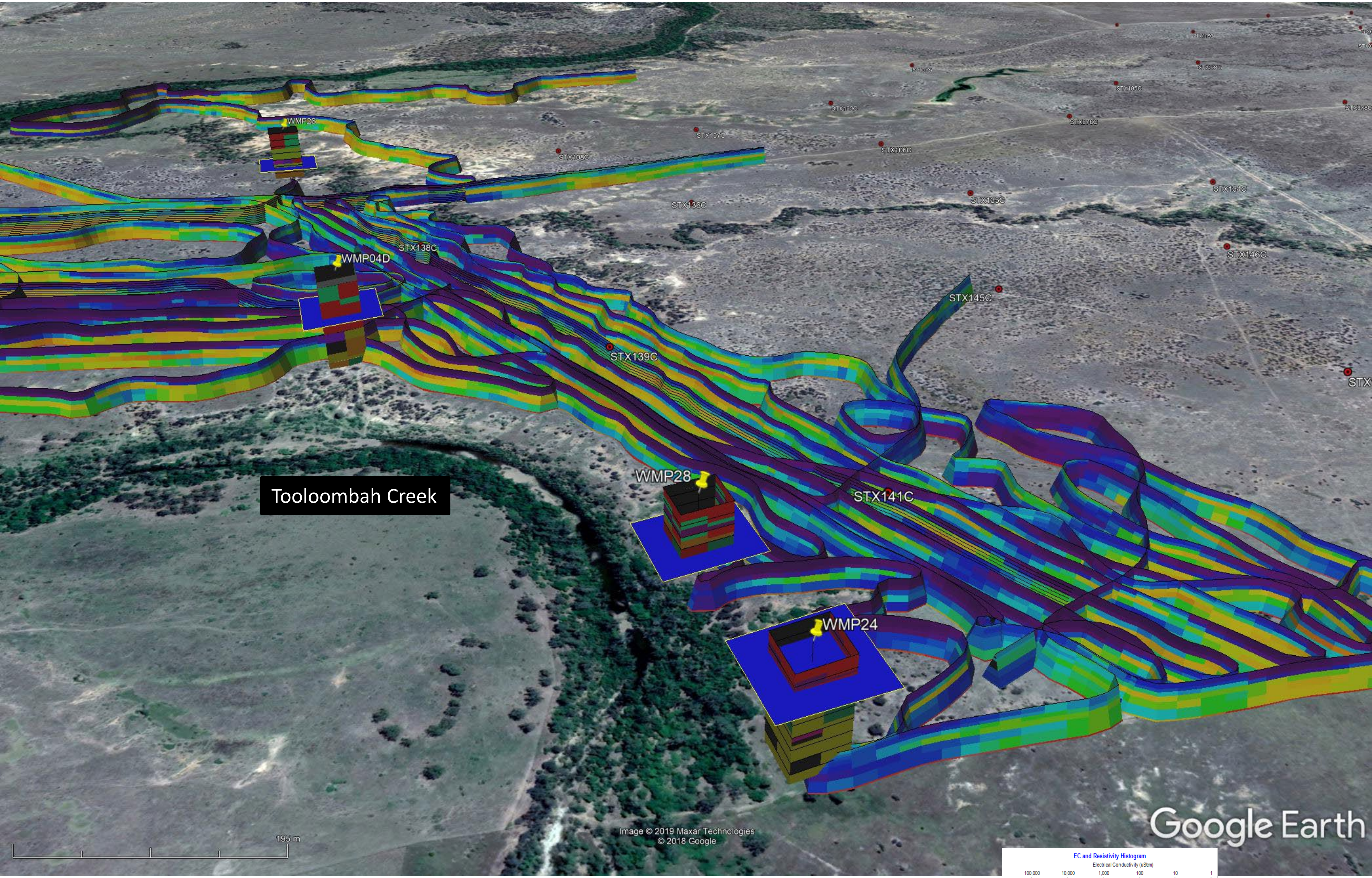
Modelled Resistivity projected up 30m

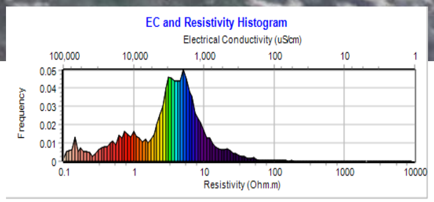
Mamelon – looking SE – Data segment 3 of 7



Modelled Resistivity projected up 30m

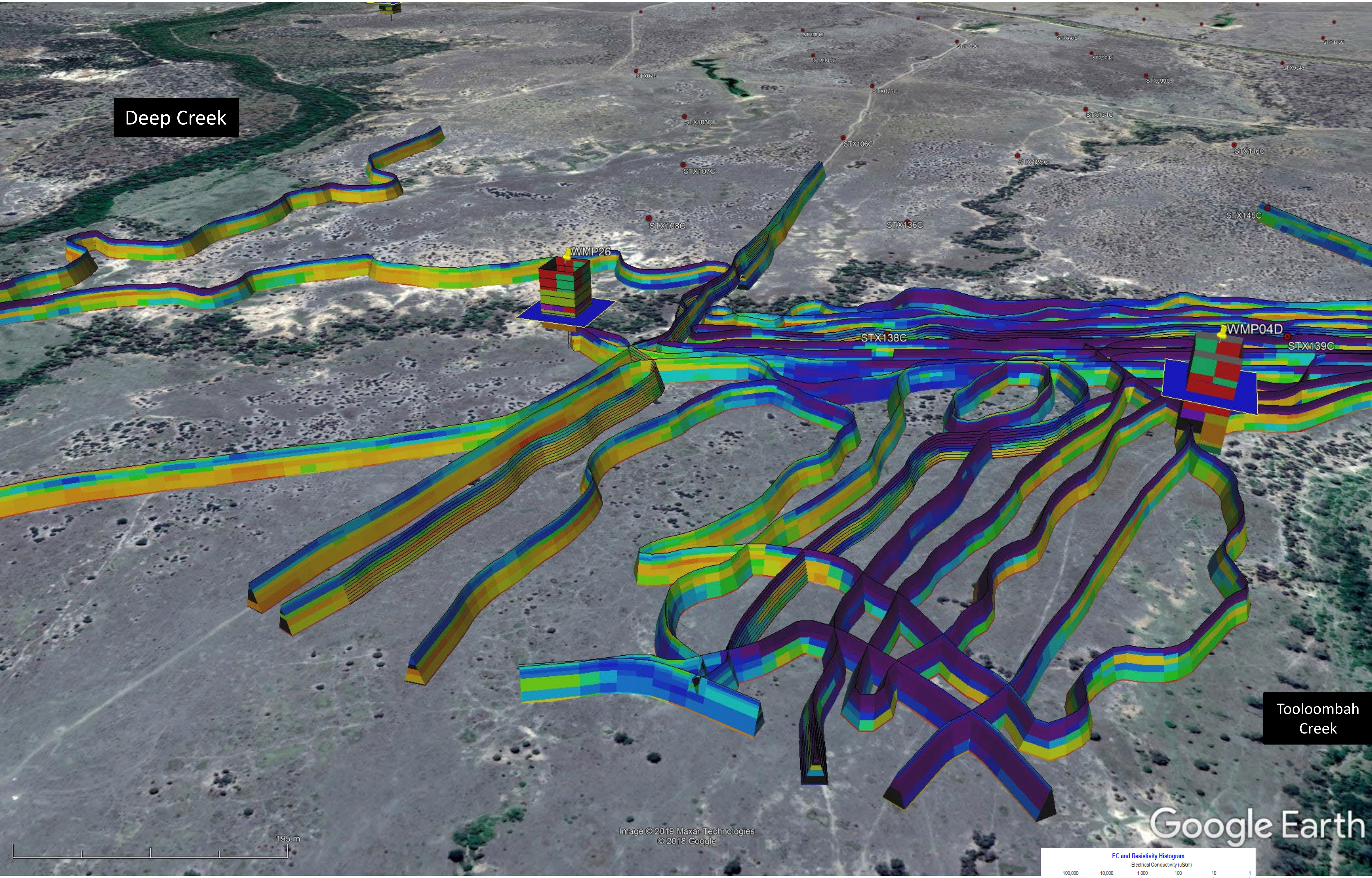
Mamelon – looking SE – Data segment 3 of 7

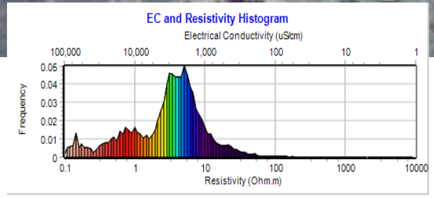




Modelled Resistivity projected up 30m

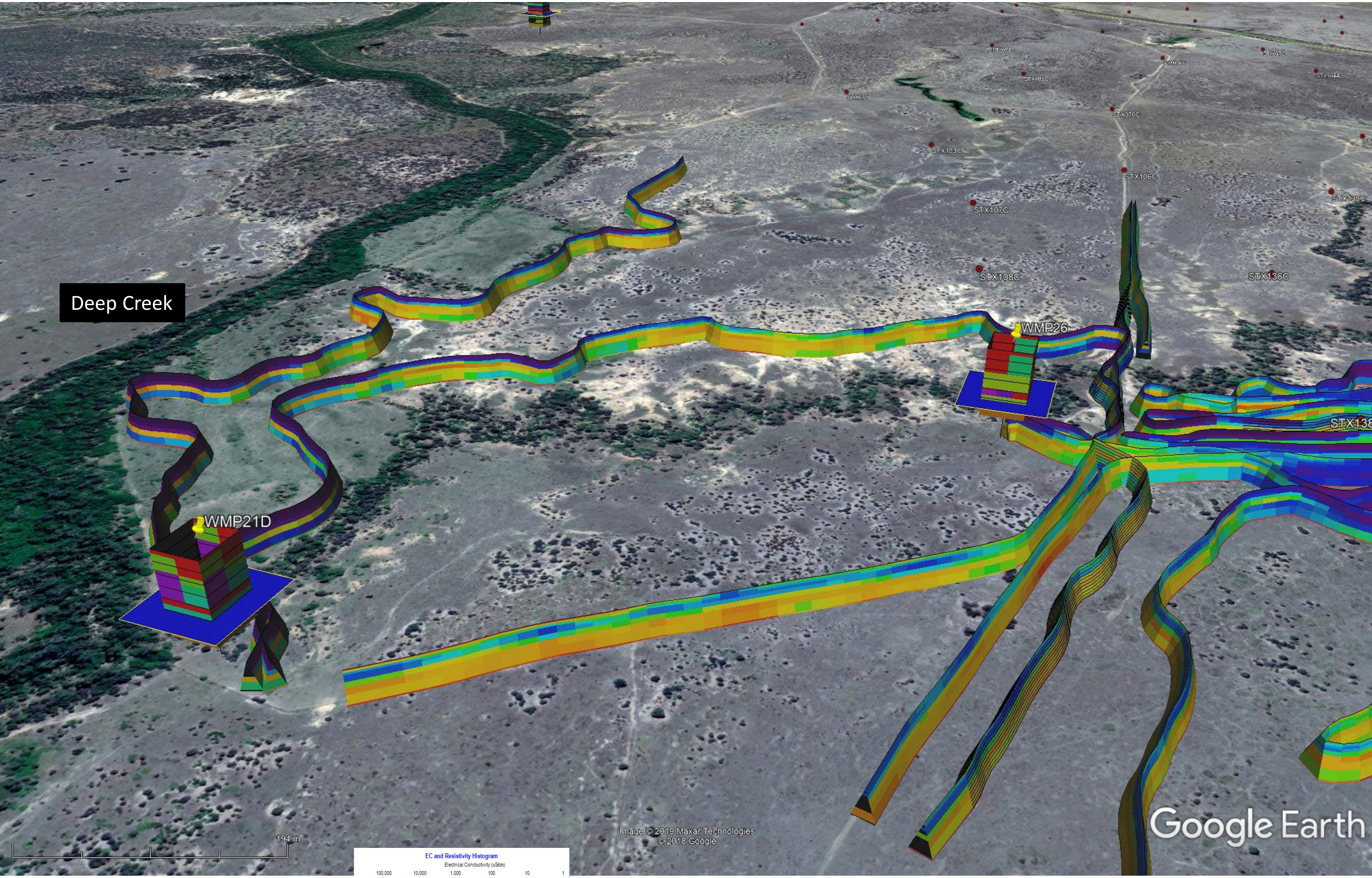
Mamelon – looking South – Data segment 3 of 7

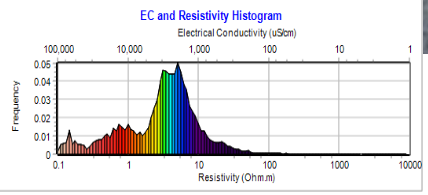




Modelled Resistivity projected up 30m

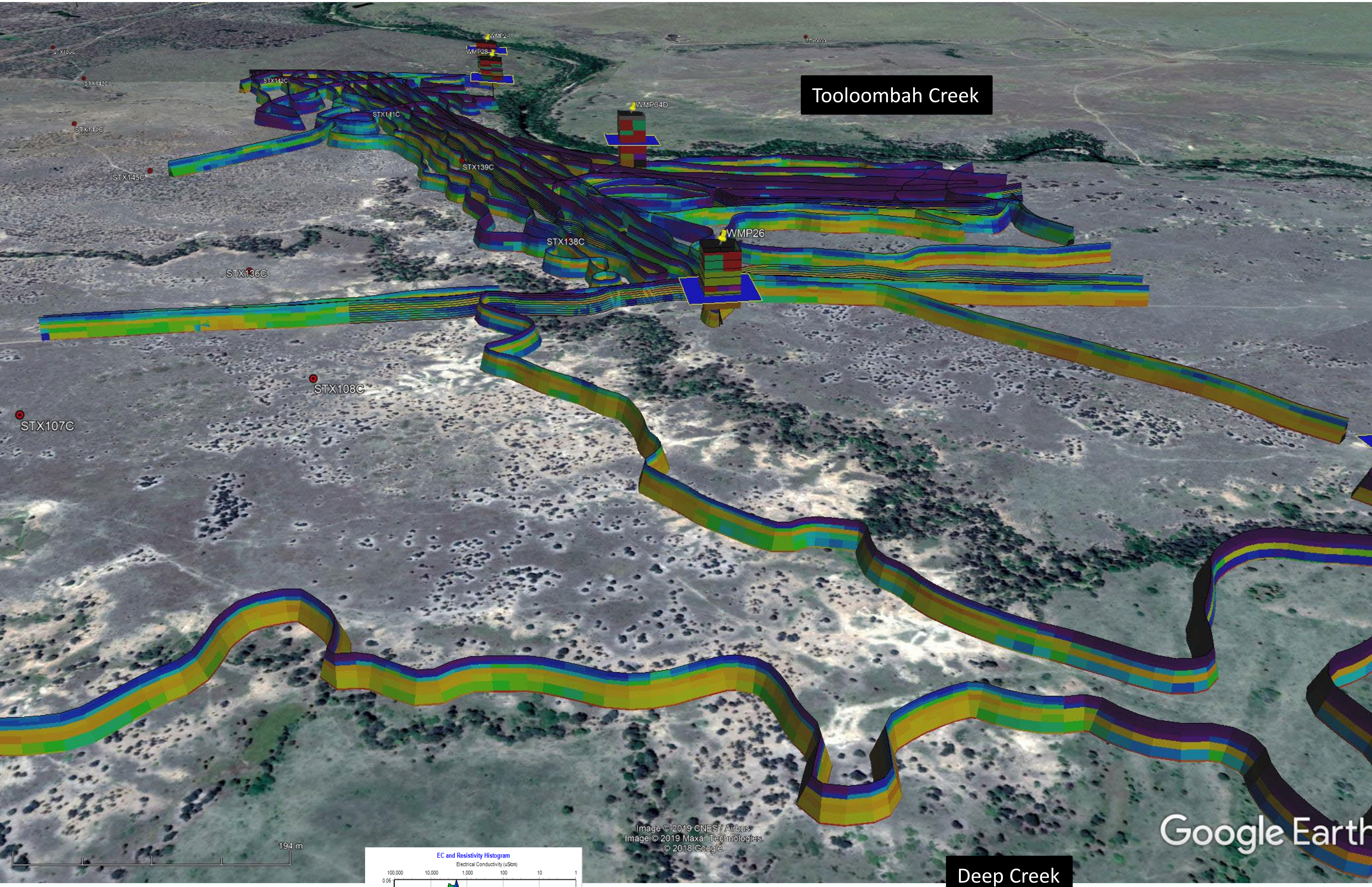
Mamelon – looking South – Data segment 3 of 7

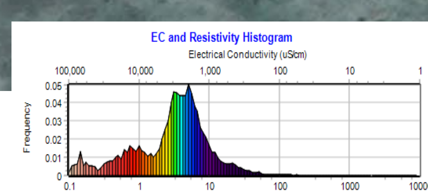




Modelled Resistivity projected up 30m

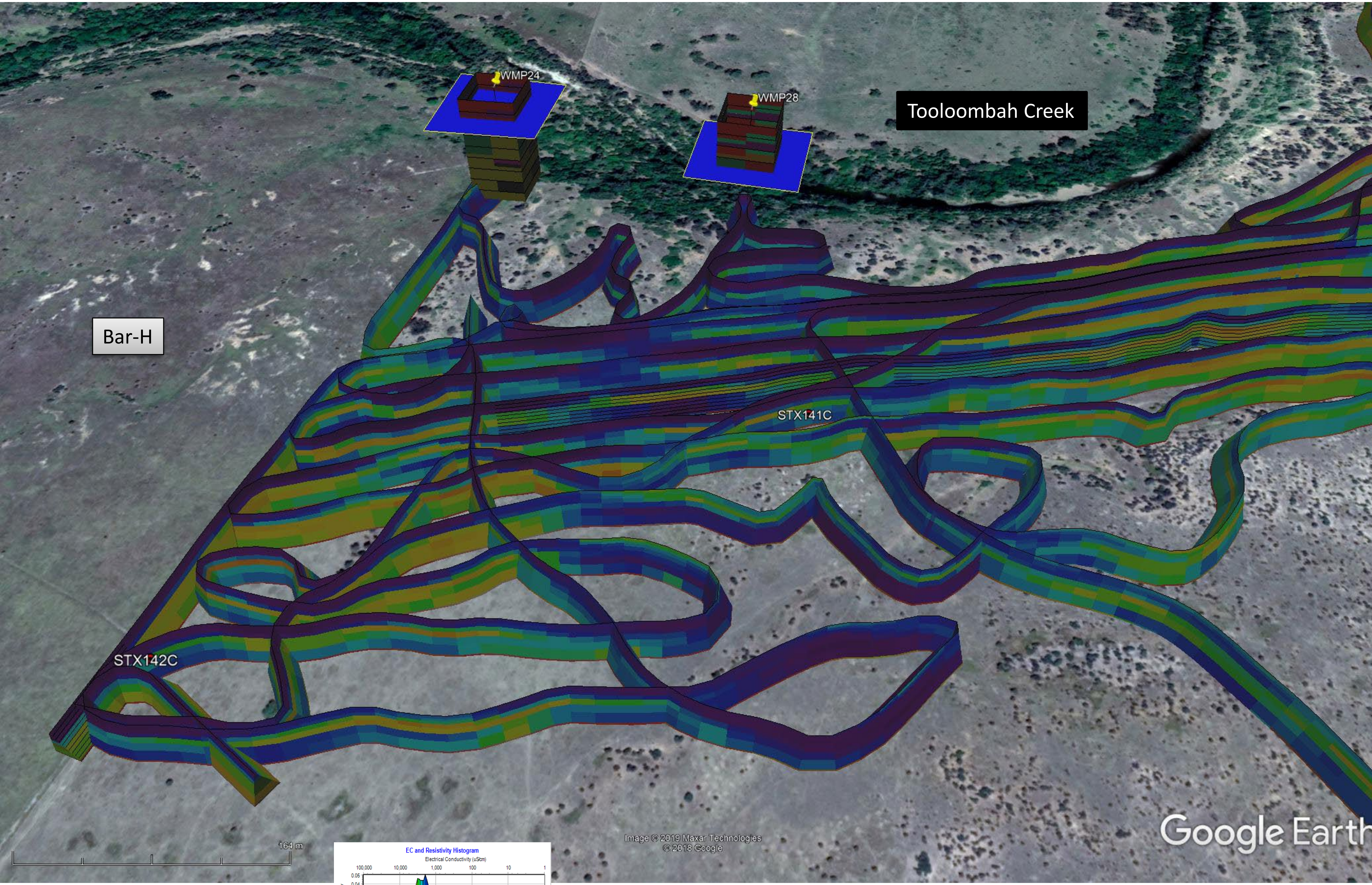
Mamelon – looking West – Data segment 3 of 7

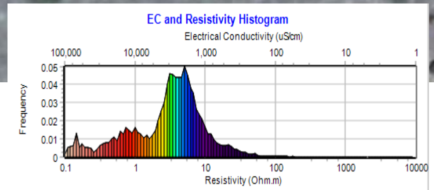




Modelled Resistivity projected up 30m

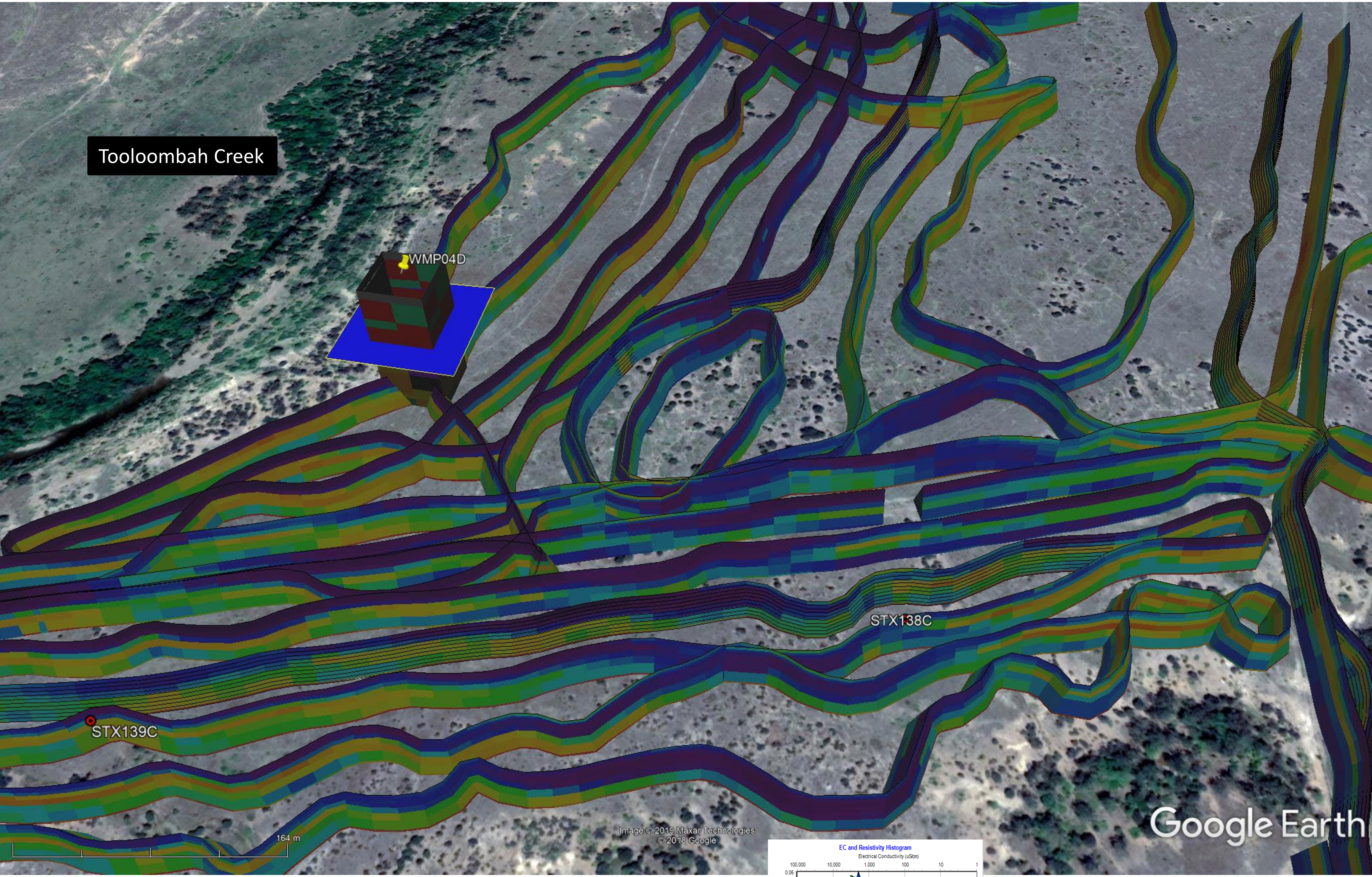
Mamelon – looking North – Data segment 3 of 7

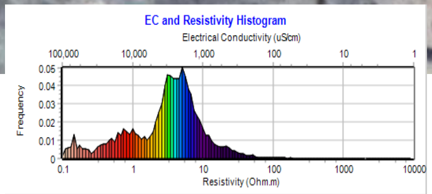




Modelled Resistivity projected up 30m

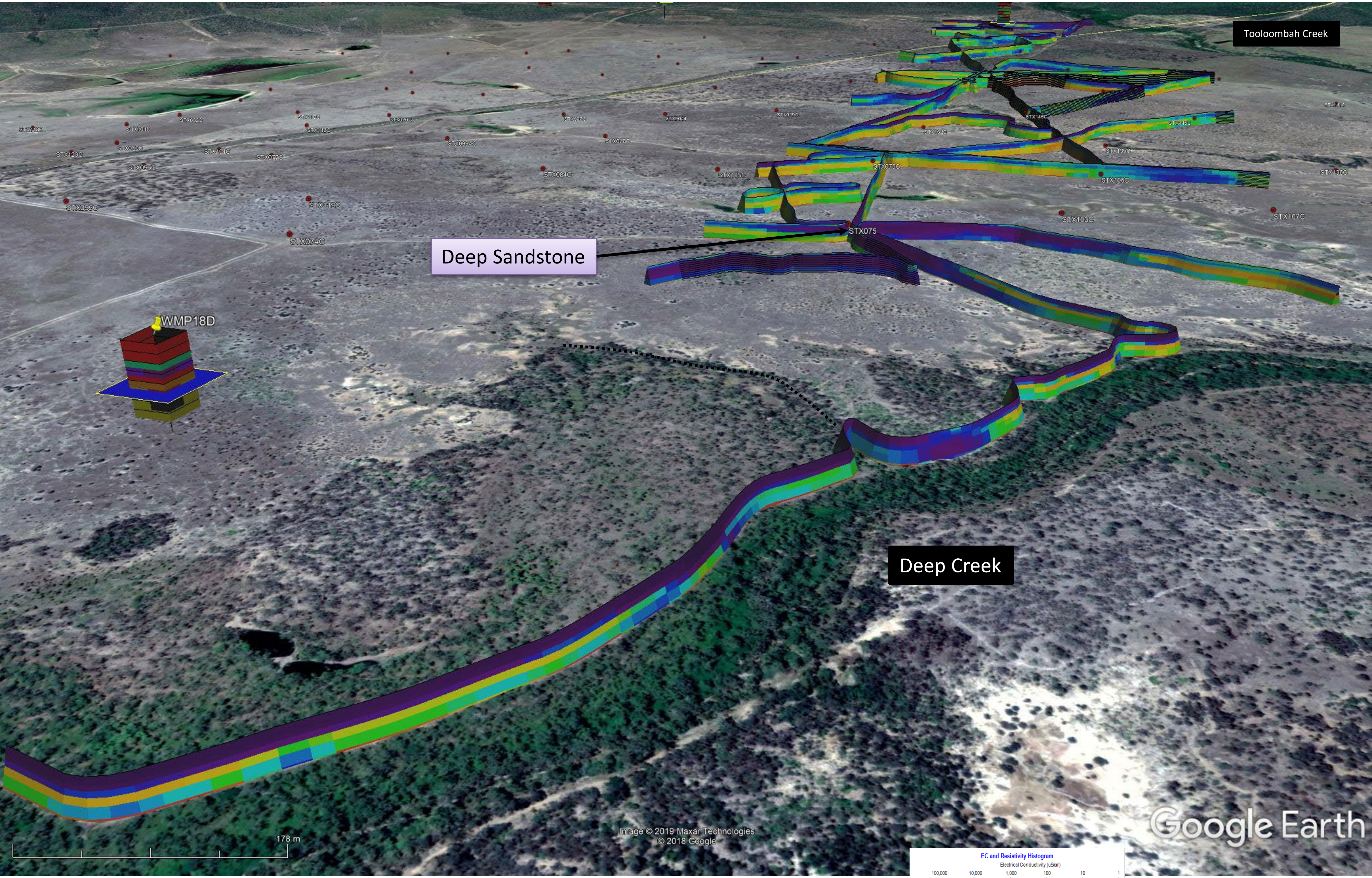
Mamelon – looking North – Data segment 3 of 7

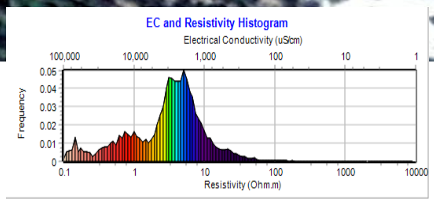




Modelled Resistivity projected up 30m

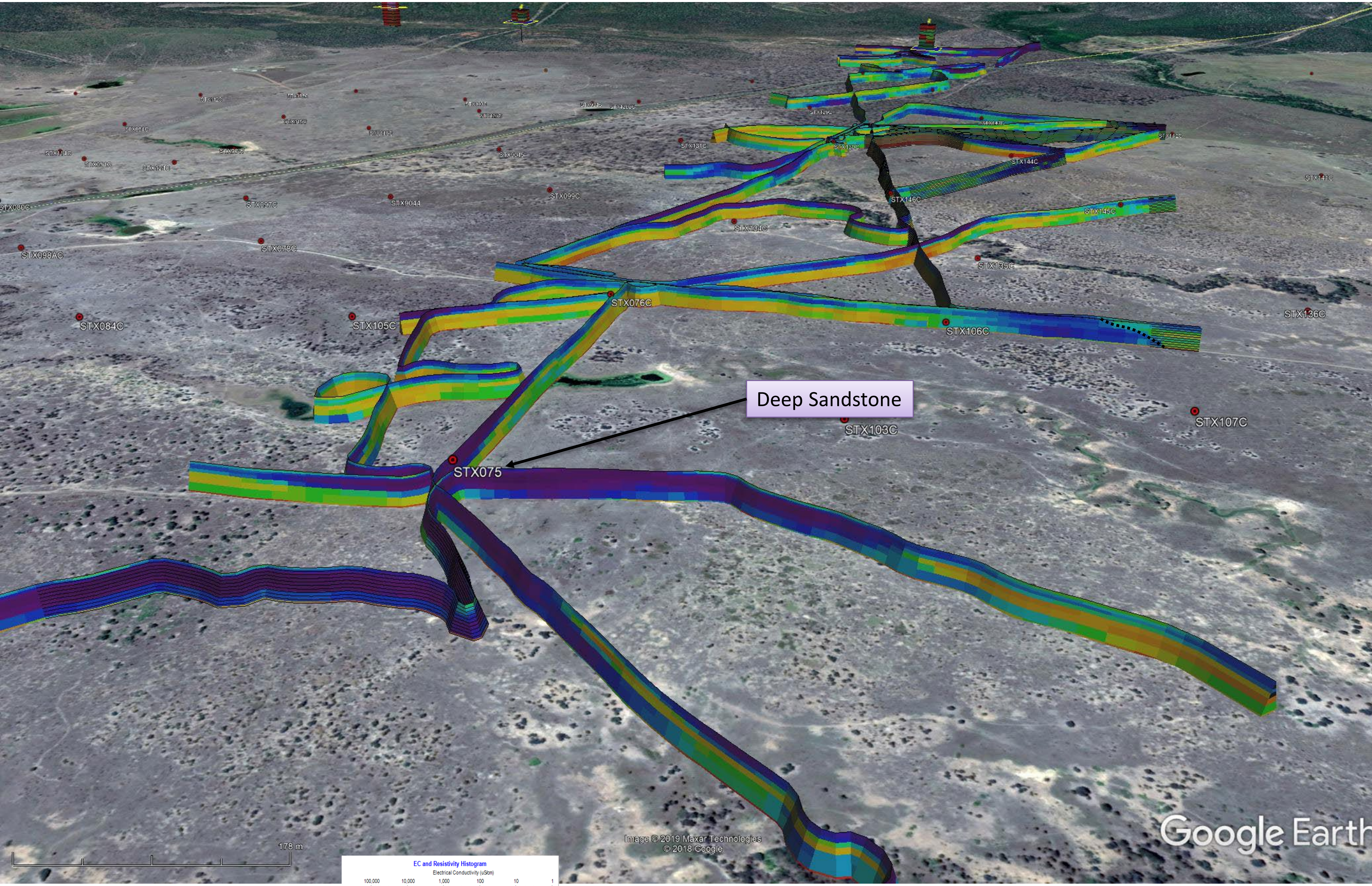
Mamelon – looking West – Data segment 4 of 7

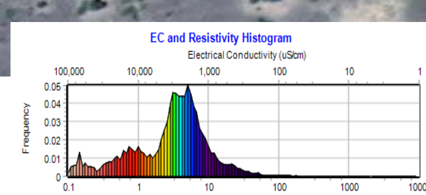




Modelled Resistivity projected up 30m

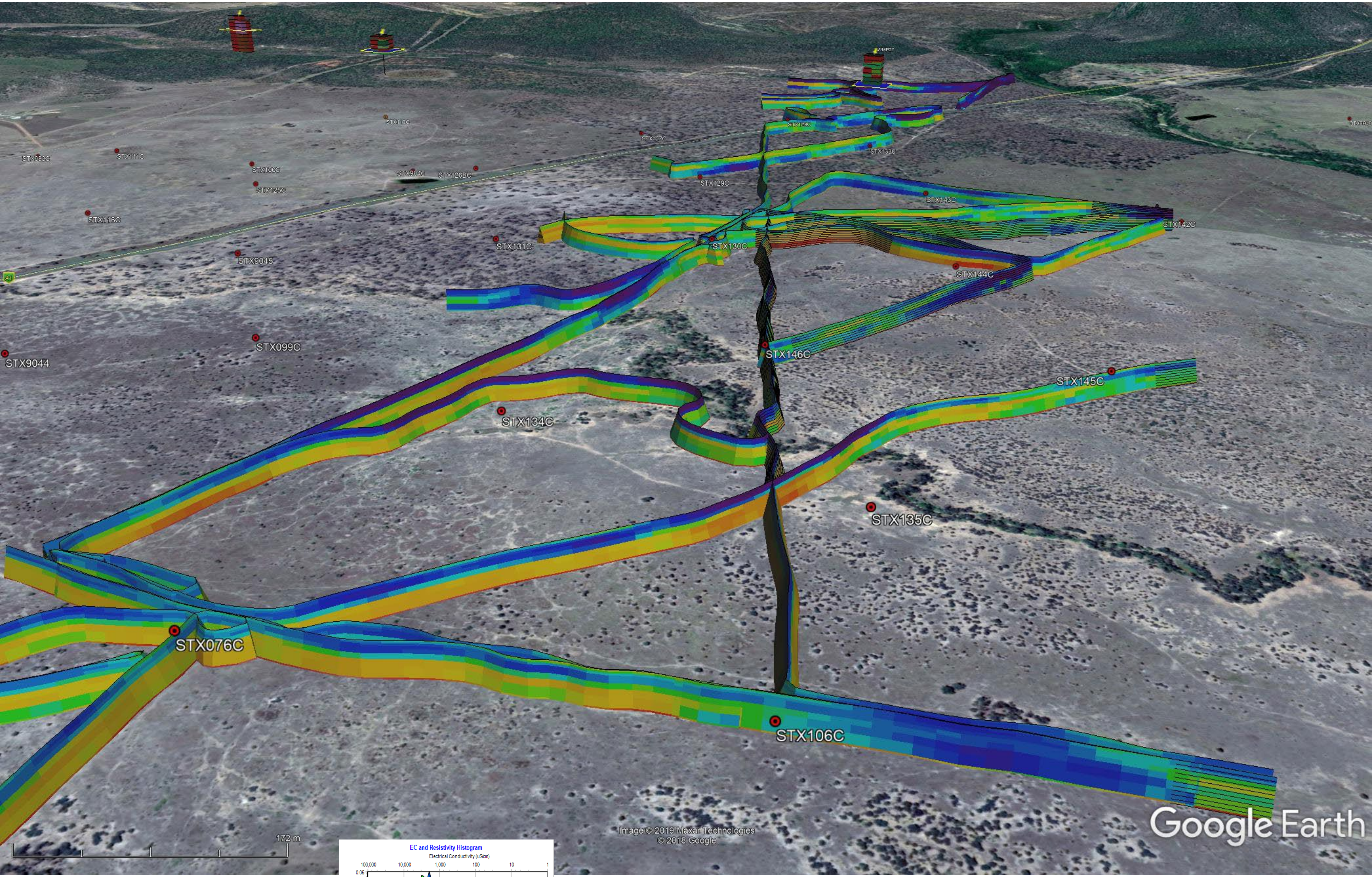
Mamelon – looking West – Data segment 4 of 7

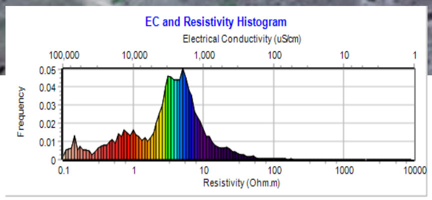




Modelled Resistivity projected up 30m

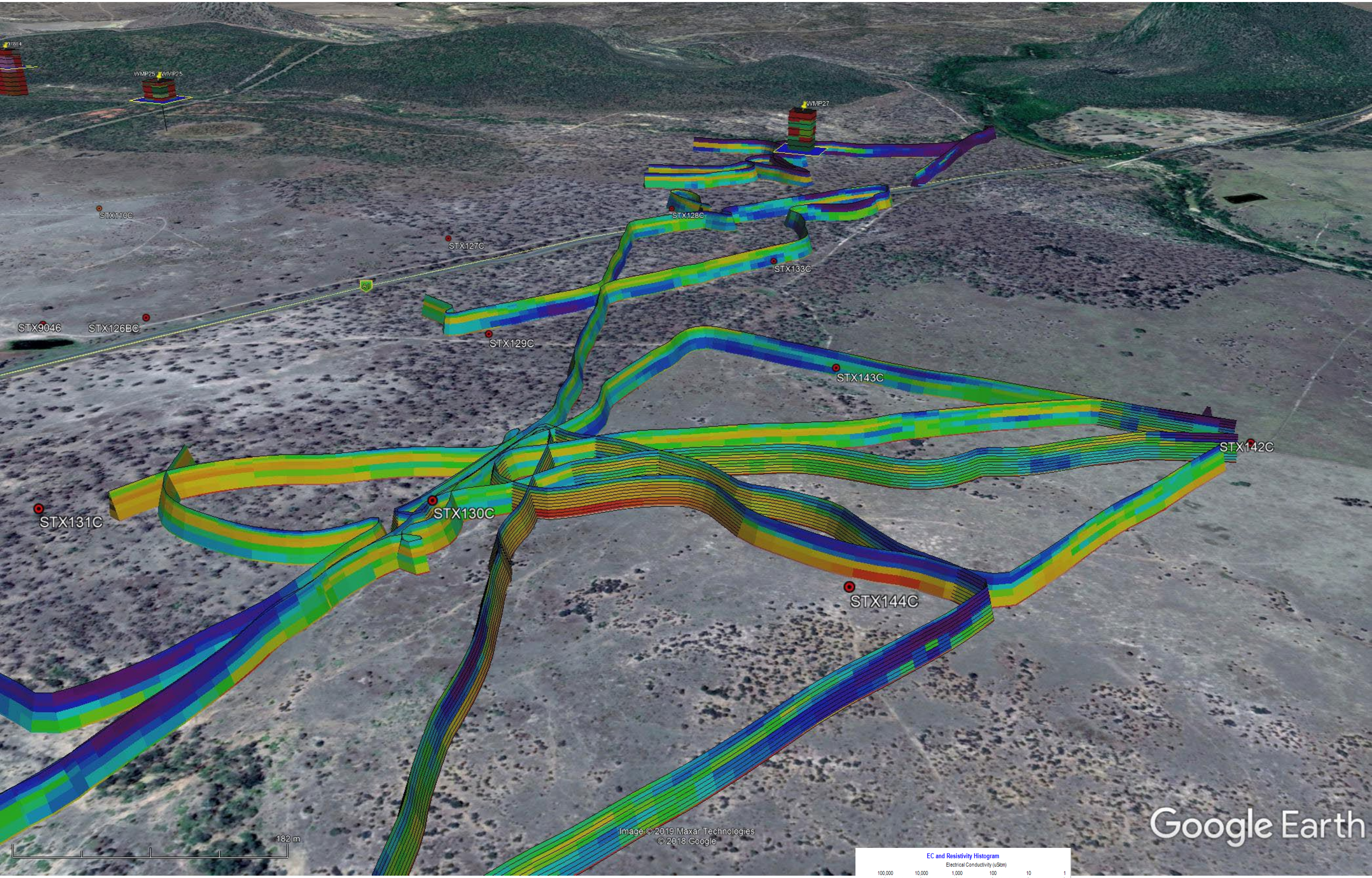
Mamelon – looking West – Data segment 4 of 7

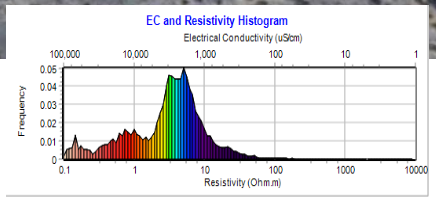




Modelled Resistivity projected up 30m

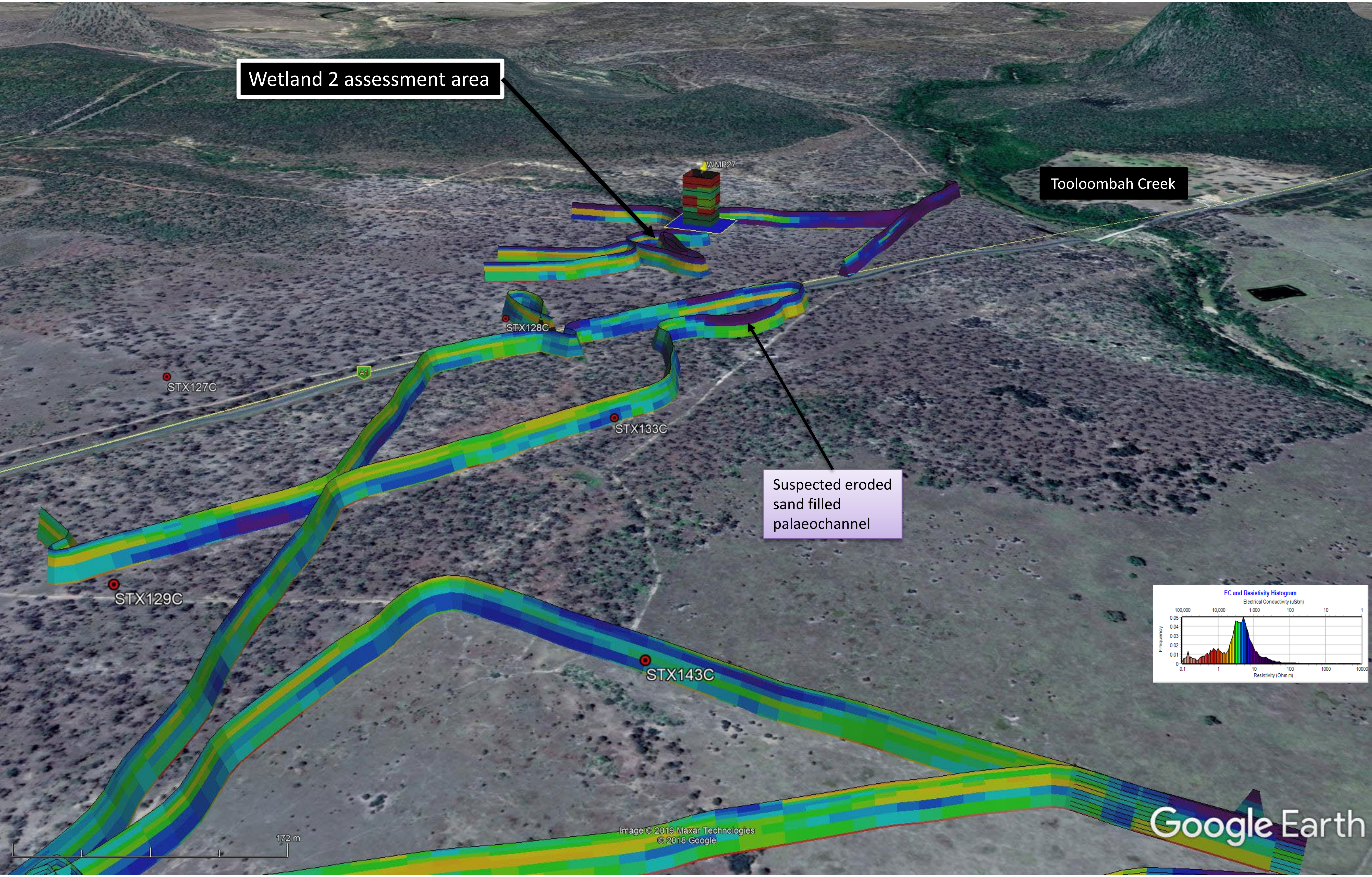
Mamelon – looking West – Data segment 4 of 7





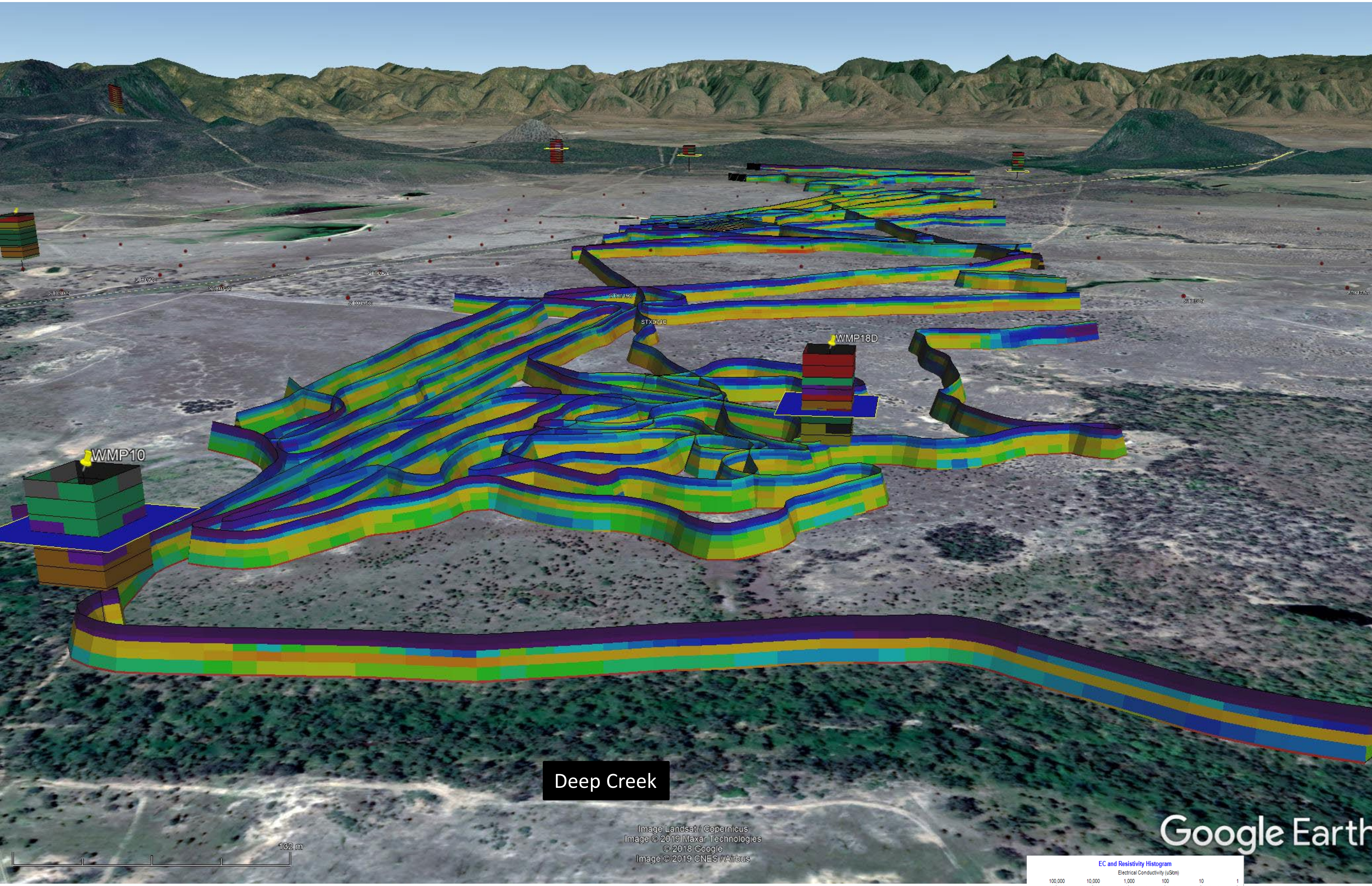
Modelled Resistivity projected up 30m

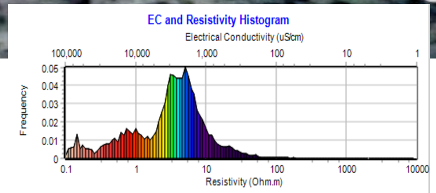
Mamelon – looking West – Data segment 4 of 7



Modelled Resistivity projected up 30m

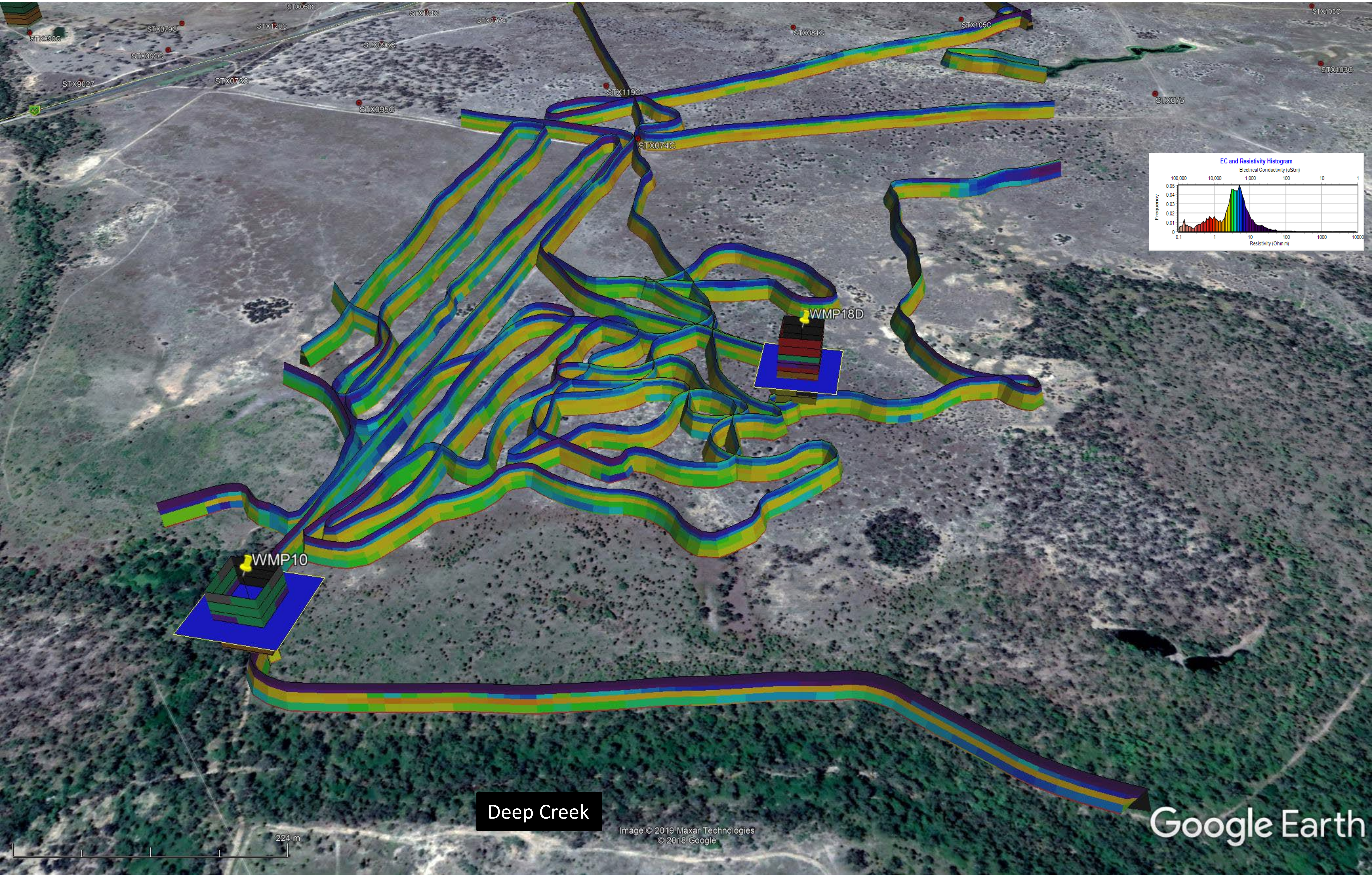
Mamelon – looking West – Data segment 5 of 7





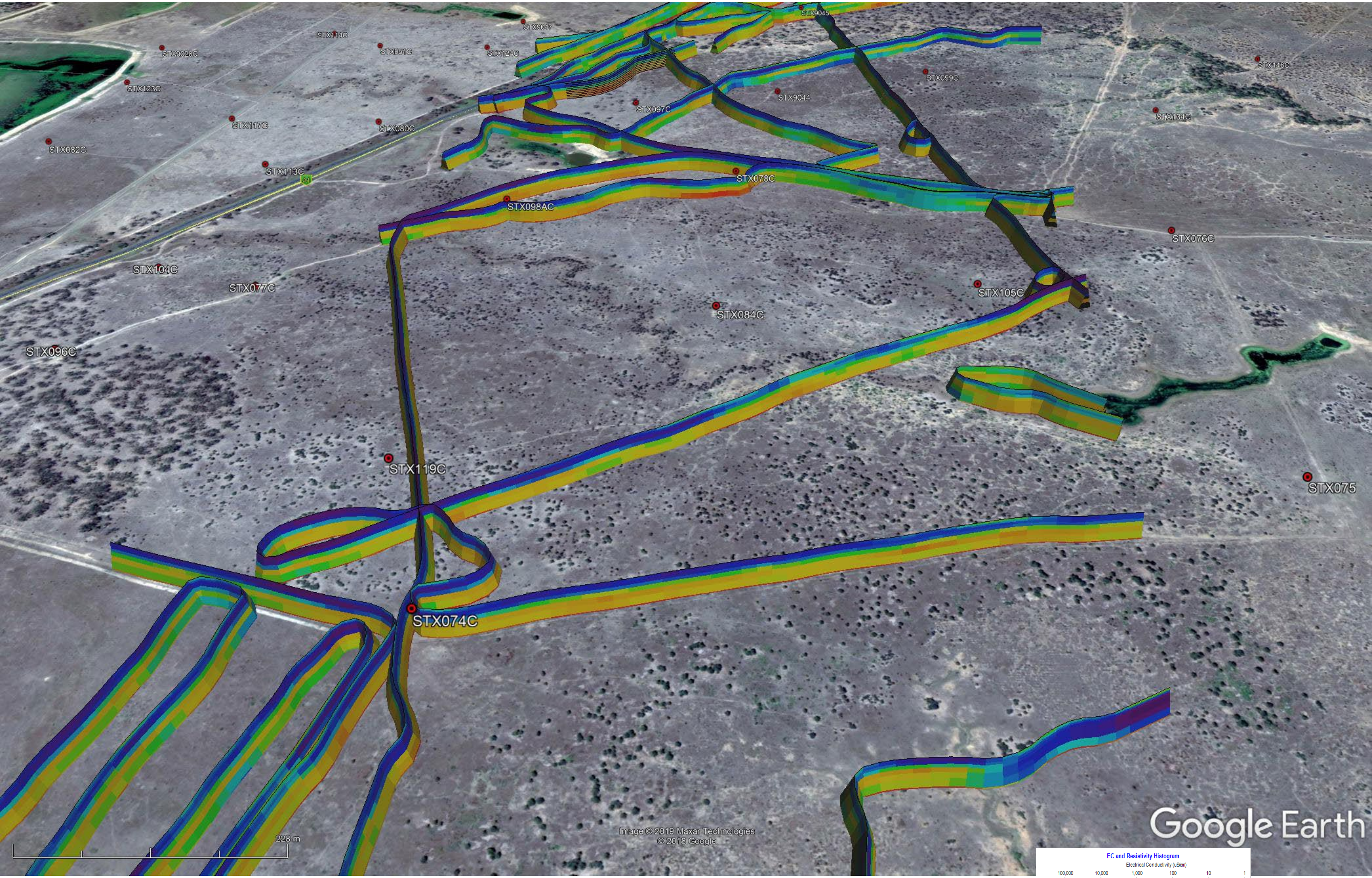
Modelled Resistivity projected up 30m

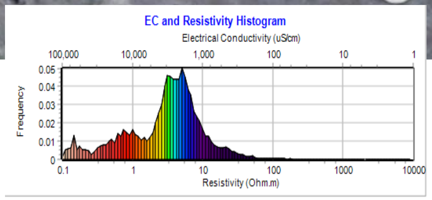
Mamelon – looking West – Data segment 5 of 7



Modelled Resistivity projected up 30m

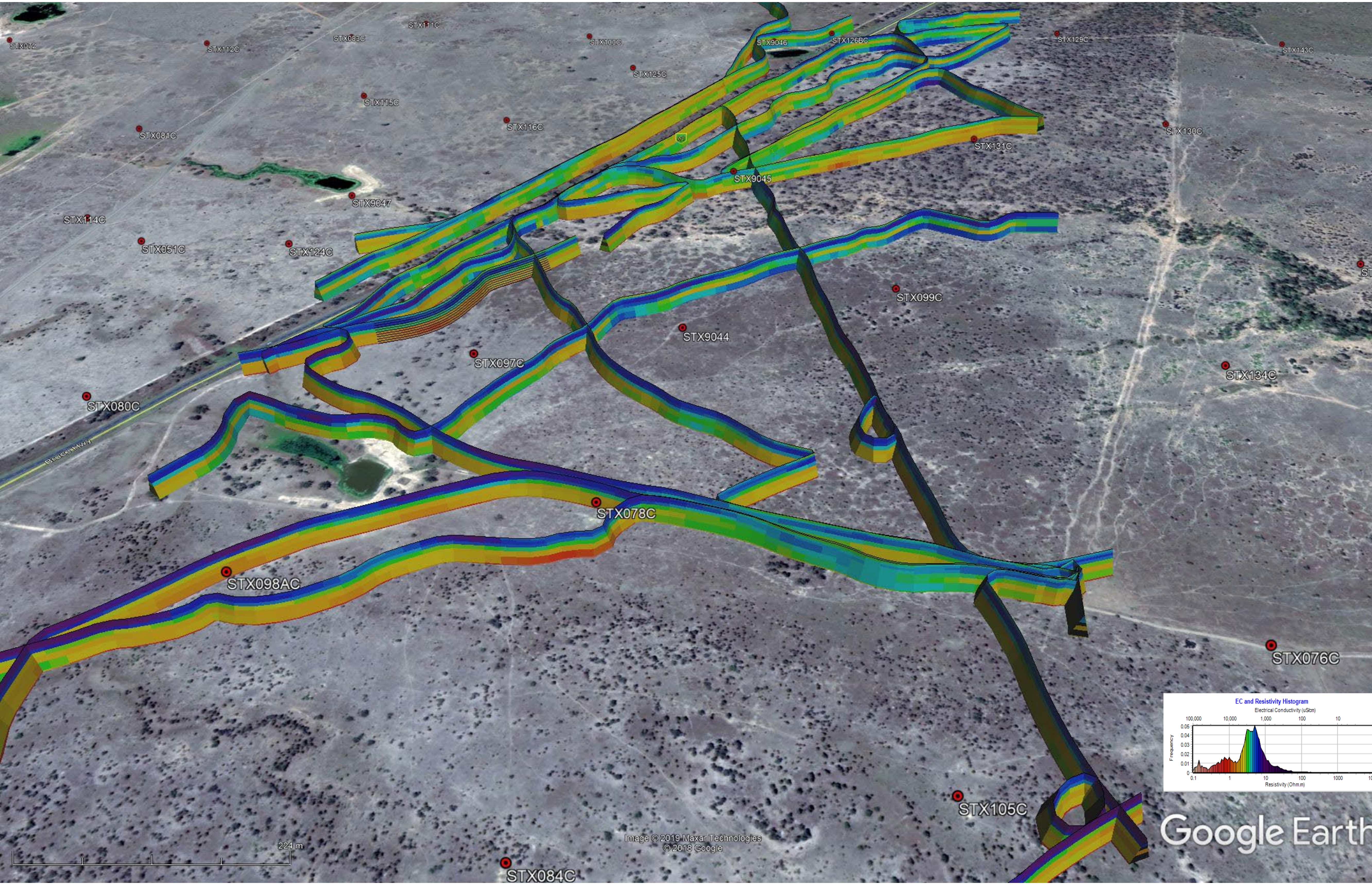
Mamelon – looking West – Data segment 5 of 7





Modelled Resistivity projected up 30m

Mamelon – looking West – Data segment 5 of 7

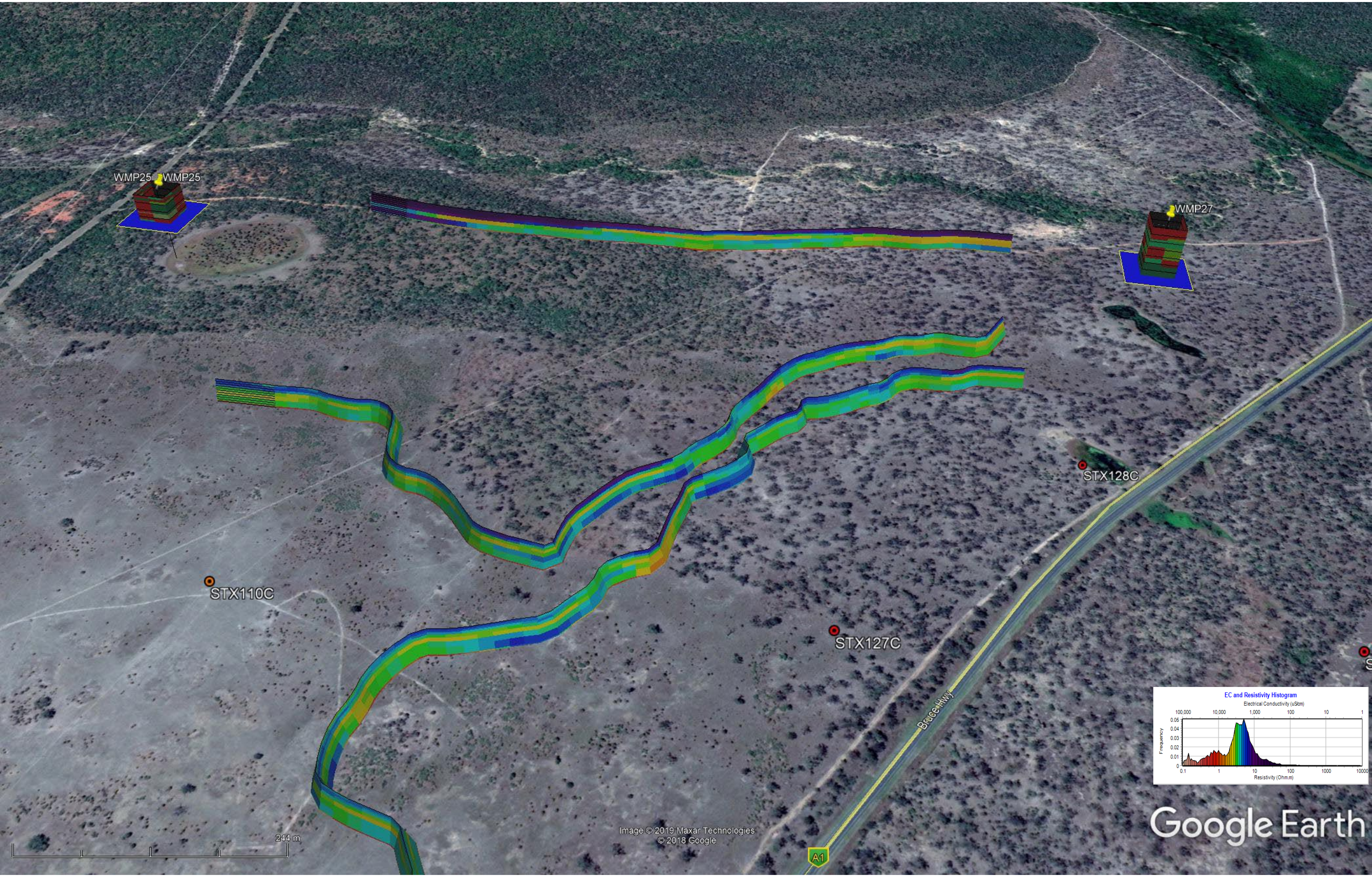


Modelled Resistivity projected up 30m

Mamelon – looking West – Data segment 5 of 7

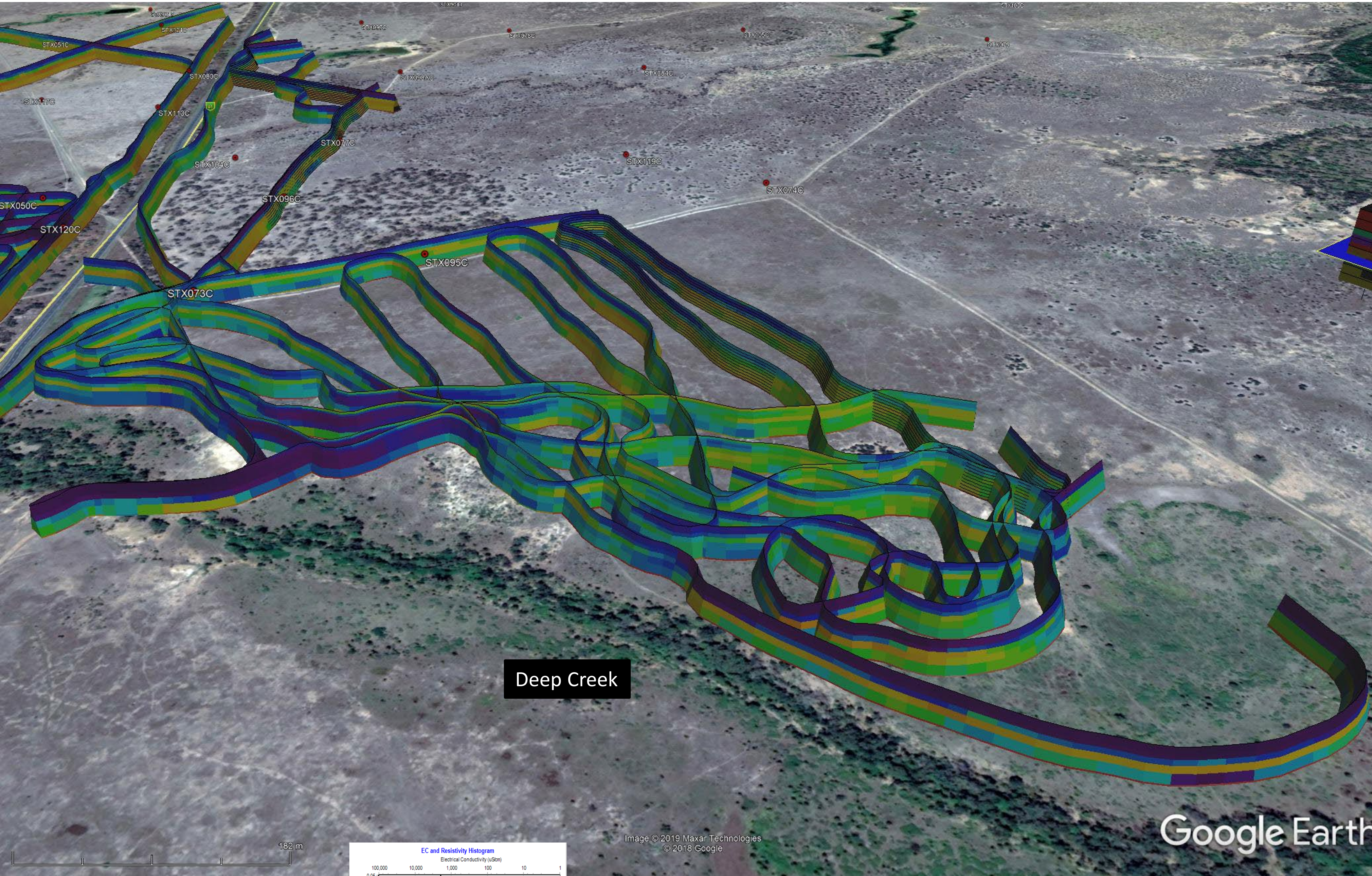
Modelled Resistivity projected up 30m

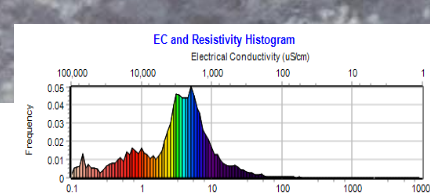
Mamelon – looking West – Data segment 5 of 7



Modelled Resistivity projected up 30m

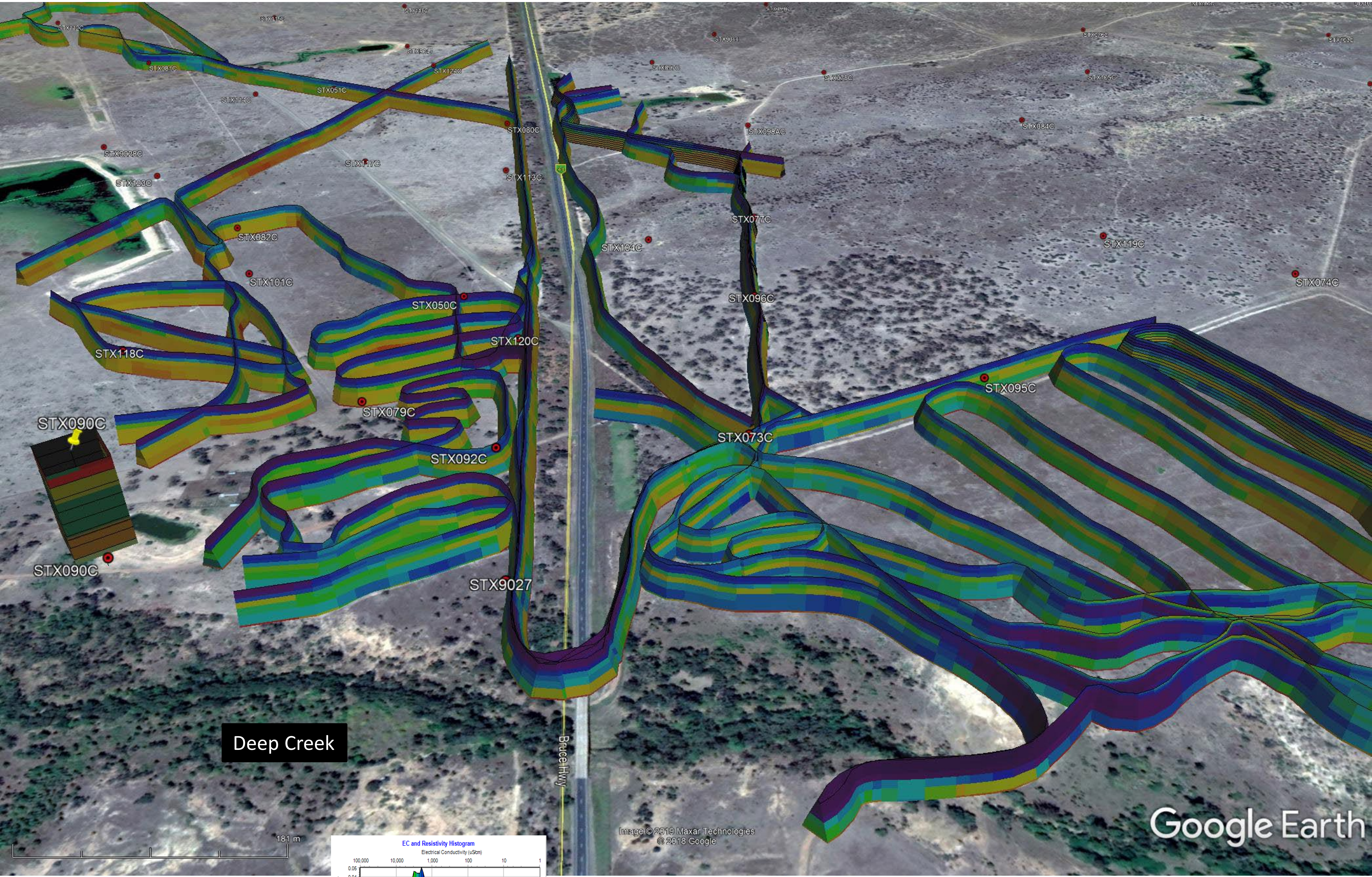
Brussels, Mamelon – looking NW – Data segment 6 of 7

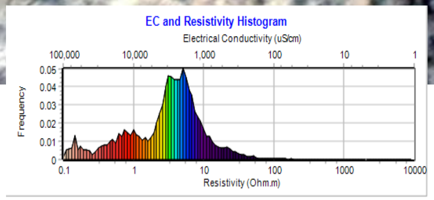




Modelled Resistivity projected up 30m

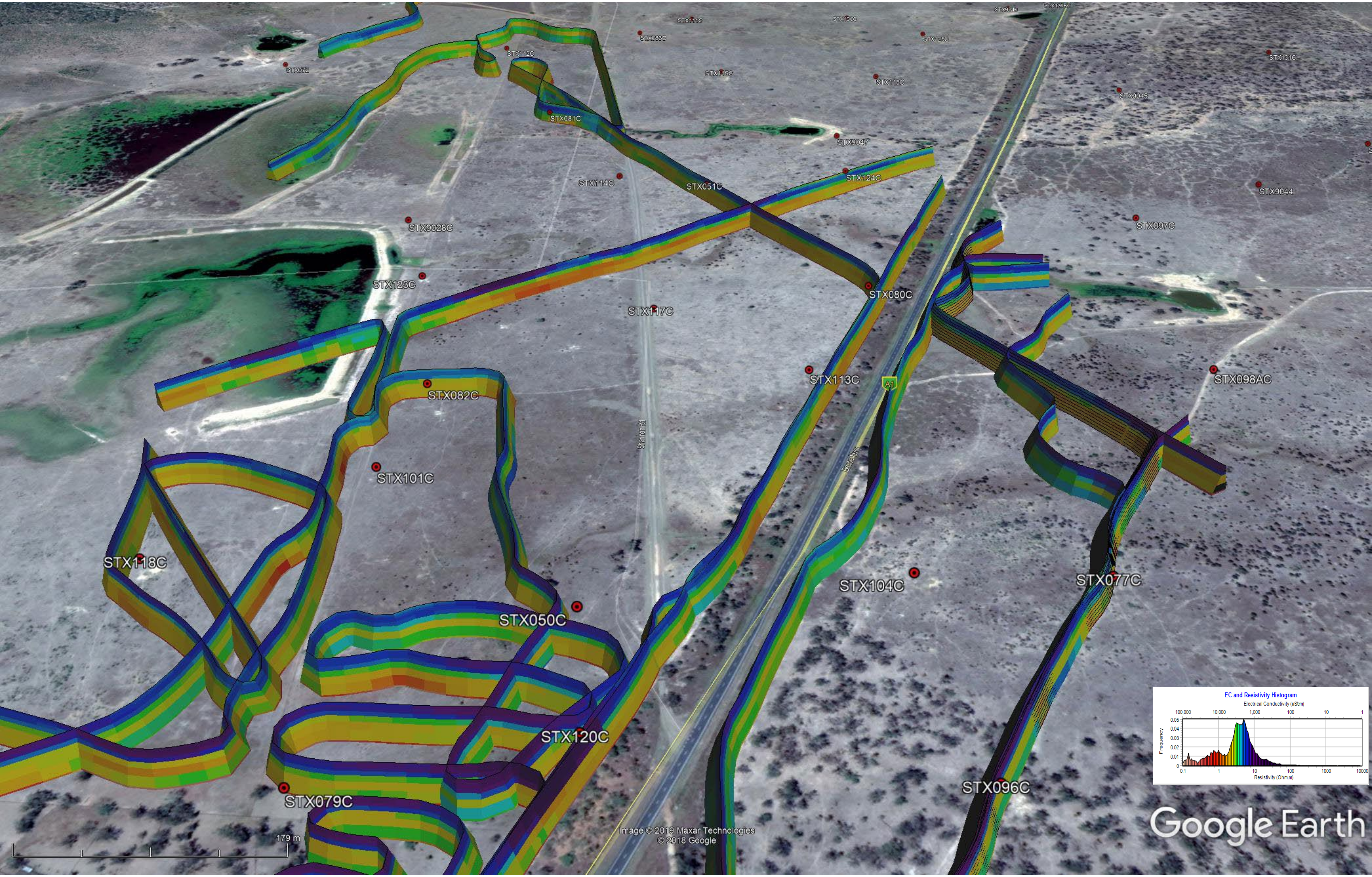
Brussels, Mamelon – looking NW – Data segment 6 of 7





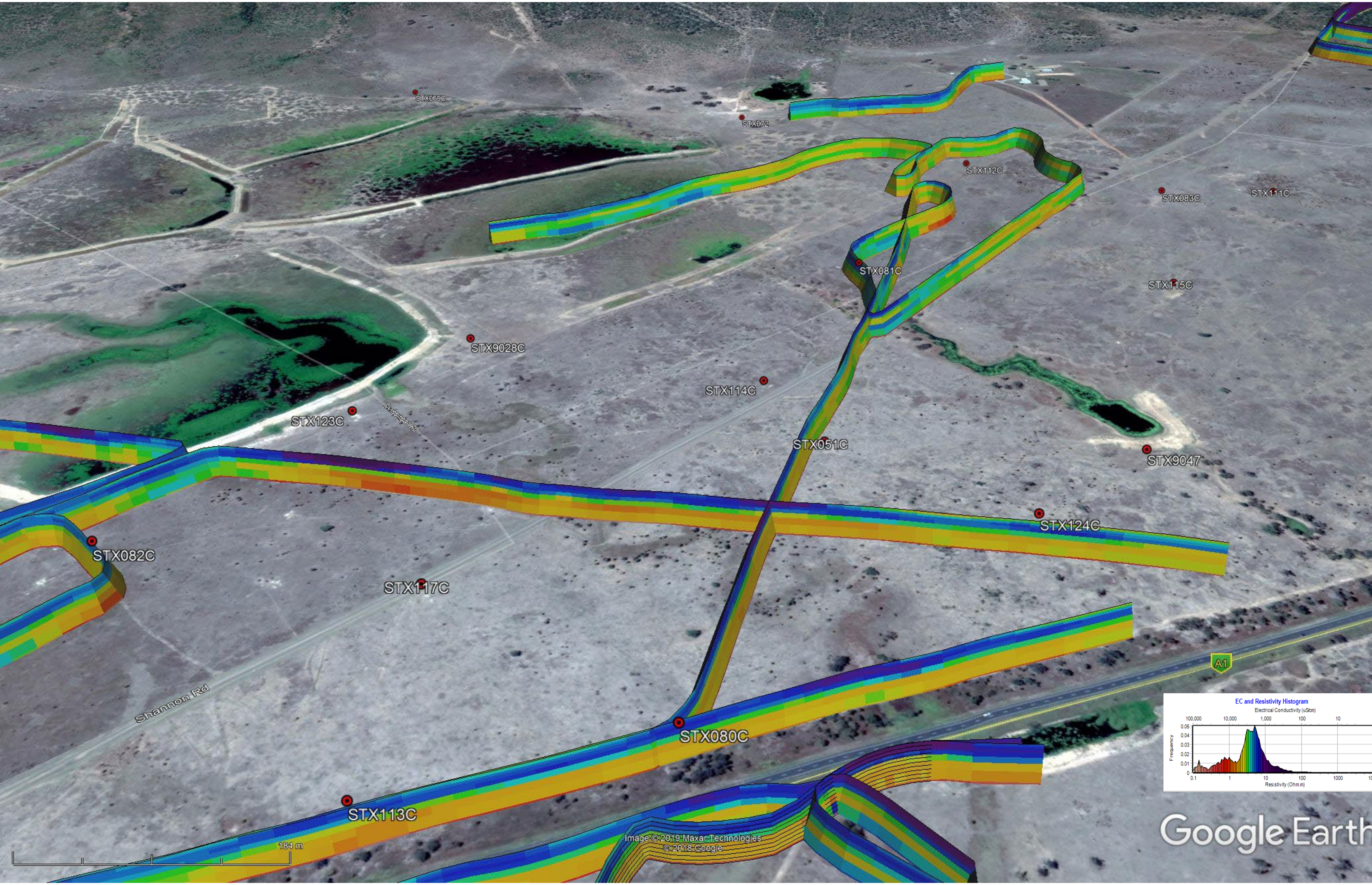
Modelled Resistivity projected up 30m

Mamelon – looking NW – Data segment 6 of 7



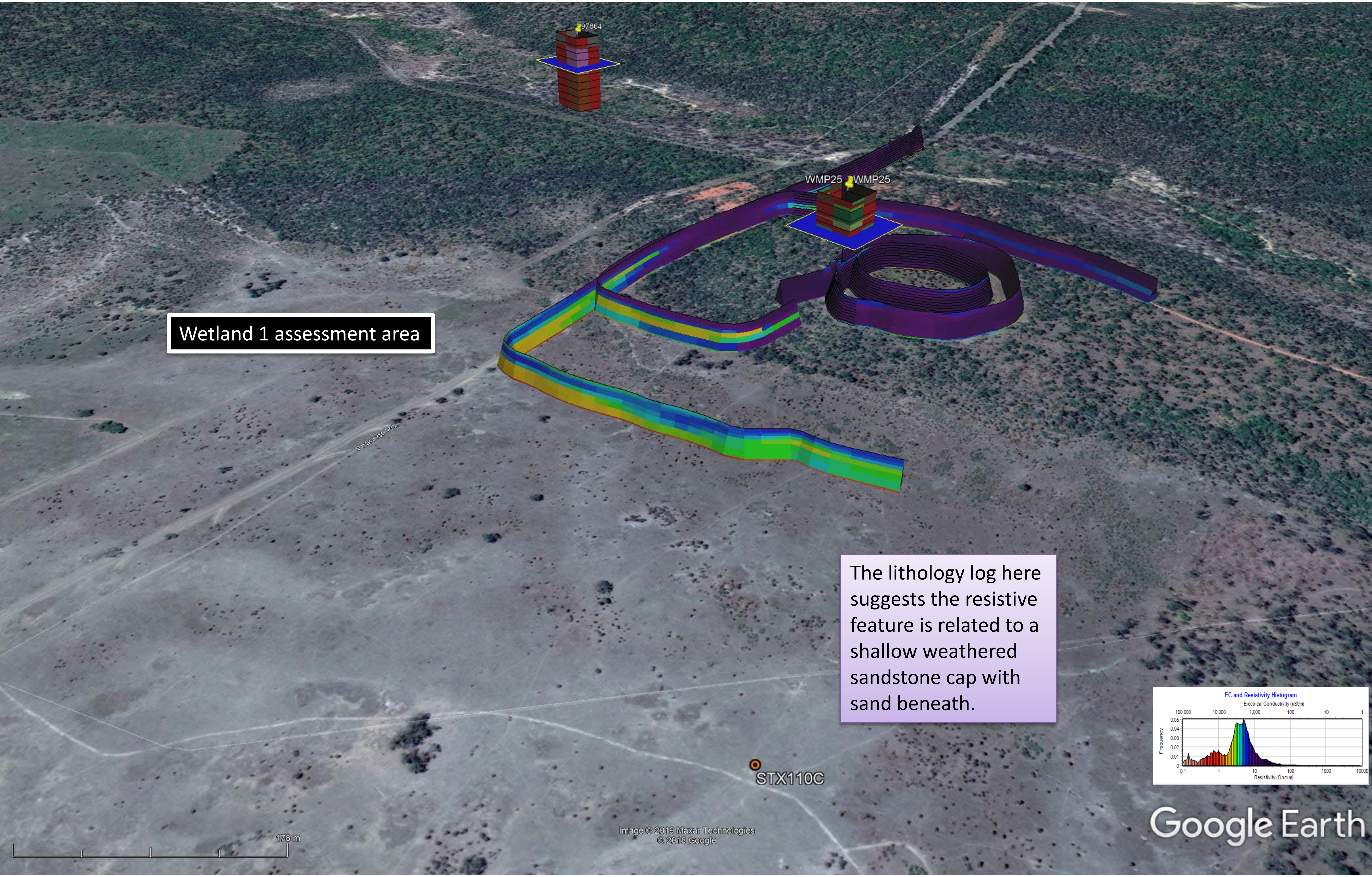
Modelled Resistivity projected up 30m

Mamelon – looking West – Data segment 6 of 7



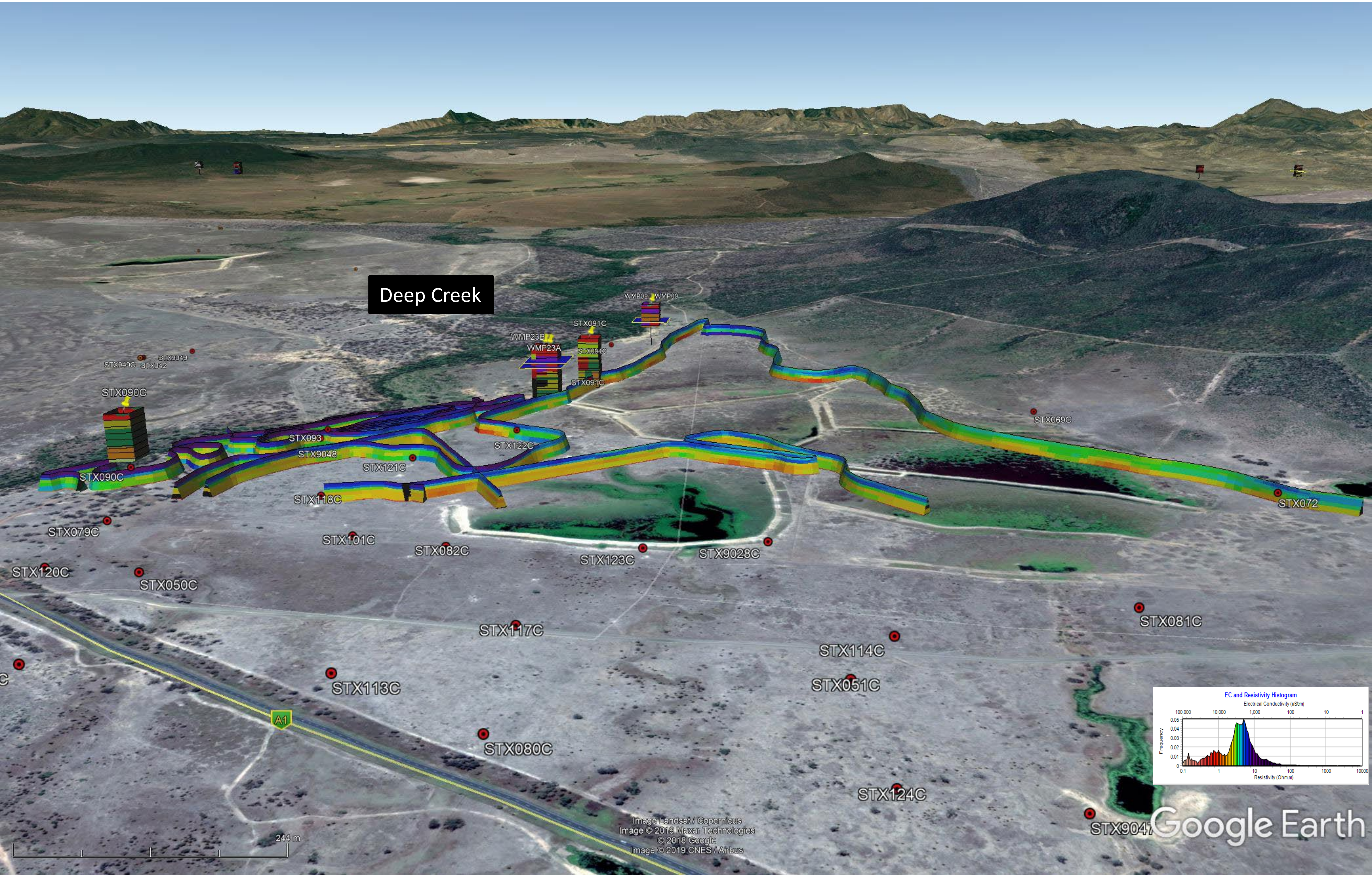
Modelled Resistivity projected up 30m

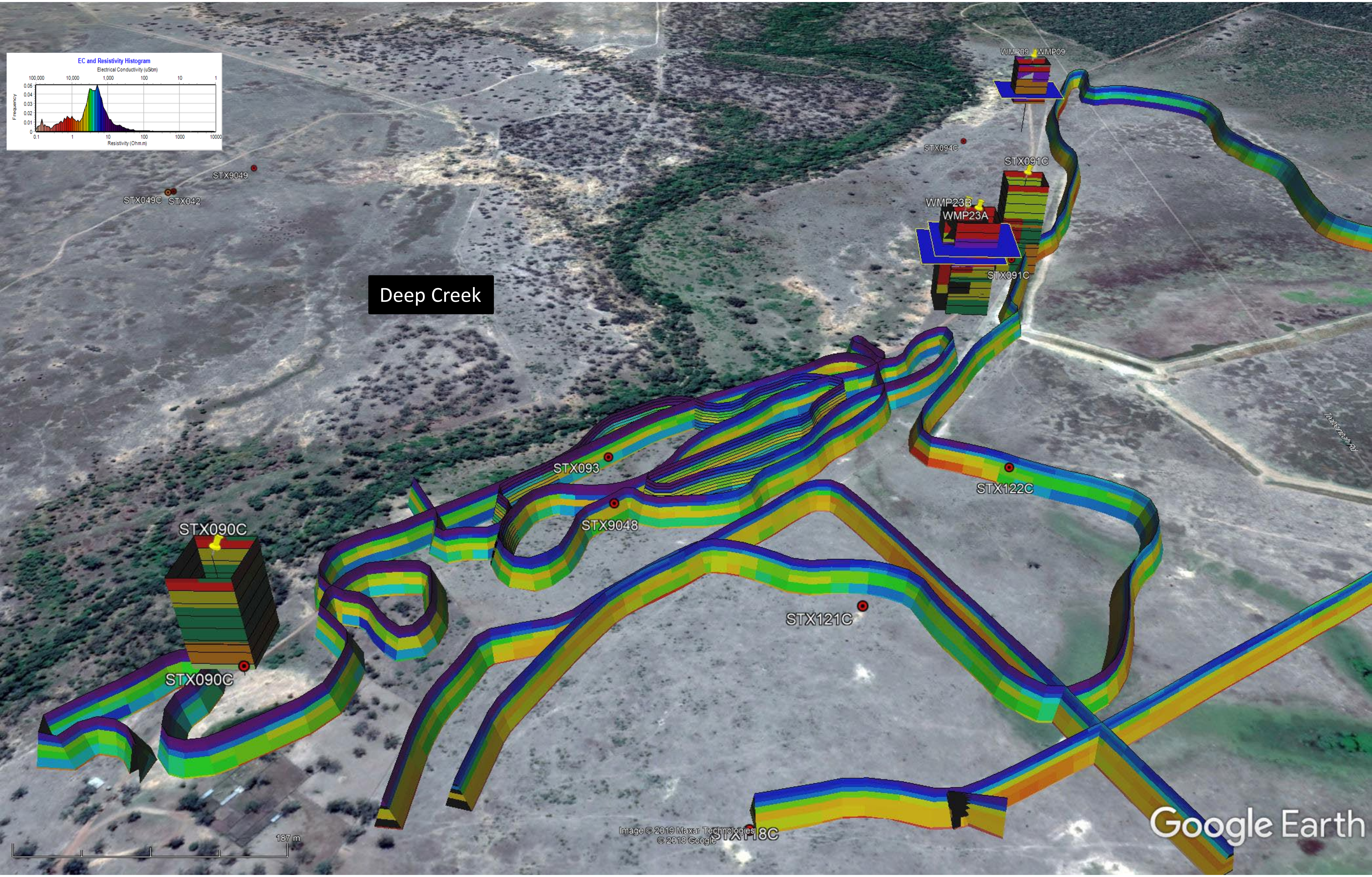
Mamelon – looking West – Data segment 6 of 7



Modelled Resistivity projected up 30m

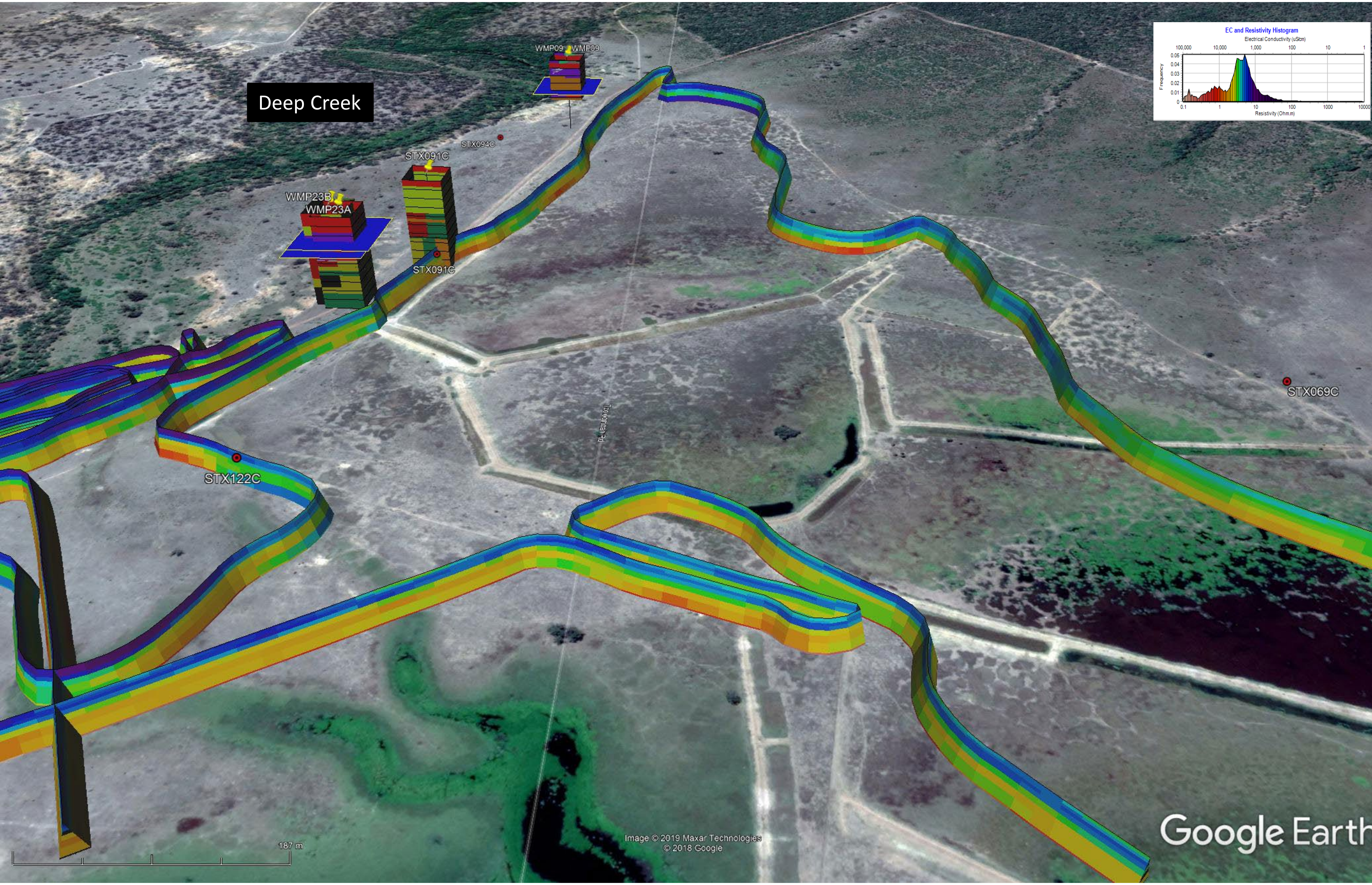
Mamelon South – looking South – Data segment 7 of 7




EC and Resistivity Histogram
Deep Creek
STX9049
STX049C
STX042
WMP09
STX094C
STX091C
WMP23B
WMP23A
STX093
STX122C
STX9048
STX090C
STX121C
Google Earth
187 m

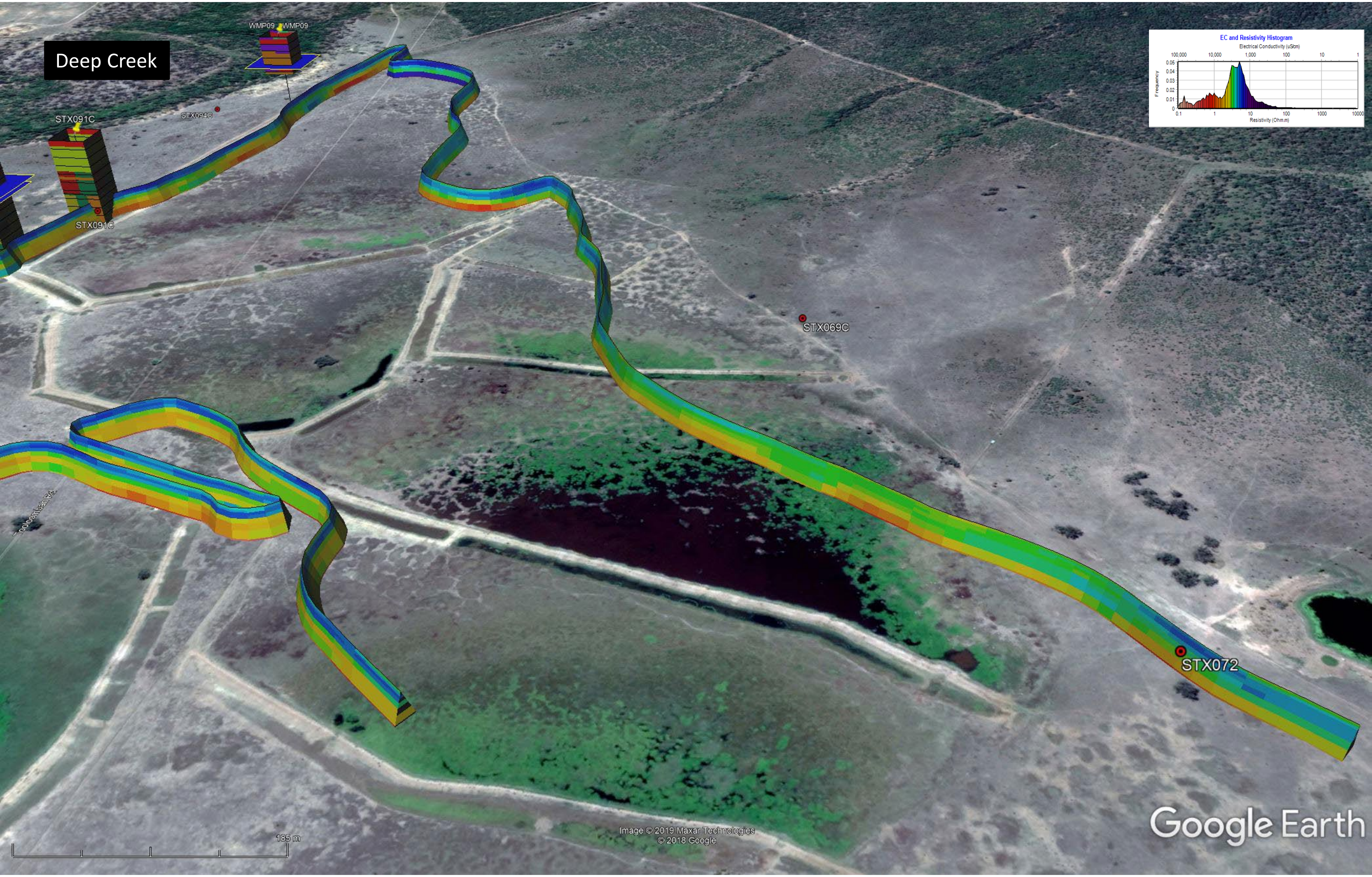
Modelled Resistivity projected up 30m

Mamelon South – looking South – Data segment 7 of 7



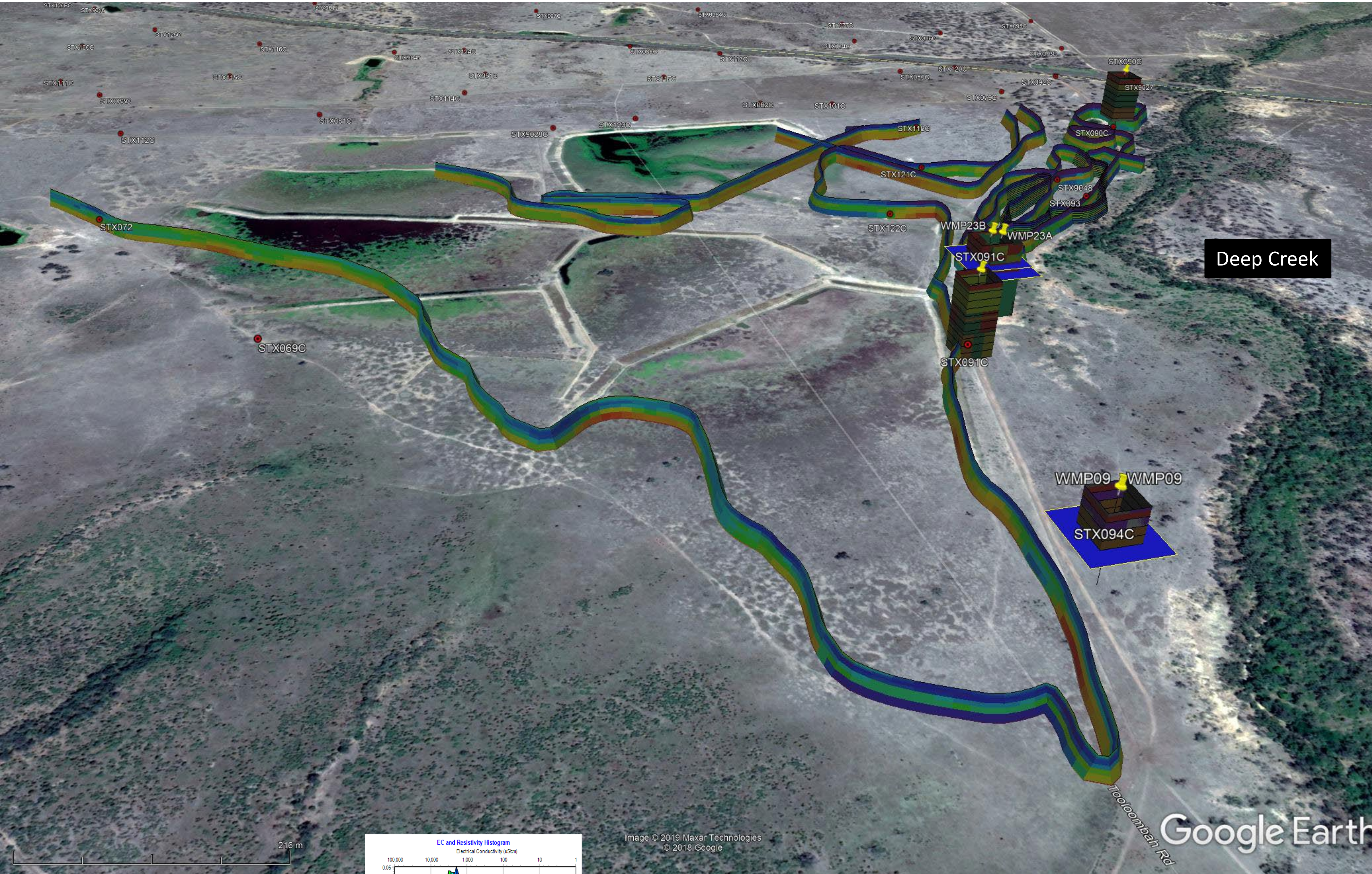
Modelled Resistivity projected up 30m

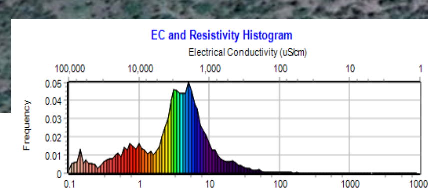
Mamelon South – looking South – Data segment 7 of 7



Modelled Resistivity projected up 30m

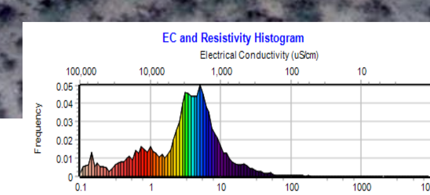
Mamelon South – looking North – Data segment 7 of 7





Modelled Resistivity projected up 30m

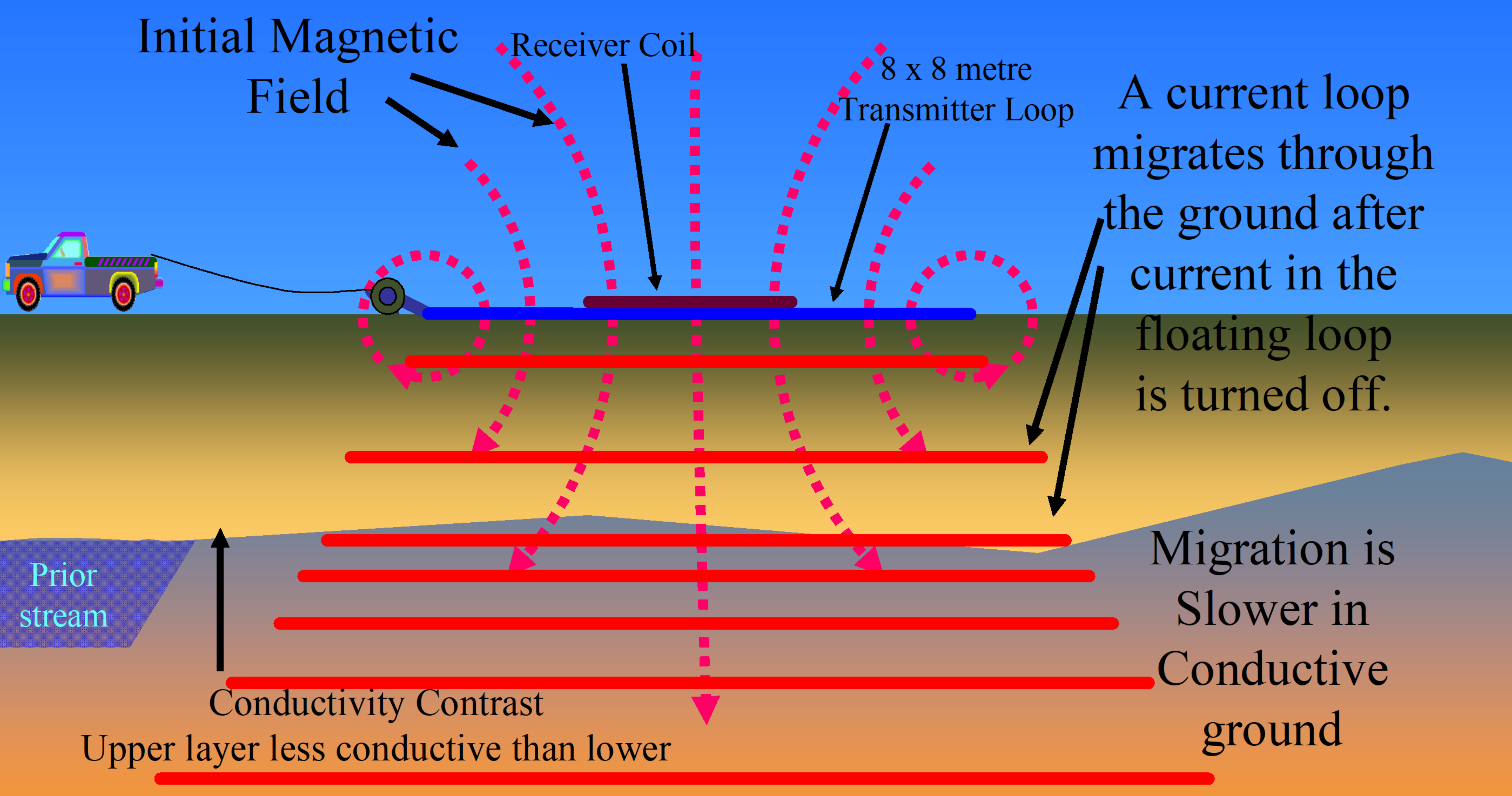
Mamelon South – looking NW – Data segment 7 of 7



Appendices

- Identifying depths on ribbon images
- Towed Transient Electromagnetic schematic
- TEM platform configuration schematics
- TerraTEM specifications

Towed Transient Electromagnetic System



Small AgTEM prototype for shallower surveys

USA patented.

The trailer must be largely non-metallic for TEM survey.

Booms holding the large horizontal transmitter loop are held in place by elastic cords that yield and spring back upon tree or rock impact.

The drawbar is an arrangement of fibreglass tube and tensioned kevlar ropes.

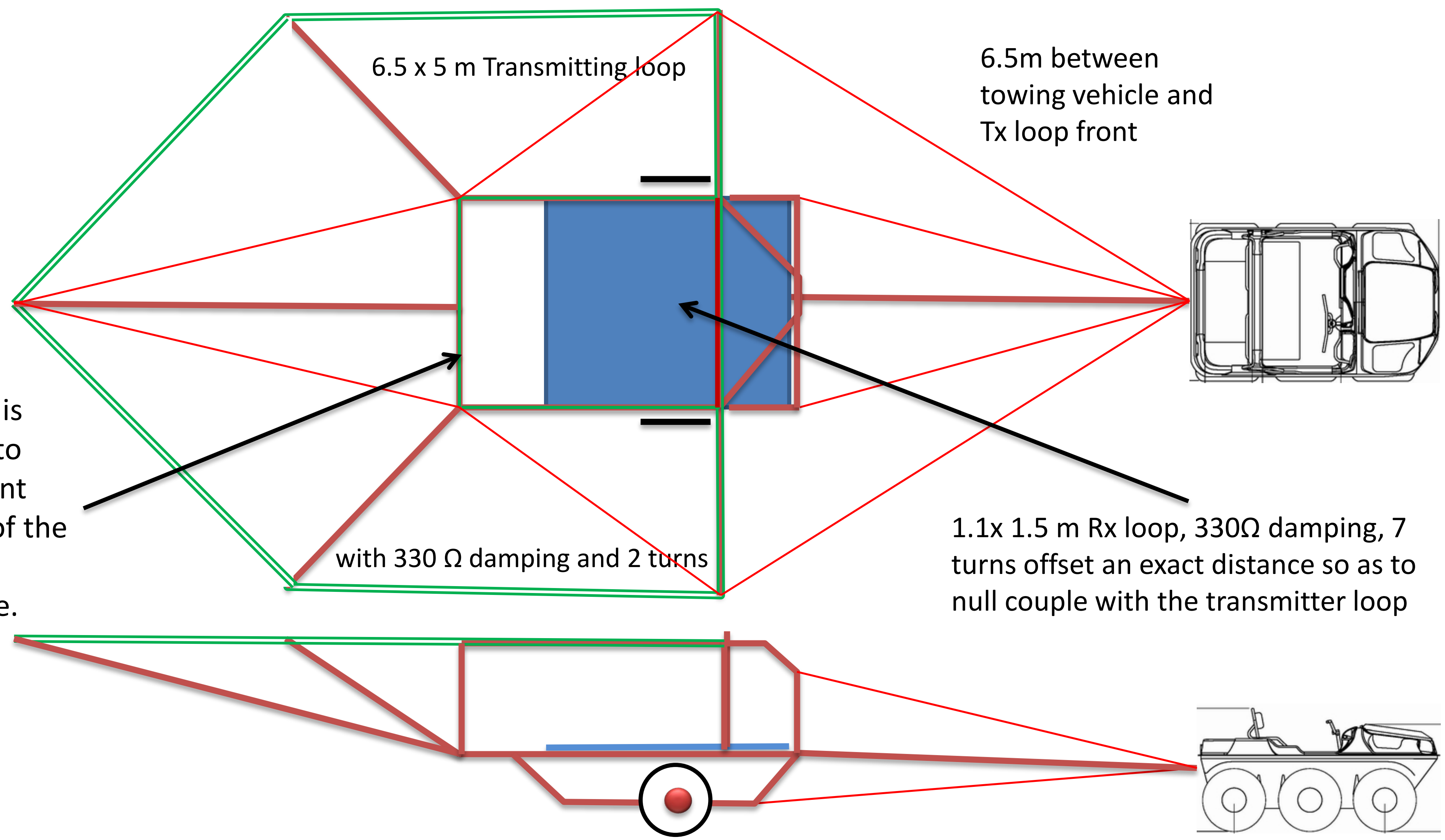
TEM Method Details

- A schematic of a towed transient electromagnetic survey system is provided on the next slide. Electrical current is pulsed through a large transmitter loop and each pulse induces a 'smoke ring' of current in the ground below as it turns on and off. As the 'smoke ring' dissipates out into the ground its magnetic field decays and it is the decay of this magnetic field, along with the decay of the magnetic field resulting from the transmitter loop, that is detected by various receiver loops. The decay is abated by conductive layers and enhanced by resistive layers in the substrate.
- The system used on this job, photographed on the previous page, had a 2 turn 6.5 x 5m transmitter loop with a centrally located receiver loop under the indented front of the transmitter loop and in a null coupled arrangement. The system was operated using a Monash Geoscope TerraTEM with an accelerated transmitter (to see shallower features) called TEMTx32, the continuous acquisition option, a Trimble AgGPS114 receiving Omnistar DGPS corrections and several truck batteries for power supply. The system was towed by a Landrover Defender separated from the equipment by a 5.5m fibreglass boom and rope assembly. The receiver loop had a 330 ohm damping resistor across it as did the transmitter loop and 16.5 Amps was driven though the two turn Tx loop. The receiver also had a pre-amp with a 60 kHz low pass filter invoked.
- Processing of this data involves numerous steps presented in a the next slides. The main steps are removal of movement noise, primary field stripping, cleaning of the data (removal of data mainly affected by metallic objects etc.), spatial smoothing, modeling to transform the voltage versus time data to smoothness constrained layers of resistivity versus depth, more data cleaning, gridding and presentation. The principle step is the transformation (matrix inversion) which is carried out using the Aarhus Hydrogeophysics Group algorithm EM1DInv.

Transient EM equipment configuration

6.5 x 5 m transmitting loop towed TEM system

Plan view



One turn of the transmitter loop is tucked in over the receiver loop to facilitate more compact placement and less dimensional sensitivity of the placement of the null coupled receiver loop within the structure.

Vertical section

Exact loop dimensions

To avoid intellectual property loss, the exact loop dimensions have been displayed separately in a file SoilImagerJustTheLoops.png which is not openly distributed.

Transmitter loop suspension arms are attached elastically to prevent attrition upon impact with trees. Arms may be raised from the towing vehicle and fold inwards for obstacle avoidance and for compact transport when not surveying. The trailer draw-bar is detached for between-job transport. The trailer is lightweight and can be lifted by one person. Attrition is also avoided by addition of a breakaway pin. **Australian Patent Pending.**

General Processing Sequence

Define System Geometry

–

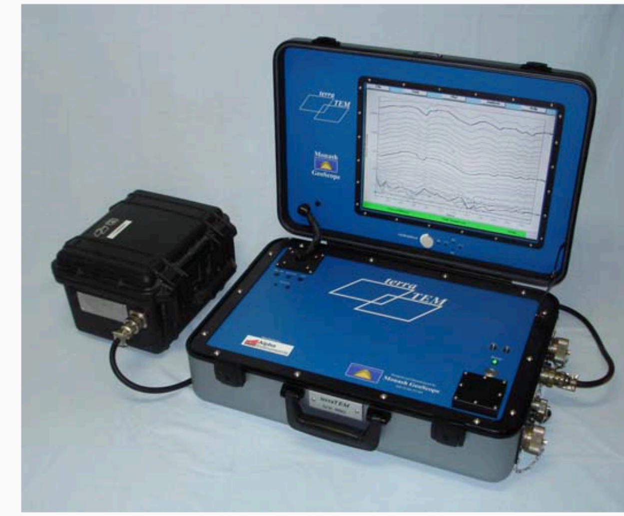
1. Quality control and data parsing during acquisition
    1. At the beginning of each day, select a reference sounding and plot it along with all incoming data.
    2. Watch all incoming data constantly making comparison with the reference sounding.
    3. Cancel acquisition or note problems as noise sources, metal artefacts, or equipment malfunctions are encountered. Alter course across ground to both more clearly define noise and artefacts and to subsequently avoid them.
    4. Each night, convert BIN file into TEM and TXT files and back them up.
    5. Each night, display selected channels of the data in plan view to appraise layout of geological features and any present geophysical artefacts.
2. Acquire system response from data obtained (stacked then averaged) in a very resistive area. If a very resistive area is not available then a larger hand laid loop is laid, ideally at the most resistive low horizontal gradient location in the survey area, a sounding taken (generally in slingram mode to avoid in-loop enhanced effects such as system response itself, induced polarization and super-para-magnetic effect. Then data from that loop is inverted to give a modelled response which is then used to calculate the equivalent response for the cart configuration. That response is then subtracted from the actual measured cart response at that site to give approximate system response of the cart.
3. Determine EM1DInv inversion software initial model, constrains and control parameters.
4. –
5. Operations performed on TEM files
    1. Basetrend removal (optional – only possible on moderately to highly resistive areas). This removes movement noise from the receiver coil moving through the magnetic field of the earth slowly. Some large mat receiver loops and other structures that do not vibrate do not create much movement noise. Basetrend removal is conducted by using a timebase of acquisition much longer than necessary so as to sample basetrend during acquisition by regression analysis of the part of the stacked records beyond where the decays drop well into the noise envelope.
    2. Adjust magnitude according to primary field response (optional). This is not appropriate and not done with nulled coils but is useful when using slingram coils.
    3. Reject records with low or high primary field response as they are clearly suffering from equipment malfunction (eg. Receiver loop blown over by wind) (optional). This may be conducted automatically or manually by visualizing a primary field channel on a map display and culling all soundings showing anomalous primary field.
6. Convert TEM file into a relational voltage database (*Volt.DBF, *XVolt.DBF,*YVolt.DBF)
7. Normalize data using average magnitude of log10(data) from a small receiver placed directly on the transmitter loop wires (*YVolt.DBF) (This is optional as the data is already normalized according to current monitored (every 10 soundings in 2014 version of TerraTEM firmware)).
8. Remove system response, optionally taking magnitude of transmitted data (proportional to *YVolts.DBF) into account for every sounding - again this option is not appropriate for nulled coils.
9. –
10. Display voltage data, in map view, coloured to represent magnitude of a particular channel. Simultaneously view decay plots of picked soundings, along with a reference sounding.
    1. Interactively remove geophysical artefacts by clicking on points or data segments.
    2. Display automatically updates - repeat a.
    3. Repeat a,b. until satisfied that data is suitably cleaned.
    4. Interactively clip channel count on soundings with procedure as for a., b. and c. (optional).
11. Smooth voltage data horizontally. Trapezoidal filtering is ideal (optional). Note well that this step is conducted after removal of artefacts which would have spread their mess throughout the data if smoothed.
12. Calculate noise levels from sounding tails and specify ready for inversion. Should telecom cable or powerline noise be encountered, then this step will lead to recovery of shallow information without unduly corrupting deeper information!
13. Determine valid time range for inversion input from each sounding using noise levels specified in step 14.
14. Create EM1DInv inversion input files.
15. Run EM1DInv on each sounding, conjunctively inverting both in-loop and out-of-loop data (if obtained). This is scheduled using batch files and runs overnight, or even over several days or weeks.
16. Run EM1DInv again with lateral constraint (optional – also time consuming).
17. Read inversion output files to create relational *Ohmm.dbf files.
18. View *Ohmm.dbf files in plan view.
    1. Colour proportional to curve fitting RMS error and view to determine an appropriate cut-off RMS threshold. Exercise caution in determining the threshold as data in resistive areas will still be valid at much higher threshold than in conductive areas.
    2. Reject soundings with RMS error greater than the threshold level determined in a..
    3. Colour proportional to resistivity of successively deeper layers. Interactively remove or depth-limit soundings containing artefacts by clicking on points or data segments.
19. View *Ohmm.dbf in 3D – check data more, switching back and forth to 2D view to remove further artefacts.
20. Horizontally smooth the *Ohmm.dbf file to clean up erratic variation in inverted data.
21. Horizontally shift *Ohmm.dbf files to account for GPS antenna offset.
22. –
23. Divide day *Ohmm.dbf files into logical segments (where appropriate) and recombine into *Ohmm.dbf files covering logical geographic extents.
24. Calculate resistivity distribution histograms and combine to make a master histogram for the area.
25. –
26. Re-load regional *Ohmm.dbf files and colour with master histogram equalization (quantization).
27. Query state bore databases and generate a subset of bore data for the area.
28. Interpret the drillers logs into lithological categories.
29. View bore log graphics with the resistivity data for each region.
30. Create graphics of histograms and lithological keys for posting externally.
31. Pack regional *ohm.dbf files and augment with shapefile indexes, projection files etc.
32. Create 3D polygon KML and shapefiles for each region (both resistivity and lithological files).
33. Slice each regional resistivity file into depths and output as *.csv with columns of logarithmically transformed resistivity for external gridding in packages such as Golden Software Surfer 12.
34. Create any other appropriate theme datasets (eg. Depth to maximum resistivity) and 3D graphics (eg. Voxler).
35. Grid and display depth slices, stacked if required in 3D space (Surfer).
36. Organize and refine KML files in Google Earth and select enhanced snapshot views. Combine into a folder and collectively output as a new KMZ file. The KMZ files are compact - Email to interested parties.
37. Collect all graphics in MS Powerpoint (A3 resolution!) and create a report. Make a summary report in MS Word (optional). Generate PDF report.
38. Package job DVD and printing, mailing etc.

Transient EM equipment specifications

Alpha Geo Instruments

terraTEM
Time-Domain EM Surveying System

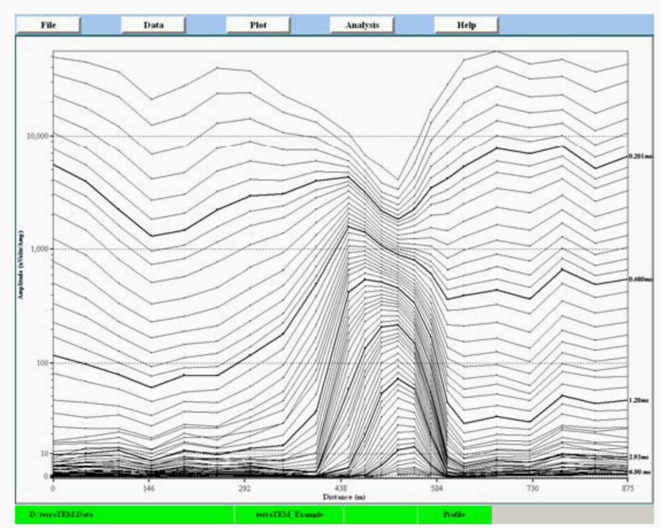
terraTEM Features



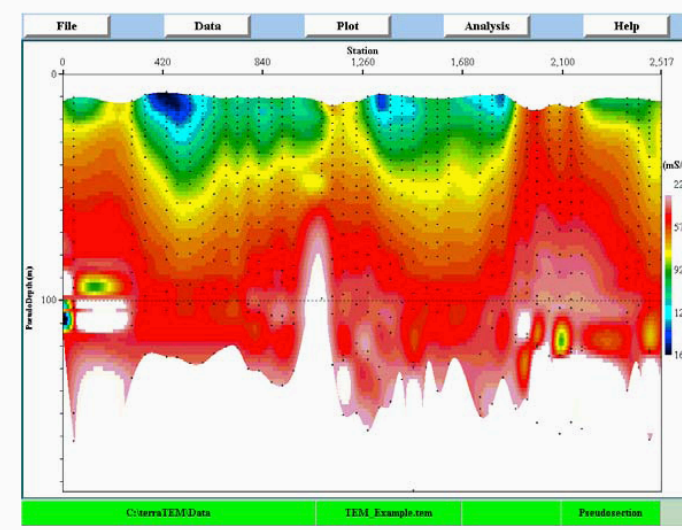
- Transmitter and receiver in one unit
- Single or 3 channel receiver with 10 amp. transmitter
- High speed sampling at 500 kHz for superior near surface resolution
- Easy to use touch screen with auto set-up and smart menus
- Large 15″ LCD display for data visualisation
- Fast and easy data transfer via USB port
- Integrated 12 channel GPS system for seamless station positioning (option)
- Integrated PC for data visualisation, data processing, and interpretation in field using built-in software
- Rugged construction with external 24 V battery power pack and charger
- Several optional extras to broaden capability
- Designed and built in Australia

Screen Dumps

The following are a number of screen views from the **terraTEM** system.



Full control of all aspects of data display, post-survey filtering, and decay curve analysis



Multiple display formats, including gridding and raster images (options)

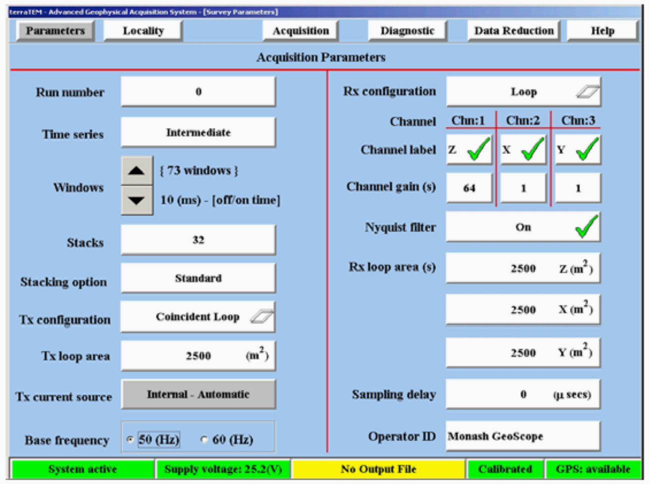
The **terraTEM** is designed, developed and manufactured by **Monash GeoScope**

Monash GeoScope

Applications

The **terraTEM** can be used for various applications including the following:

- Mineral exploration
- Near surface including geo-technical and engineering investigations
- Groundwater and salinity studies
- Environmental surveys



Easy access to all parameters, multiple binning and stacking options; smart menu system.

Internal GPS, for positional accuracy (option)

General Specifications

	terraTEM	Options
Transmitter Output	10 Amps. (max.)	**Enhanced Transmitter**
Receivers	1 Channel	**3 Channels (simultaneous)**
High Resolution Sampling Rates	500 kHz	-
User Selectable Multiple Time Gates	-	**Option**
Data Visualisation and Processing in field	Standard Software	**Enhanced Software**
Storage Device – 1 GB Flash Disk	Standard	-
GPS Receiver – 12 channel	-	**Option**
Communications – Port for Data Transfer	USB and RS-232 Standard	-
External Synchronisation	-	**Option**
Continuous Recording (with external GPS Interface)	-	**Option**
Extra Stacking Options and Gain Functions	**10 Selectable Gain Settings from 1 to 8,000**	**Auto Gain**
Vectem 3 Interface Module (for down-hole surveying)	-	**Option**
Interface Options (third party devices)	-	**Option**
Dimensions: Console: 530 x 350 x 160 mm. 13 kg. Battery Box: 280 x 250 x 180 mm. 12 kg.		
Operating Temperature: -10 to 40 degrees C.		

Further Information

For further information regarding this product, either technical or sales, please contact:

Alpha Geo Instruments

Unit 1, 43 Stanley Street, Peakhurst. N.S.W. 2210. Australia
Phone +61 (0) 2 9584 7555 **Fax** +61 (0) 2 9584 7599
e-mail info@alpha-geo.com **website** www.alpha-geo.com

Your Distributor:

Alpha Geoinstruments is a division of Alpha Geoscience Pty. Ltd. (ABN 14 080 819 209)
The above Technical Specifications could change without notice.

terraTEM
Technical Specifications

Transmitter

Output	10 Amp. (max.)
On/Off Period	Adjustable 10 ms (50 Hz) or 8.33 ms (60 Hz) increments

Receiver

Sampling	500 kHz per channel, fixed
Inputs	+/- 40 V maximum continuous voltage.
Gain	User selectable fixed gains Other Gains Optional
Resolution	Maximum 28 bits, effective
Functions Measured	Tx/Rx loop resistance, Tx current, Tx turn-off time, battery voltage, automatic gain/offset calibration, transient response

Console

Display	LCD TFT, 15 inch
Touch Screen	Splashproof
Storage	1 GB flash RAM

External Interfaces

Communications	USB and Serial port for data transfer

Equipment Supplied

- Console
- Loop connectors
- Battery Pack (24 volts), complete with connector cable (overseas batteries not included)
- Battery charger
- USB flash disk (for data transfer)
- Operations manual

Sensor Attachments Available

Surface Receiver	RVR-1 or cable loop
Downhole	Vectem 3 or equivalent

Physical

Housing	Aluminium "Zero" case
Console: Weight	13 kgs.
Dimensions	530 x 350 x 160 mm.
Battery Pack: Weight	12 kgs.
Dimensions	280 x 250 x 180 mm.
Operating Temperature	-10 to 40 degrees C.

Options

GPS Receiver	12 channel receiver
Multi-channel Receiver	3 channel simultaneous A/D
External Transmitter Interface	External synchronisation option (for use with TEMTX-32, Zonge high powered transmitters)
Vectem 3 Interface	Internal interface module
Continuous Recording	Continuous recording of unit with external GPS interface using NMEA standard
Software Packages	Extra Stacking Options, Sferics Rejection and Gains, Spectral Analysis and Digital Signal Processing User-defined time series

Further Information

For further information regarding this product, either technical or sales, please contact:

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The above Technical Specifications could change without notice.

How do I interpret the imaging

Image types and the common colour scale

Imagery has been presented as both 3D ribbons and 2D map views. Both are presented with and without satellite imagery backgrounds. The same EC colour scale has been used for all the imagery so that it is all directly comparable. This scale was derived by binning all the data in a histogram of EC and then spreading the colour evenly over the histogram (equal area colour distribution).

2D map imagery is of three types:

- EC slices at constant depth below the canal water surface;
- EC slices at constant depth below the canal bed; and
- Maximum EC of any layer intersected. This type is designed to give, **as low EC anomalies**, a rough indication of the most likely prolific seepage pathways.

Background satellite imagery has been added to many images using Google Earth. It is useful for locating seepage pathways in relation to features on the ground. For instance, particular types of trees, or anomalous crop vigore may indicate groundwater seeped from a nearby seepage pathway. Salinity scalds, evident on the imagery, may also be related to seepage pathways.

Files have been supplied so that users can image the data themselves in Google Earth, HydroGeoImager (available from the author), ESRI products or other products capable of reading dBase files, ESRI Shapefiles or CSV ASCII files.

Hints on use of these images

This document is a Microsoft Powerpoint Presentation supplied on the attached CD. Cutting and pasting these images from this document to other computer programs is best done by selecting the actual images rather than the slides because powerpoint desamples cut and pasted slides. Alternatively you may print to a hi-res PDF file.
In powerpoint, you will get an animation effect as you page through the depth slice image slides (back and forth as you please). It is much easier to compare the slices using this animation effect than it is on paper.

Data files and GIS integration

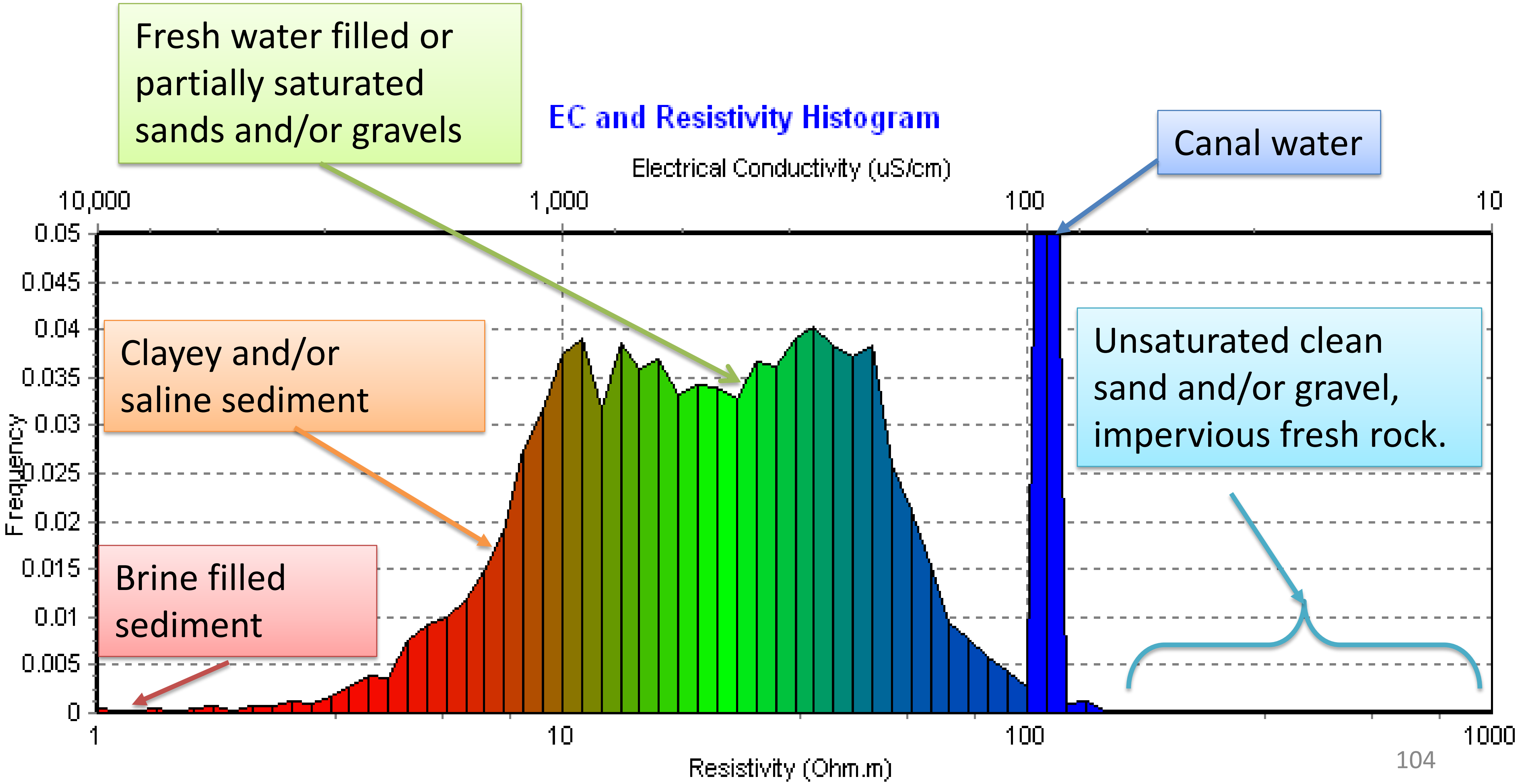
Accompanying data files in dBase IV format can be loaded in and out of MS Excel. The format has been chosen because it is easy to load into ESRI ArcView products. The final data is labelled *Ohmm.dbf and is of course in units of Ohm.m, the reciprocal of Siemens per metre. Each resistivity column is accompanied by a depth column indicating the base of the layer of that resistivity. Simple queries can be used to make a multitude of meaningful themes for adding to GIS images. Google Maps and Google Earth may be used for viewing some themes in the KMZ files supplied (zipped KML files). CSV (Comma Separated Variable) files of depth below bed slices also are supplied and may readily be loaded into most packages including Golden Software Surfer and ESRI ArcMap.

Where exactly am I looking?

In most cases, data may be located by identifying features such as fences and trees on the satellite imagery, however, accurate locations may be attained by loading files into Google Maps, Google Earth, ESRI products such as ArcMap or free ArcExplorer or even by loading the dBase files into Microsoft Excel. The viewer will find functions in most of these products that allow them to save sites they click with the mouse to a text file of co-ordinates which can then be loaded into a GPS receiver or printed as a list.

Imagery color scale and histogram calculated for all data collected from all canals in the Irrigation Scheme

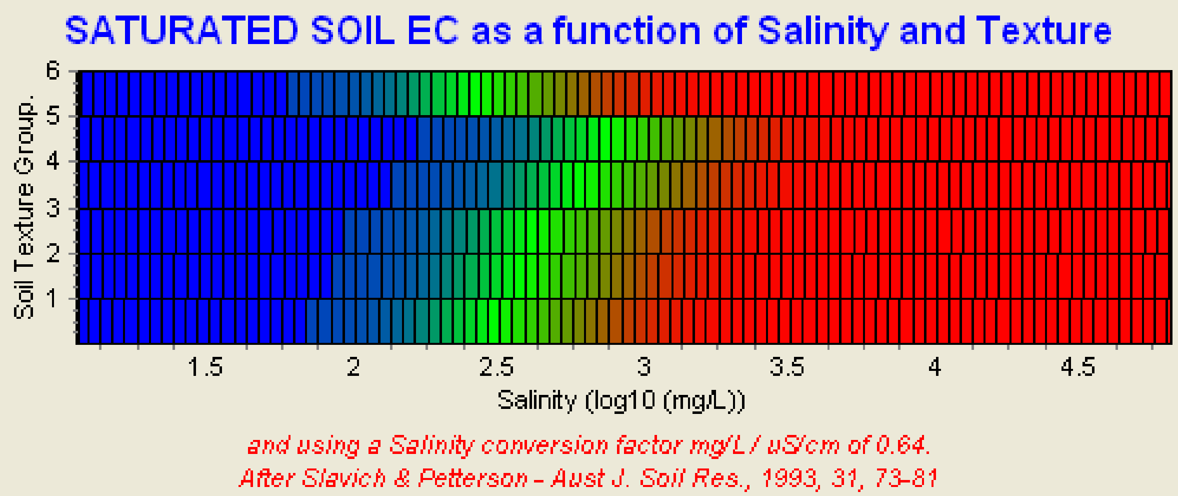
EC has been represented by a colour scale ranging from red, through green to blue with red representing the higher EC values. A histogram of EC values of all the data collected was generated and colour was distributed across that histogram so that each colour in the colour scale representing EC filled an equal area of the histogram. This has resulted in all important features in the datasets being visible.



Understanding the 3D graphics

Sediment texture and Pore Water Salinity

6: Water
5: Sands <10%Clay
4: Sandy Loams 10-25% Clay
3: Loams 25-30% Clay
2: Clay Loams, Light Clay 30-45% Clay
1: Medium, Heavy Clays >45% Clay



For any histogram of EC, we can show what colour is generated by various combinations of soil texture and salinity in saturated sediment using an empirically derived algorithm.

Bore Lithology Graphics

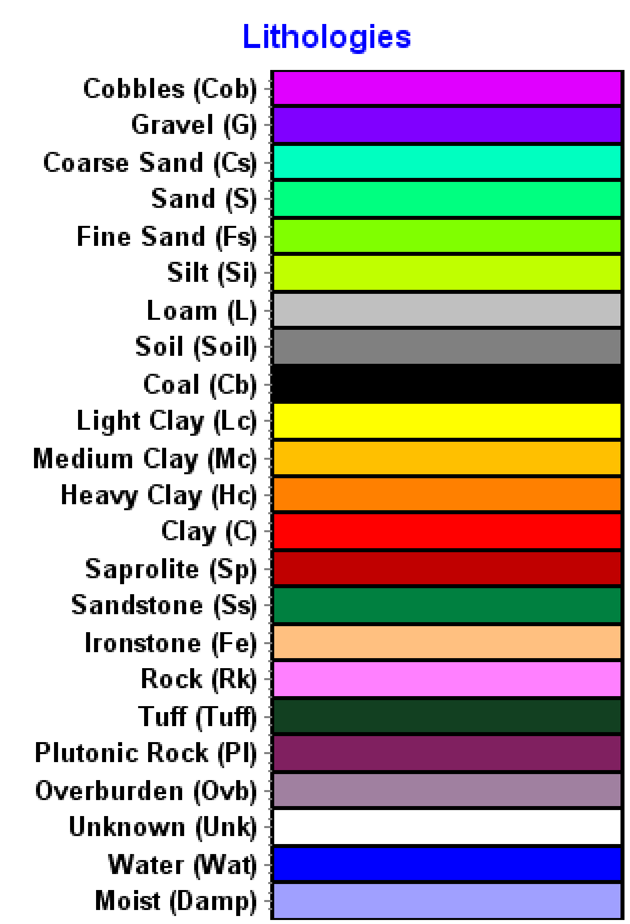
In the images, bore logs are displayed graphically using lithology keys such as the one given here.

Lithologies have been extracted from drillers written logs using an automated text interpreter. Due regard to the limitations and quality of this source of data and the interpretation process must be given.

Many lithologies have been presented with composite codes – eg. a Sandy Light Clay hosting water would display the codes for Sand, Light Clay and Water. Alternatively the driller may have given a water level. In this case the water level would be displayed at a horizontal blue plane.

Beware that the images are either not elevation corrected, or, if displayed in Google Earth, corrected only using the coarse Google Earth DEM. Because rivers are normally incised, imagery beneath them should normally be compared to lithologies about 10m lower in the bore logs.

In Google Earth, you can turn the icons and lithology key on/off. If you click on an Icon it displays a text box of any available bore details (water level, salinity, lithologies etc.).



Identifying depths on ribbons

The 3D imagery may have either linear or log (as shown here) depth scales. It is labelled on the south-west corner of the 3D viewing space (as shown). Notice here that the increments are logarithmic. Logarithmic depth plotting is often used so that deep data can be examined at the same time as detailed shallow (near canal bed) data. The geophysical data loses resolution with increasing depth and so this type of depth scale presents all the data in a way that is easy to see.

Look on the ribbon behind the depth scale and you will see a column of black ticks. These correspond to the ticks on the annotated depth scale. Notice that they bunch up at 1m. Black dots mark the projection of the ribbon onto the base plane of the viewing space which is 20 m below the surface. When lithological logs are also displayed, a linear depth scale is preferred as the lithology does not blur out with depth.

The canal bed is marked with an aqua line.