Conclusions

• East of a straight line approximating the route of Sandy Creek the substrate is typically resistive inferring that it is composed of relatively impervious unweathered rock. There is not clear evidence that westerly dipping resistive strata, exposed east of the creek, extend west of the creek under more conductive cover – rather the resistivity contrast occurs at all depths at approximately the same lineament. A steep fault is thus inferred.

• West of the same line, the substrate near the surface is much more conductive inferring relatively clayey and/or saline weathered sediment.

• There are some conductive features trending in other directions that in no way relate to present day watercourses. At O'Leary's, to the northwest, the main resistivity contrasts are more north-south and again do not exactly relate to the position of the river and are thought to be unrelated to alluvium.

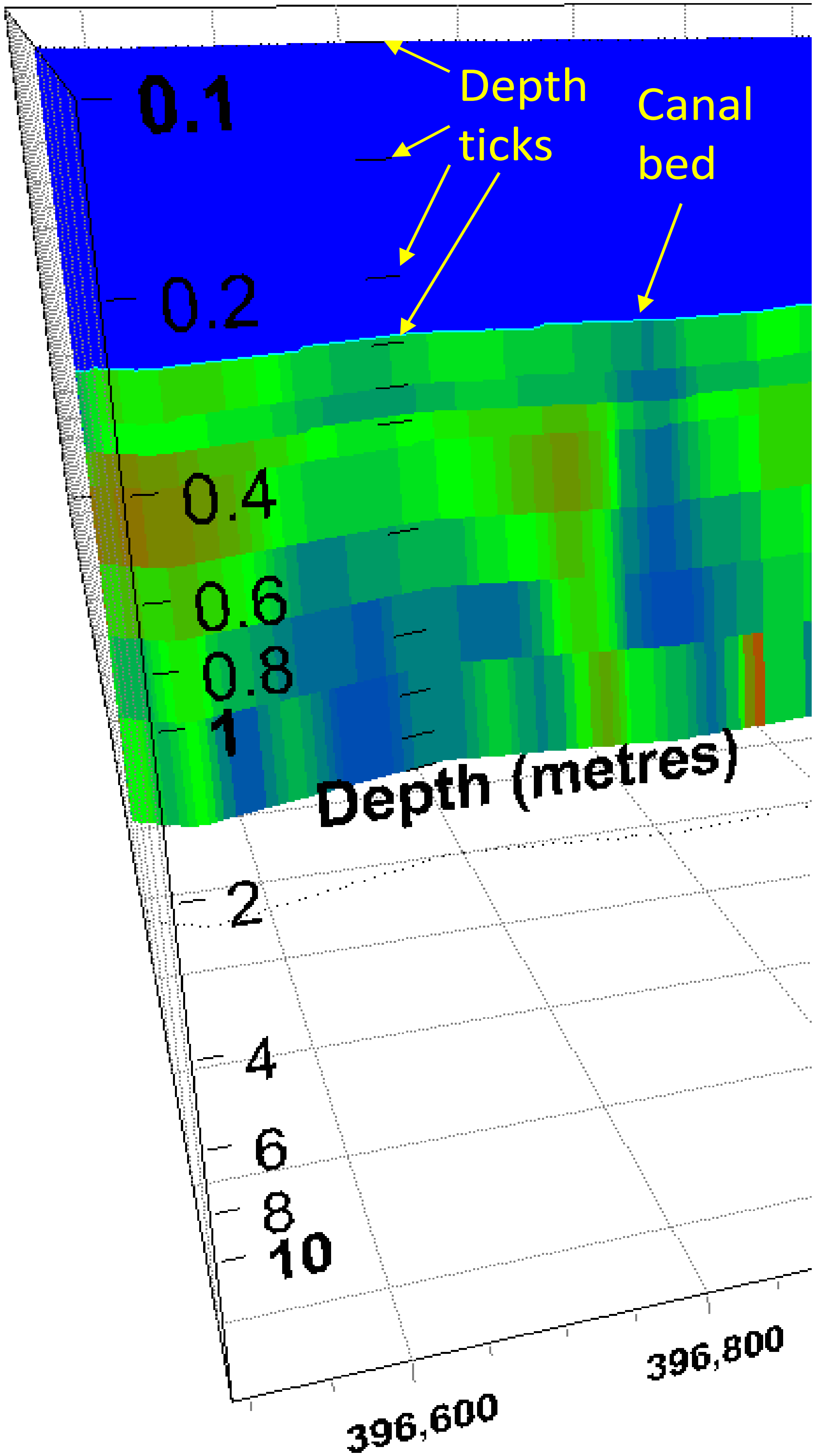
• Apart from some very shallow TEM features along the Talbragar River that are shaped like river meanders, there appears to be little correlation between the TEM data and alluvial thickness and this strongly suggests that alluvium related to the present day watercourses apart from the Talbragar River is close to absent from the site. There is potentially little difference between the composition and salinity of the alluvium that is present and underlying eluvium. Possibly even some of the types of consolidated rock beneath have similar salinity and permeability to this eluvium and alluvium. It is suspected that it is not possible or at least not easy to distinguish eluvium from alluvium in bore logs.

•Meander shaped TEM anomalies around the Talbragar River are most prominent at 1m and have almost disappeared by 12m deep. They are very conductive and do not extend to the river itself suggesting that they are charged with saline baseflow while sediment closer to the river has been recharged with fresh river sourced water from recent floods. They may also be clay filled billabongs.

Appendices

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

Identifying depths on ribbons

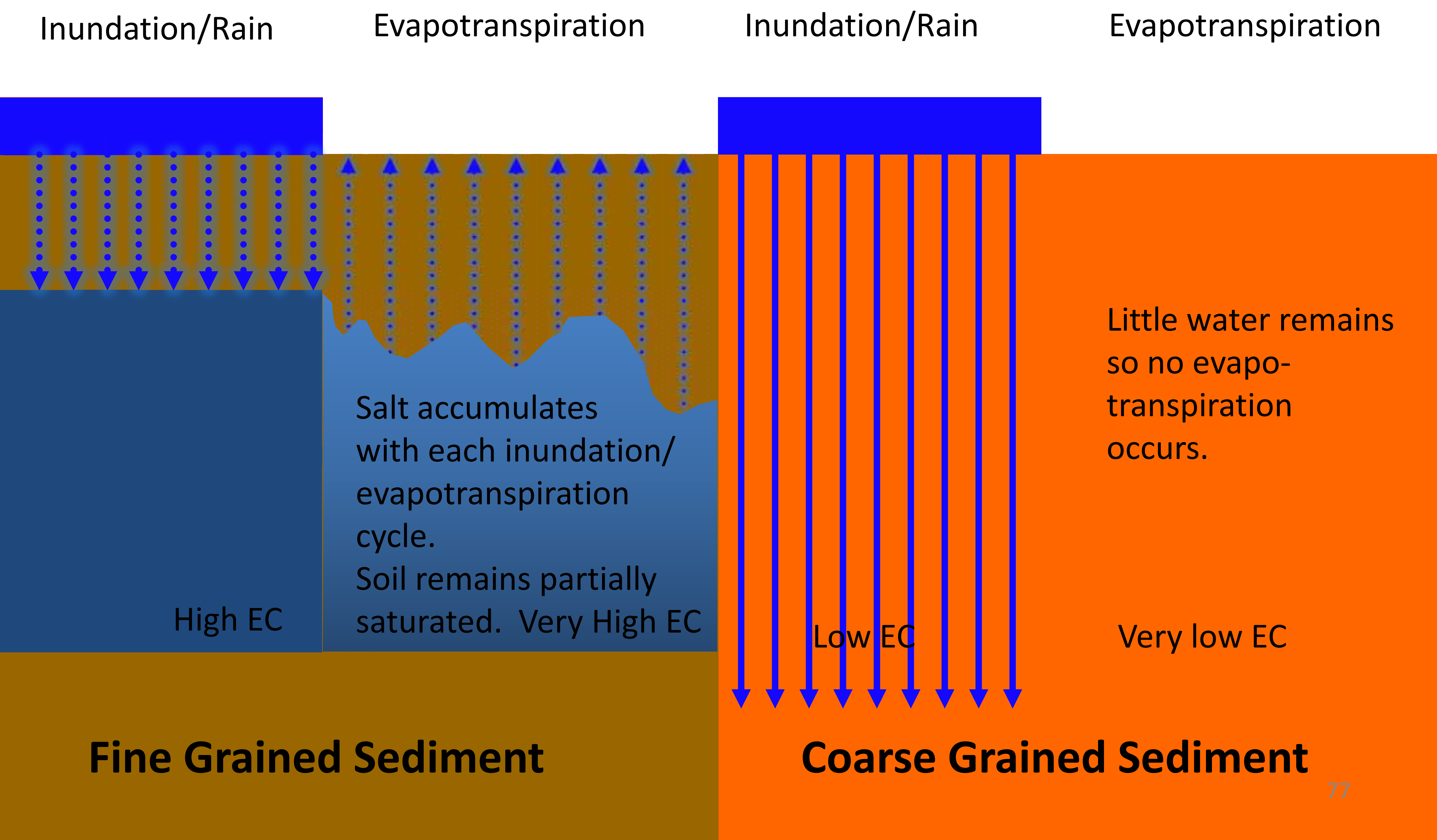


All the 3D imagery has the log or linear depth scales. It is labelled on the south-west corner of the 3D viewing space (as shown). Notice the increments are logarithmic. Logarithmic depth plotting is used so that deep data can be examined at the same time as detailed shallow (near canal bed) data. The 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.

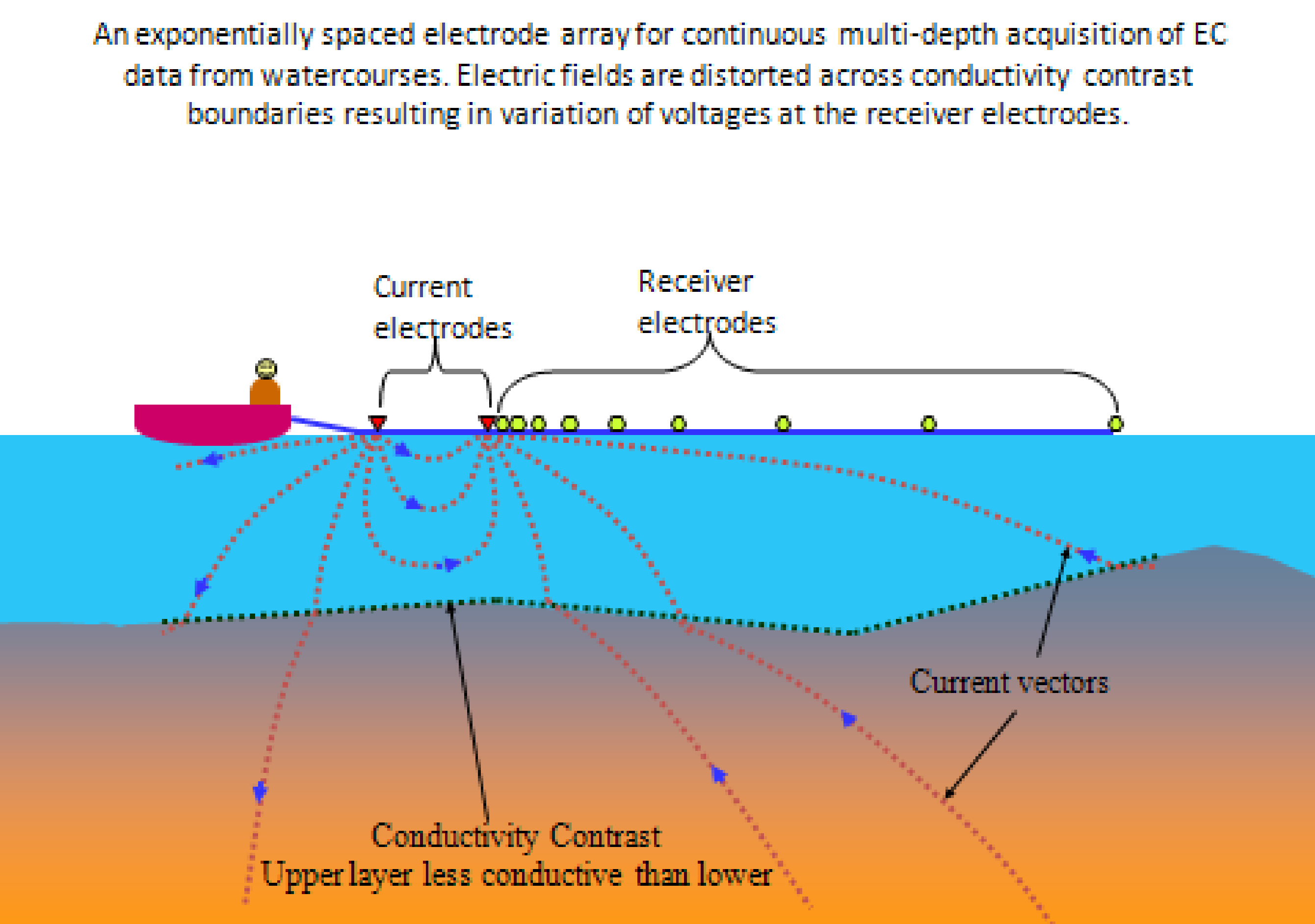
The canal bed is marked with an aqua line.

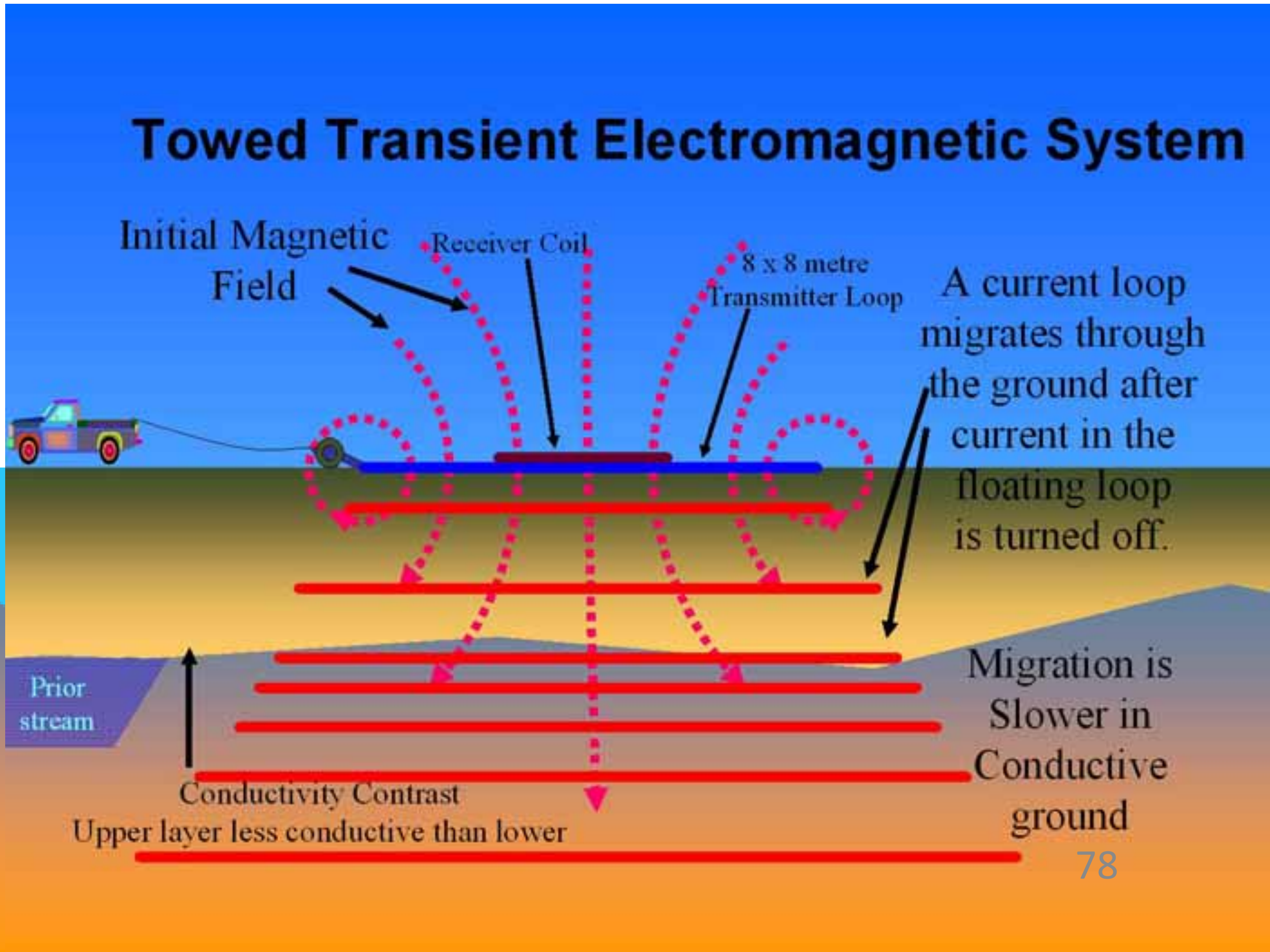
Seepage, EC and soil texture in a recharge dominated environment.



At depths significant to groundwater investigation, EC imaging may be conducted

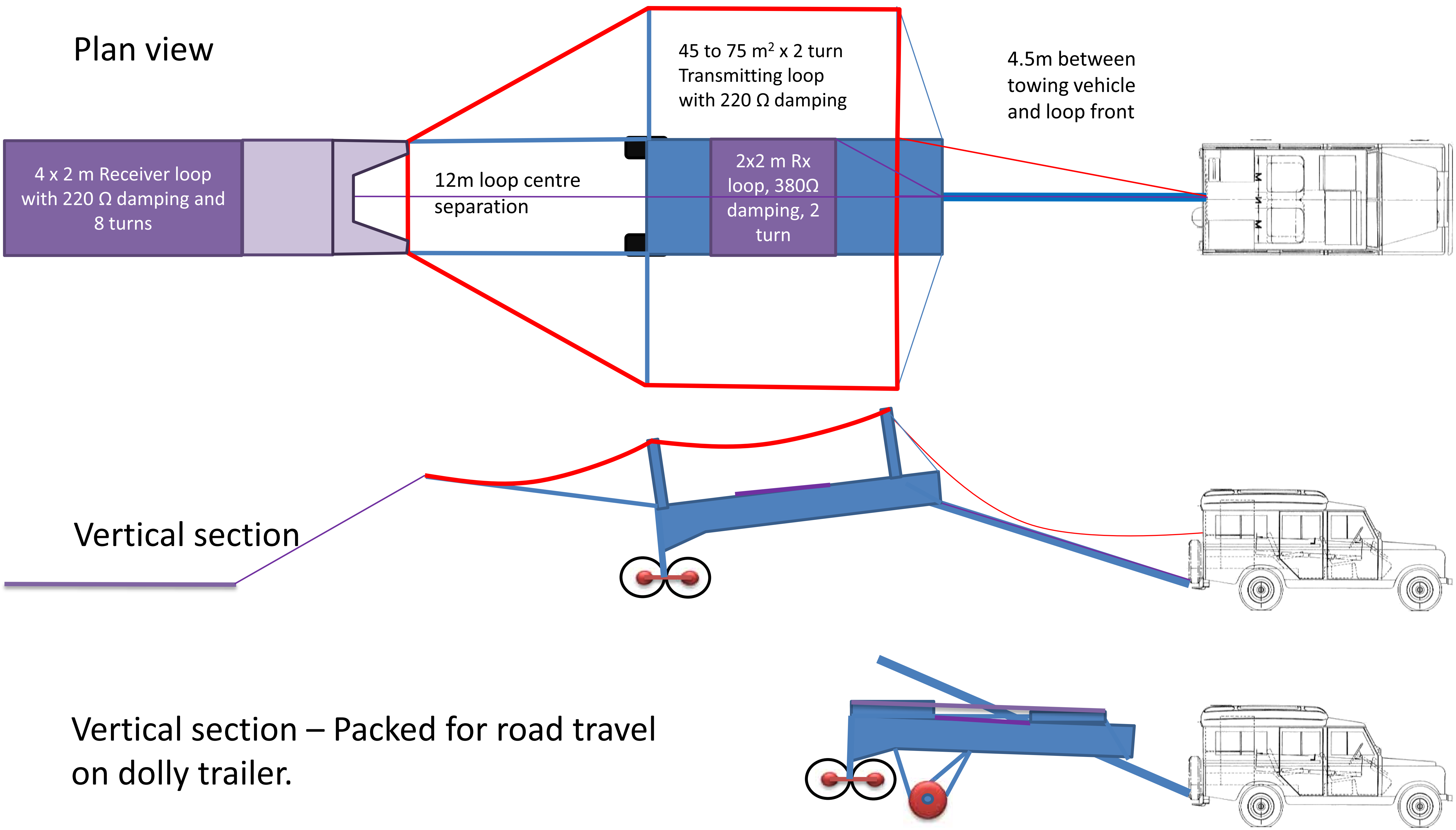
- on water, using geo-electric streamers
- on land, using Transient Electromagnetics (TEM)





Transient EM equipment configuration

(6 to 10 adjustable width) x 10 (length) metre transmitter loop platform

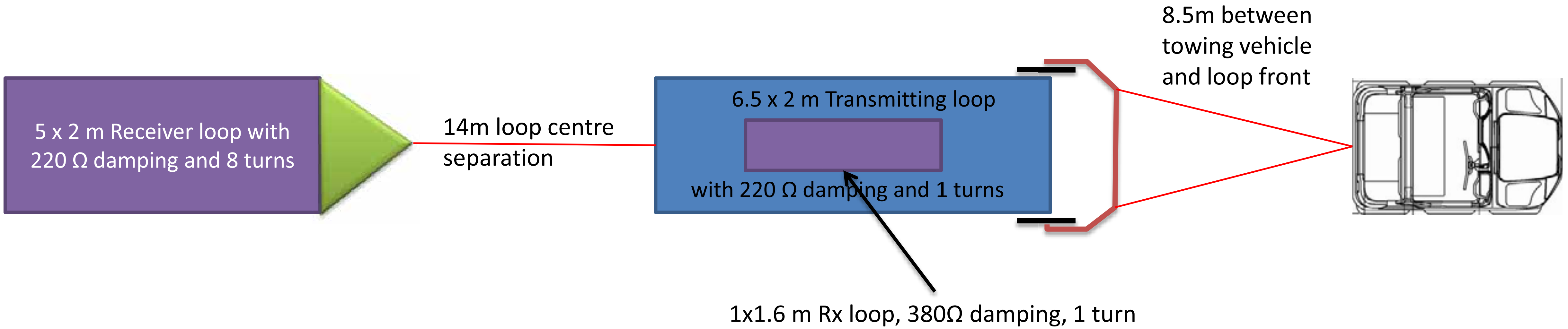


This schematic is not to scale

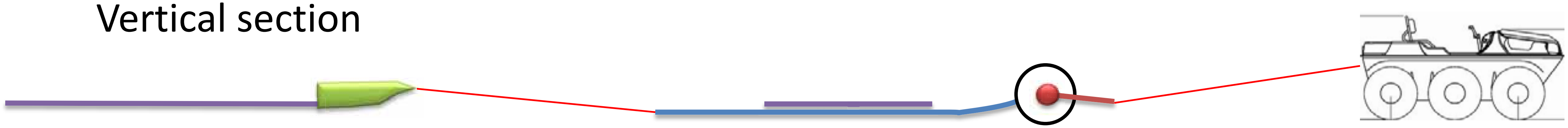
Transient EM equipment configuration

6.5 x 2 m transmitting loop towed mats system

Plan view

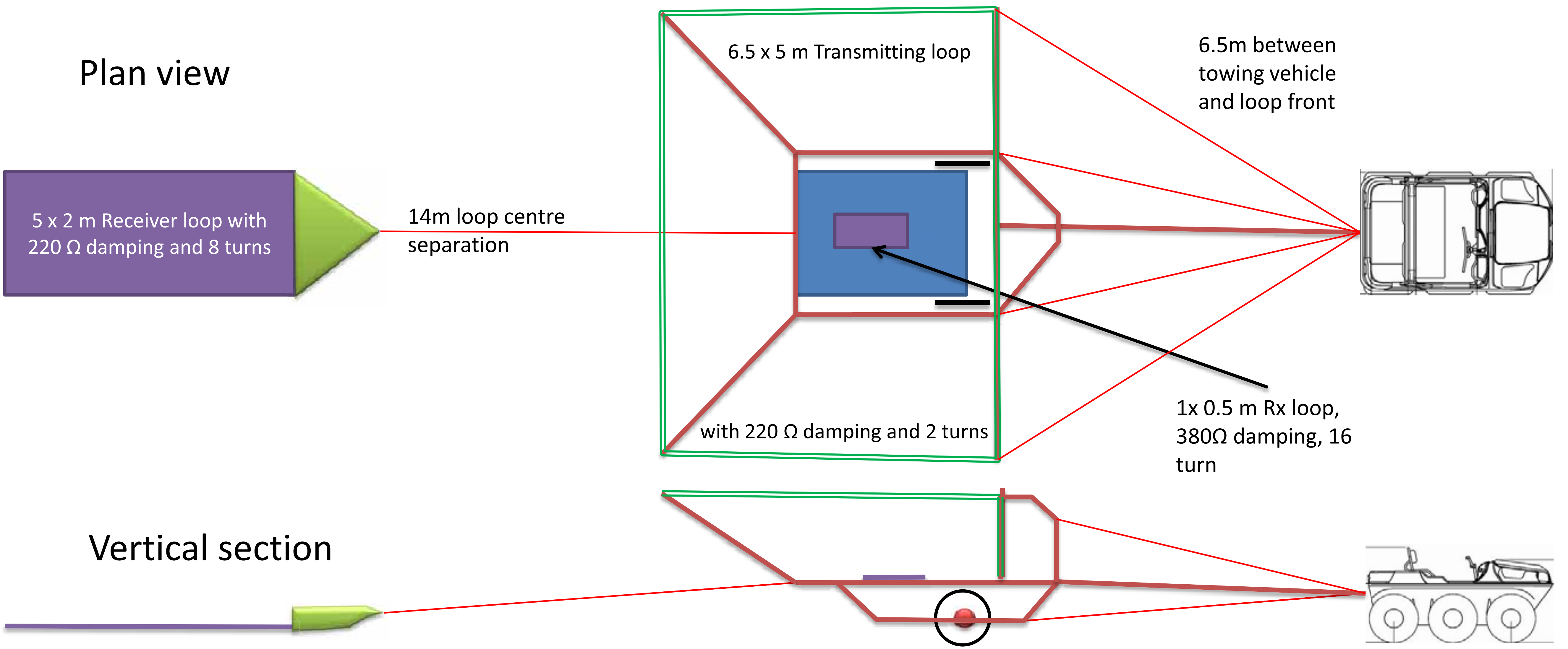


Vertical section



Transient EM equipment configuration

6.5 x 5 m transmitting loop towed TEM system



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.

The 6.5 x 5m transmitter loop towed electromagnetic system

Transient EM equipment specifications

Alpha Geo Instruments

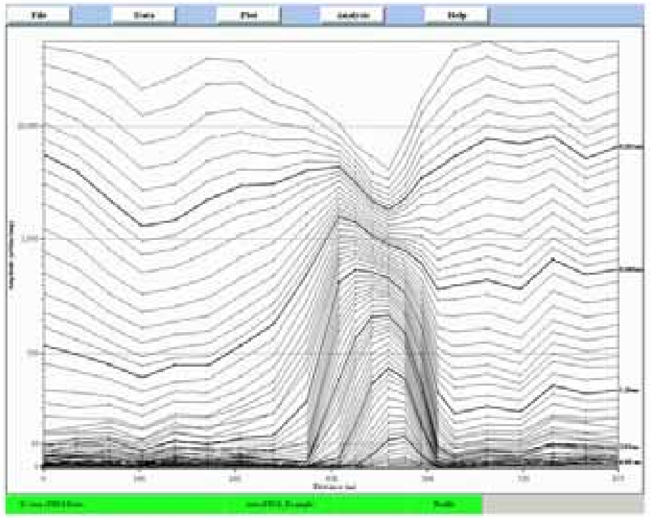
terraTEM
Time-Domain EM Surveying System

terraTEM Features

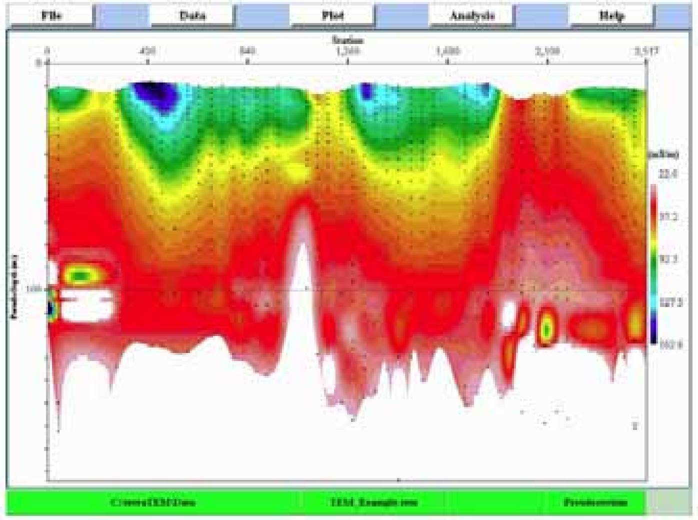
- Transmitter and receiver in one unit
- Single or 3 channel receiver with 10 amp. transmitter
- High speed sampling at 500 kHz for superior near surface resolution
- Easy to use touch screen with auto set-up and smart menus
- Large 15" LCD display for data visualisation
- Fast and easy data transfer 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)

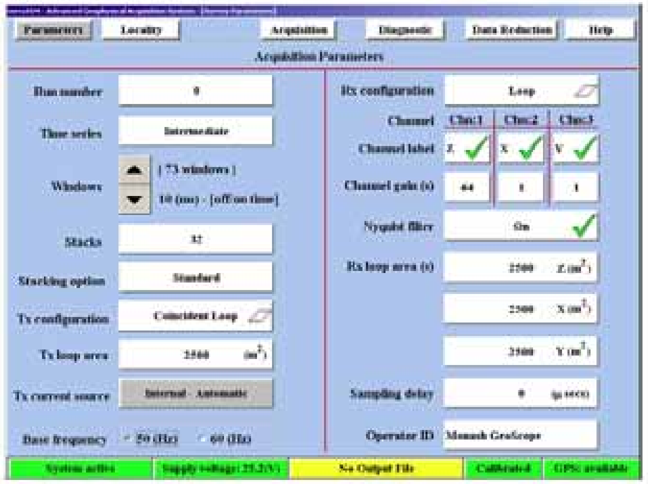
The **terraTEM** is designed, developed and manufactured by **Monash GeoScope**

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 GeoInstruments

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:

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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Unit 1, 43 Stanley Street, Peakhurst. N.S.W. 2210. Australia
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e-mail info@alpha-geo.com **website** www.alpha-geo.com

Your Distributor:

Towed platform TEM Method Description

- ***Towed platform TEM Method Description***
- Towed platform specifications are given on prior slides.
- Towed transient electromagnetic arrays have been applied by Sørensen, et. al.(2000), and the author (Allen, 2007) however the full potential of the technique is far from being realised. Other options for fast TEM data acquisition have been described by Harris et. al. (2006) and Hatch et. al. (2007).
-
- Key features of practical towed TEM devices are:
- They must facilitate towing of sufficiently large area transmitter loops and one or more receiver loops upon largely non-metallic structure;
- They must be robust enough to withstand field use;
- They must be capable of passing through farm gates and between other common obstructions without undue delay;
- They should be designed in such a way that they can isolate and minimise effects of incomplete transmitter turn off, loop self and mutual inductance, super-paramagnetic near-surface minerals and chargeable near-surface minerals;
- The transmitters need to be able to cleanly transmit high currents. Dual moment operation is beneficial;
- They must be readily road transportable and GPS equipped.
-
- Figure 4 presents a platform with the transmitter and receiver loops placed on dragged sheets, the sides of which can be raised when passing through gates. The main sheet is 2mm thick polyethylene which is heavy enough to prevent lifting by all but strong wind and rigid enough not to catch on stumps, barbed wire, and other obstacles. Practical size of the sheet is limited by the combination of the necessity of weight per unit area needed to prevent lifting by wind, and total weight which needs to be low enough to permit man-handling. The sheet is very useful for permitting precise layout of primary field nulling coils when using central loop receiver loops, and for spacing multi-turn transmitter loops so as to reduce self-capacitance and, to a lesser extent, self-inductance. It is difficult to increase the number of transmitter loop turns without compromising turn-off ramp integrity. This is a problem well understood by designers of airborne TEM systems.
-
- Receiver coil movement through the earth's magnetic field produces noise. When the coil is on a mat, it generally does not suffer from movement at frequencies above the sampling frequency as there are no taut elastic components that can resonate. Noise lower than the sampling frequency can be removed in post-processing of appropriately stacked data using techniques common to airborne TEM survey (eg. Noteboom, 2007).

Processing – introductory notes

One of the big advantages of a towed system is that it has a small near surface footprint that can isolate and avoid most problematic cultural effects. Further, it can be manoeuvred in order to test the effect of culture. In this way, processing, in effect, really starts during acquisition. Cultural effects need to be identified and this is done by repeatedly driving close to them and noting their response. Once problematic culture is identified, it is either avoided or its location is noted for later removal of affected data. The TerraTEM continuously displays decays of incoming data, and for quality control and verification of system response, these are continuously monitored while driving.

Data from all the relevant devices was merged together using interpolation and extrapolation where necessary. Position data was written in WGS84 UTM(MGA94 equivalent at the accuracy of the DGPS that will be used). Data is in tabular format in dBase files suitable for importing into ArcGIS and Google Earth products as specified in *Allen, D.A., 2005, Towards creation of a national multi-depth electrical conductivity database. Australian Society of Exploration Geophysicists, Preview, August, Issue No. 117.*

The Gridding was conducted as follows:

- Depth slice data was all log transformed;
- A proximity filter averaged points closer than 20m apart;
- An exclusion filter removed null records caused by depth slicing beneath cutoff depths;
- Natural neighbour gridding was performed with a cell size of 20m;
- The grid was blanked to remove most overshoots occurring around grid extremities in the absence of data;
- Gridding was imaged with valid and non-valid colour coded points registering data locations posted on the image so that viewers can determine what are real geological features and what are simply gridding artefacts. Non-valid points are important for showing where data cutoff above slicing depth as soundings penetrate much deeper depth when modelling resistive features – the result being that gridded data will be excessively resistive at depths below conductive feature cut out depths.

Data was then interpreted.

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.
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. Large mat receiver loops do not create much movement noise.
    2. Adjust magnitude according to primary field response (optional).
    3. Reject records with low primary field response as they are clearly suffering from equipment malfunction (eg. Receiver loop blown over by wind) (optional).
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 100 soundings in 2010)).
8. Remove system response, taking magnitude of transmitted data (proportional to *YVolts.DBF) into account for every sounding.
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. Alter the channel and repeat a.
    3. Repeat 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. This 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 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 9.
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.

Results – digital products

- EC datafiles in resistivity units - Ohm.metres accompany this presentation. There is one column for each layer sampled and one column for the depth to the bottom of each layer sampled. The datafiles are in dBase format and may be read using MS Excel, MS Access or ESRI software. ArcView contains a routine for expanding the dBase files into ESRI shapefiles but in most cases this is already done. Co-ordinates are all WGS84 (equivalent to MGA94 to the degree of accuracy of the survey) and are given as both UTM projection and latitude and longitude decimal degrees. Google Earth KML (or zipped = KMZ) format files are also provided for various 2D themes and in 3D. CSV ASCII files of depth slices also provided for generic loading into any spreadsheet or GIS software.
- **Results – Accompanying CD contents**
- The accompanying CD contains this document, digital data, the power point presentation, the A3Earth Plus. Further explanation is as follows:
- This report is stored as a *.doc (MS Word 2003 format) and *.pdf
- The powerpoint presentation is stored as *.ppt and *.pdf
- The Google Earth datasets are stored as *.KML and/or *.KMZ and are opened using File:Open in Google Earth.
- The A3 maps are stored, ready for viewing as *.pdf or *.jpg files
- Data files *Volt.dbf
- Transformed Data files *Ohmm.dbf.
- Depth slice files *DepthSlice.csv
- ESRI ArcMap file *.Mxd demonstrates access to transformed data files and can be used to locate them all.
- Golden Software Surfer *.srf displays and provides locations of all the gridded data files.
-
- All data is stored in GDA94/MGA94 UTM Zone 55 coordinates (Lat Long, E N, or both).

Production Report

Total production distance
excluding gaps >60m
= 286.46km Averaging 35.8km/day

Date	Charge	Details
7th October 2011	Reconnaissance	Drive Dubbo-Cobbora-Dubbo Conduct reconnaissance and discuss access with farmers and Cobbora Holdings Ltd. Staff. Arrange accommodation. Assess ground conditions after recent heavy rain.
8/10/11	Nil	Delay start due to wet ground
9/10/11	Nil	Delay start due to wet ground
10/10/11	Nil	Delay start due to wet ground
11/10/11	Production	Drive Dubbo to Cobbora 100m spaced survey of O'Leary's Farm. Float equipment to Mates and reassemble ready for survey again.
12/10/11	Production	Survey Mates Farms north-west of the River then east of the river.
13/10/11	Production	Survey Mates Farms north of the Highway and south of the river and then start south of the highway.
14/10/11	Production	Survey south of the Highway down the west side of Sandy creek. Return to Dubbo
17/10/11	Production	Drive Dubbo to Cobbora Survey northern Sandy creek.
18/10/11	Production	Survey southern Sandy Creek. Timing belt failed returning to Woolandra Cottage at end of day.
19/10/11	Nil	Towed back to Dubbo.
25/10/11	Production	Drive Dubbo to Cobbora. Survey Laheys Creek. Return to Dubbo.

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- Allen, D.A., 2007, Electrical Conductivity Imaging of Aquifers Connected to Watercourses - A Thesis Focused on the Murray Darling Basin, Australia., 480 pages (http://hdl.handle.net/2100/428, Abstract 0.1 MB; Full Thesis 12 MB)
- Allen, D.A., and Merrick, N.P., 2007, Robust 1D inversion of large towed geo-electric array datasets used for hydrogeological studies: Exploration Geophysics, Vol 38 No 1, ISSN0812-3985; Butsuri Tansa (Japanese) 60.1; and Mulli-Tamsa (Korean) 10.1. (http://www.publish.csiro.au/paper/EG07003.htm, Abstract 0.1 MB; Full Paper 1.7 MB).
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Appendix H

Groundwater Model Technical Report

Cobbora Coal Project Groundwater Model

Technical Report

January 2013

Cobbora Holding Company Pty Limited

PARSONS BRINCKERHOFF

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Certified to ISO 9001, ISO 14001, AS/NZS 4801
A+ GRI Rating: Sustainability Report 2010

2162570A PR_6743RevC

Revision	Details	Date	Amended By
00	Draft for EMM/CHC review	4 May 2012	Malcolm Graham
A	Final draft for adequacy	28 June 2012	Leah Gleeson
B	Final for public exhibition	14 September 2012	Liz Webb
C	Revised final post exhibition	25 January 2013	Malcolm Graham

Author: Malcolm Graham ....

Signed: ....

Reviewer: Stuart Brown; Noel Merrick (Heritage Computing) ....

Signed: ....

Approved by: Stuart Brown..

Signed: ....

Date: 25 January 2013..

Distribution: Client, Parsons Brinckerhoff file...

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Glossary

Aquifer	Rock or sediment in a formation, group of formations or part of a formation that is saturated and sufficiently permeable to transmit economic quantities of water to bores, wells and springs.
Aquifer properties	Characteristics of an aquifer that determine its hydraulic behaviour and its response to abstraction.
Aquifer, confined	Aquifer that is overlain by a confining, low-permeability layer. The hydraulic conductivity of the confining bed is significantly lower than that of the aquifer.
Aquifer, semi-confined	Aquifer confined by a low-permeability layer that permits water to slowly flow through it. During pumping, recharge to the aquifer can occur across the confining layer; also known as a leaky artesian or leaky confined aquifer.
Aquifer, unconfined	Also known as a water table or phreatic aquifer. An aquifer in which there are no confining beds between the zone of saturation and the surface. The water table is the upper boundary of unconfined aquifers.
Aquitard	Low-permeability unit that can store groundwater and also transmit it slowly from one aquifer to another. Aquitards retard but do not prevent the movement of water to or from an adjacent aquifer.
Artesian water	Groundwater that is under pressure when tapped by a bore and is able to rise above the level at which it is first encountered. It may or may not flow out at ground level. The pressure in such an aquifer is commonly called artesian pressure, and the formation containing artesian water is called an artesian aquifer or confined aquifer.
Australian Height Datum (AHD)	Reference point (very close to mean sea level) for all elevation measurements, and used for correlating depths of aquifers and water levels in bores.
Baseflow	Part of stream discharge that originates from groundwater seeping into the stream.
Bore	Structure drilled below the surface to obtain water from an aquifer system.
Boundary	Lateral discontinuity or change in the aquifer resulting in a significant change in hydraulic conductivity, storativity or recharge.
Drawdown	Lowering of the water table in an unconfined aquifer or the potentiometric surface of a confined aquifer.
Fissility	The property of rocks that causes them to split down planes of weakness.
Fracture	Breakage in a rock or mineral along a direction or directions that is not due to cleavage or fissility.
Groundwater	Water contained in interconnected pores located below the water table in an unconfined aquifer or located in a confined aquifer.

Groundwater age	The amount of time which has passed since groundwater was recharged to an aquifer as rainfall or via infiltration from surface water bodies.
Groundwater flow	Movement of water through openings in sediment and rock; occurs in the zone of saturation.
Groundwater flow system	Regional aquifer or aquifers within the same geological unit that are likely to have similar recharge, flow, yield and water quality attributes.
Hydraulic conductivity	The rate at which water can move through pore spaces or fractures. It depends on the intrinsic permeability of the material and on the degree of saturation.
Hydraulic gradient	Change in total hydraulic head with a change in distance in a given direction, which yields a maximum rate of decrease in head.
Hydraulic head	Specific measurement of water pressure or total energy per unit weight above a datum. It is usually measured as a water surface elevation, expressed in units of length. The hydraulic head can be used to determine a hydraulic gradient between two or more points.
Hydrogeology	Study of the interrelationships of geological materials and processes with water, especially groundwater.
Hydrostatic pressure	Gravitational pressure exerted by a fluid at equilibrium.
Infiltration	Flow of water downward from the land surface into and through the upper soil layers.
Parameterisation	The process of defining the parameters necessary for the specification of a model.
Permeability	Property or capacity of a porous rock, sediment, clay or soil to transmit a fluid. Measures the relative ease of fluid flow under unequal pressure. Hydraulic conductivity is a material's permeability to water at the prevailing temperature.
Permeable material	Material that permits water to move through it at perceptible rates under the hydraulic gradients normally present.
Piezometer (monitoring well)	Non-pumping monitoring well, generally of small diameter, which is used to measure the elevation of the water table and/or water quality. A piezometer generally has a short well screen through which water can enter.
Potentiometric surface	Surface to which water in an aquifer would rise by hydrostatic pressure.
Pumping test	Test made by pumping a bore for a period of time and observing the change in hydraulic head in the aquifer. It may be used to determine the capacity of the bore and the hydraulic characteristics of the aquifer.
Recharge	Process that replenishes groundwater, usually by rainfall infiltrating from the ground surface to the water table and by river water entering the water table or exposed aquifers; addition of water to an aquifer.
Recovery	Difference between the observed water level during the recovery period after pumping stops and the water level measured immediately before pumping stopped.

Saturated zone	Zone in which the voids in the rock or soil are filled with water at a greater pressure than atmospheric. The water table is the top of the saturated zone in an unconfined aquifer.
Sedimentary aquifers	Aquifers in consolidated sediments (such as porous sandstones and conglomerates, in which water is stored in the intergranular pores) and limestone (in which water is stored in solution cavities and joints). They are generally located in sedimentary basins that are continuous over large areas. Up to tens or hundreds of metres thick, they contain the largest groundwater resources.
Slug test	A hydraulic test in which a small volume (or slug) of water is suddenly removed from a well, or a small volume of water or material is added to the water column in the well. The water level response in the well over time is used to estimate the transmissivity or hydraulic conductivity of the aquifer.
Specific yield	Ratio of the volume of water a rock or soil will yield by gravity drainage to the volume of the rock or soil. Gravity drainage may take many months to occur.
Spring	Location where groundwater emerges on to the ground surface. Water may be free-flowing or slowly seeping.
Storativity	Volume of water and aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. It is equal to the product of specific storage and aquifer thickness. In an unconfined aquifer, the storativity is equivalent to specific yield.
Stratigraphy	The study of stratified rocks (sediments and volcanics), including their sequence in time, the character of the rocks and the correlation of beds in different localities.
Surface water – groundwater interaction	Occurs in two ways: (1) streams gain water from groundwater through the streambed when the elevation of the water table next to the streambed is greater than the water level in the stream; (2) streams lose water to groundwater by outflow through streambeds when the elevation of the water table is lower than the water level in the stream.
Transmissivity	Rate at which water of a prevailing density and viscosity is transmitted through a unit width of an aquifer or confining bed under a unit hydraulic gradient. It is a function of properties of the liquid, the porous media, and the thickness of the porous media.
Unconfined aquifer	Where the groundwater surface (water table) is at atmospheric pressure and the aquifer is recharged by direct rainfall infiltration from the ground surface.
Unsaturated zone	That part of an aquifer between the land surface and water table. It includes the root zone, intermediate zone and capillary fringe.
Water table	Surface in an unconfined aquifer or confining bed at which the pore water pressure is atmospheric. It can be measured by installing shallow wells extending a few feet into the zone of saturation and then measuring the water level in those wells.
Well	Any structure, deeper than it is wide, that is bored, drilled, driven or dug into the ground to reach groundwater.

Executive summary

Parsons Brinckerhoff was commissioned to undertake a groundwater assessment for the proposed Cobbora Coal Project (the Project). The objective of the groundwater assessment is to identify and quantify the potential impacts of the proposed mining operation on the groundwater regime, and to propose mitigation and contingency measures, where applicable, for those impacts that are likely to be unacceptable.

A numerical model was developed to provide a quantitative assessment of impacts from the proposed mining operation. The three-dimensional finite difference model was created using the Groundwater Vistas pre-processor. MODFLOW (McDonald & Harbaugh 1988) was used in conjunction with MODFLOW-SURFACT^{TM} (version 3) to allow for saturated and unsaturated flow conditions. The model is of moderate complexity and is suitable for predicting the impacts of the proposed operations and post-mining recovery, consistent with the 'impact assessment' class described by the Murray Darling Basin Commission (MDBC 2001), and is consistent with a Class 2 model, as described by the Australian groundwater modelling guidelines (Barnett et al, 2012). The guidelines state that this type of model is suitable for estimates of mine dewatering and assessments of associated impacts. The main aspects of model development are summarised below:

- The numerical groundwater model was based on the conceptual model Parsons Brinckerhoff (2013a) developed for the assessment area. The conceptual model builds on work by Parsons Brinckerhoff and others, and includes data collected during 2010-2011 as part of an extensive groundwater monitoring and testing program.

- The model was calibrated to baseline groundwater conditions using available groundwater monitoring information. Calibration was carried out in two stages with the assistance of automated parameter estimation software. First, a steady state model was developed to simulate average long-term conditions within the assessment area. Second, a transient calibration was carried out to further refine key model parameters, particularly in respect of the model's ability to simulate the effects of changes in groundwater flows arising from variations in rainfall between March 2010 and August 2011. Calibration of the model achieved a normalised root mean square error of 2.65% and 2.43% respectively for the steady state and transient runs. This is well within the target value of 5% agreed with the independent reviewer, Dr Noel Merrick.

- Sensitivity analyses carried out on both the steady state and transient models indicate that model calibrations are relatively insensitive to the majority of the input parameters. The model is most sensitive to the horizontal conductivity of the Digby Formation, Whaka Formation, Ulan Coal Seams and Dapper Formation and also storage and recharge in the Digby Formation. The results were used to make further refinements to estimates of model input parameters.

The calibrated model was developed further, to allow a predictive simulation of mine inflow rates and changes in groundwater level over time. The proposed mine plan, provided by Cobbora Holding Company Pty Limited (CHC) (2012), was represented in the model by drain cells, which were active only during the period of excavations in that area of the mine and for one year afterwards, prior to backfilling. The recharge and hydraulic properties assigned to the backfill material were based on work by Mackie (2009), using the transient material properties capability in MODFLOW-SURFACT. Following the cessation of proposed mining activities, the model simulates the residual mine void. In all other excavated areas, backfill material has been simulated. The model records simulated flows and groundwater levels four times each year during the life of the mine, and at yearly intervals for 50 years after cessation of the proposed mining operations and subsequently at decadal intervals for a further 950 years.

The results of the predictive modelling are summarised as follows:

- Mine inflow rates are predicted to peak at approximately 2,800 megalitres per annum (ML/a) after 14 years of mining, with dewatering rates typically greater than 2,000 ML/a between 7 and 18 years after mining commences. Approximately half of all mine inflows are expected to occur in mining area B.

- Net groundwater usage during the proposed mine life is predicted to be close to 2,000 ML/a between 2021 and 2030, reaching a maximum value of approximately 2,200 ML/a in 2028.

- Predicted cumulative storage losses within the alluvium reach a maximum value of approximately 720 ML. This constitutes 0.3% of the estimated 220,000 ML (220 GL) of available groundwater storage in the alluvium within the model domain.

- The model results indicate a maximum reduction in river flows of approximately 480 ML/a, which occurs in 2036 following the end of mining operations. This constitutes 0.9% of the average annual flow in the Talbragar River.

- Thirteen privately owned groundwater bores in the area are expected to experience drawdown of more than 2 m during the life of the mine. Only three of these bores (PB32, GW012551 and GW801735) are not on land owned by Cobbora Holding Company Pty Ltd (CHC). PB32 shows a maximum drawdown of 5.1 m, predicted to occur in 2038, with drawdown of more than 2 m predicted until about 2083. GW012551 shows a maximum drawdown of 2.4 m, predicted to occur in 2041, with residual drawdown decreasing to less than 2 m by 2055. GW801735 shows a maximum drawdown of 2.2 m, predicted to occur in 2037, with residual drawdown decreasing to less than 2 m by 2042.

An analysis was conducted to assess the model response to changes in the most uncertain input parameters. The following parameter variations were applied to the model:

- +/- 50% change to the hydraulic conductivity of the Ulan Coal Seams

- +/- 50% change to the hydraulic conductivity of the backfill material.

The analysis indicates that mine dewatering rates and groundwater usage may vary by up to 12% as a result of the above parameter variations.

The groundwater model and draft version of the Groundwater Model Technical Report were externally reviewed by Dr Merrick (Heritage Computing) in February 2012. Comments from the review were addressed in the final model and incorporated into this report and a second peer review was undertaken by Dr Noel Merrick.

1. Introduction

Parsons Brinckerhoff was commissioned by Cobbora Holding Company Pty Limited (CHC) to undertake a groundwater assessment for the proposed Cobbora Coal Project (the Project).

Parsons Brinckerhoff developed a groundwater numerical model to provide a qualitative assessment of impacts from the proposed mining operation. The model and draft report were externally reviewed by Noel Merrick (Heritage Computing) in February and July 2012. Comments from the review are provided in Appendix I of *Cobbora Coal Project – Groundwater Assessment* (Parsons Brinckerhoff 2013a) and were addressed in the final model. The results from the final model are reported in this document.

A summary of the hydrogeological conceptual model developed for the assessment area is presented in this document. A more detailed description of the conceptual model is provided in the main body of the Cobbora Coal Project - Groundwater Assessment (Parsons Brinckerhoff 2013a).

2. Data analysis and hydrogeological setting

2.1 Setting

A map of the assessment area and the extent of the groundwater model are shown in Figure 2.1. A detailed description of the hydrological, geological and hydrogeological features of the assessment area is provided in the Cobbora Coal Project - Groundwater Assessment (Parsons Brinckerhoff 2013a). A summary of these features is presented in Figure 2.3.

2.1.1 Hydrological catchment

The assessment area is located within the Sandy Creek and Laheys Creek catchments, which are subcatchments of the Talbragar River, which in turn is a subcatchment of the larger Macquarie–Bogan River catchment. The Sandy Creek and Laheys Creek catchments cover an area of 282 km^2.

2.1.2 Topography and land use

The topography of the site is undulating to hilly, with elevations of approximately 320 m Australian Height Datum (AHD) to the north-west of the assessment area, rising to approximately 660 m AHD at the south-eastern end of the assessment area. The site is drained by the northerly flowing Sandy Creek and Laheys Creek. The creeks converge within the Project footprint and flow north to the Talbragar River, which forms the northern extent of EL7394.

The assessment area is mostly cleared and used for agricultural purposes, including grazing sheep and cattle, and cultivating cereal crops. Only 6% of the total area contains areas of conservation, state forest and national park (ERM 2009), including the Goodiman State Conservation Area, Dapper Nature Reserve, Tuckland State Forest and the Yarrobil National Park (M Branson, pers. comm. 28 May 2010).

2.1.3 Geology

The assessment area is located within the south-western portion of the Gunnedah Basin, in the Gilgandra Trough, to the west of the Western Coalfield. The Gunnedah Basin contains a sequence of marine and non-marine Permian and Triassic sediments, and is an important Permian coal-bearing basin. The Project’s target geology is the coal-bearing sequences of the Late Permian Dunedoo Formation. The Gunnedah Basin units within the assessment area are underlain by Silurian and Devonian units of the Lachlan Orogen.

Jurassic sandstone units of the Surat Basin overlie the Gunnedah Basin and occur on the northern periphery of the assessment area. Quaternary alluvium is present around river floodplains and some larger creeks. A summary table of the stratigraphy, predominantly based on Marston (2009), is shown in Table 2.1. A more detailed representative stratigraphic column for the assessment area is presented in Figure 2.2.

The outcropping geology is presented in Figure 2.3, along with the locations of cross-sections shown in Figure 2.4 to Figure 2.7.

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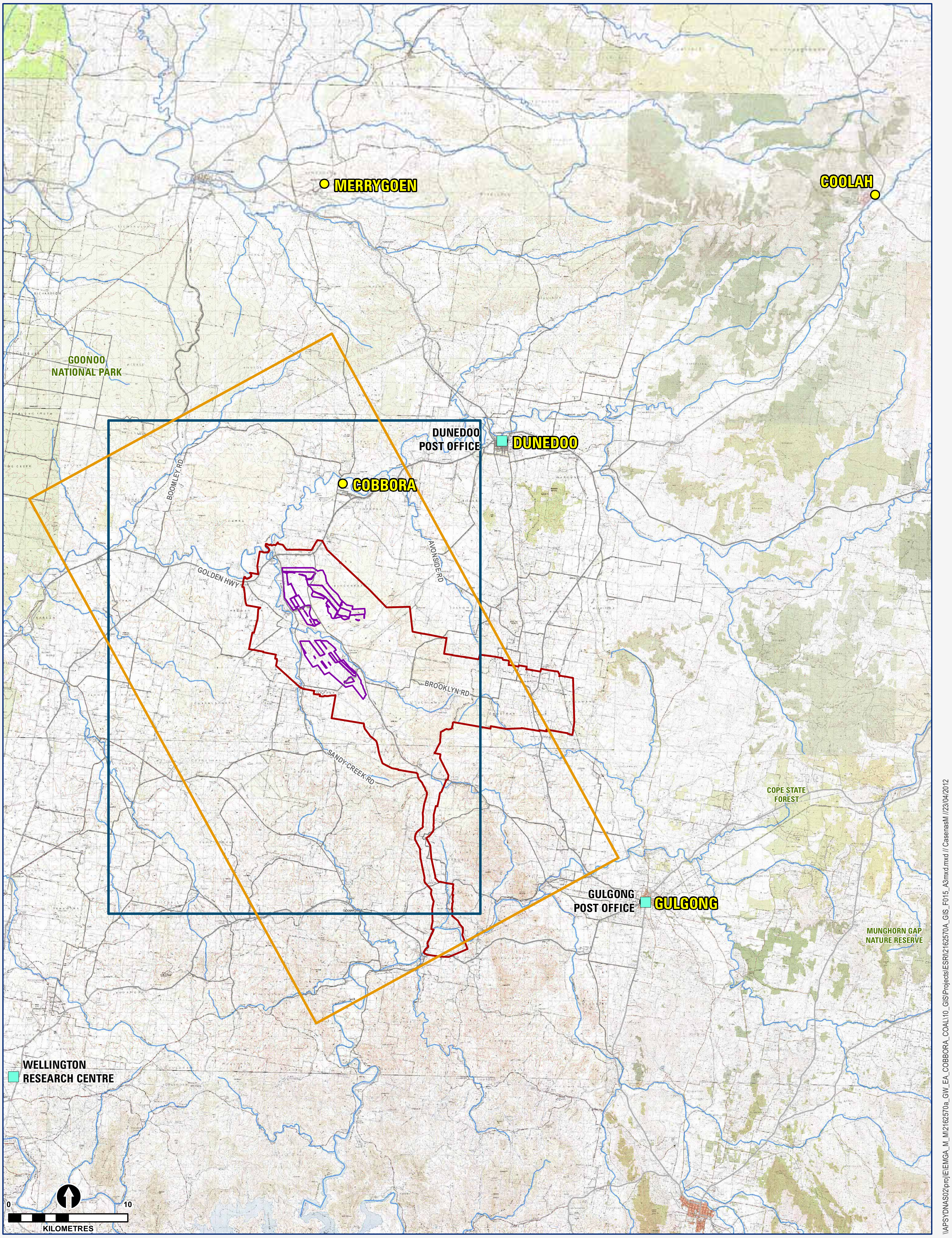


- Bureau of Meteorology station
- Assessment area
- Model extent
- Project Application Area (approximate) (as of February 2012)
- Drainage lines
- Roads
- National parks & state forests
- Proposed mining areas

Figure 2.1 Site plan and model extent

Topographic map source: NSW Department of Lands, 1989

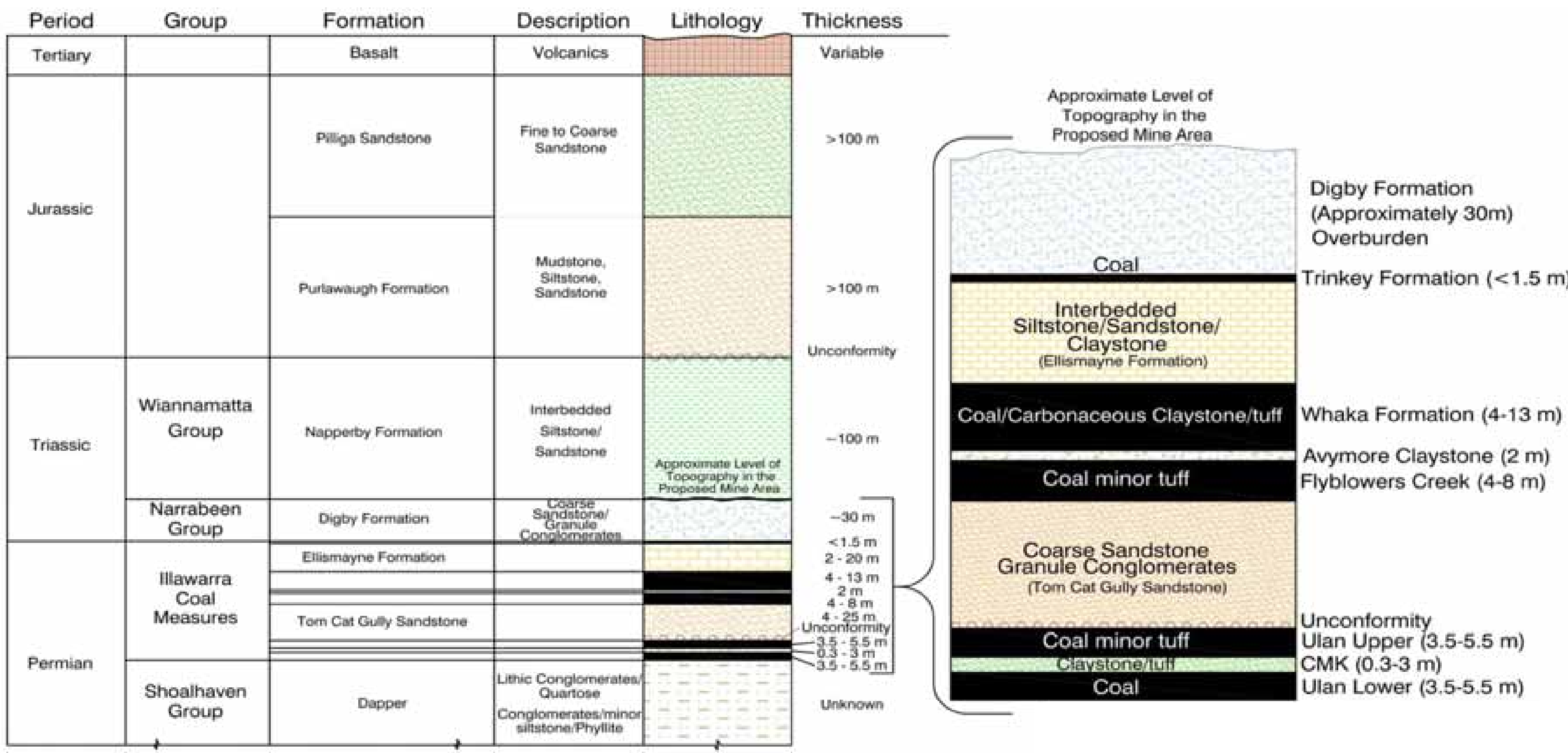
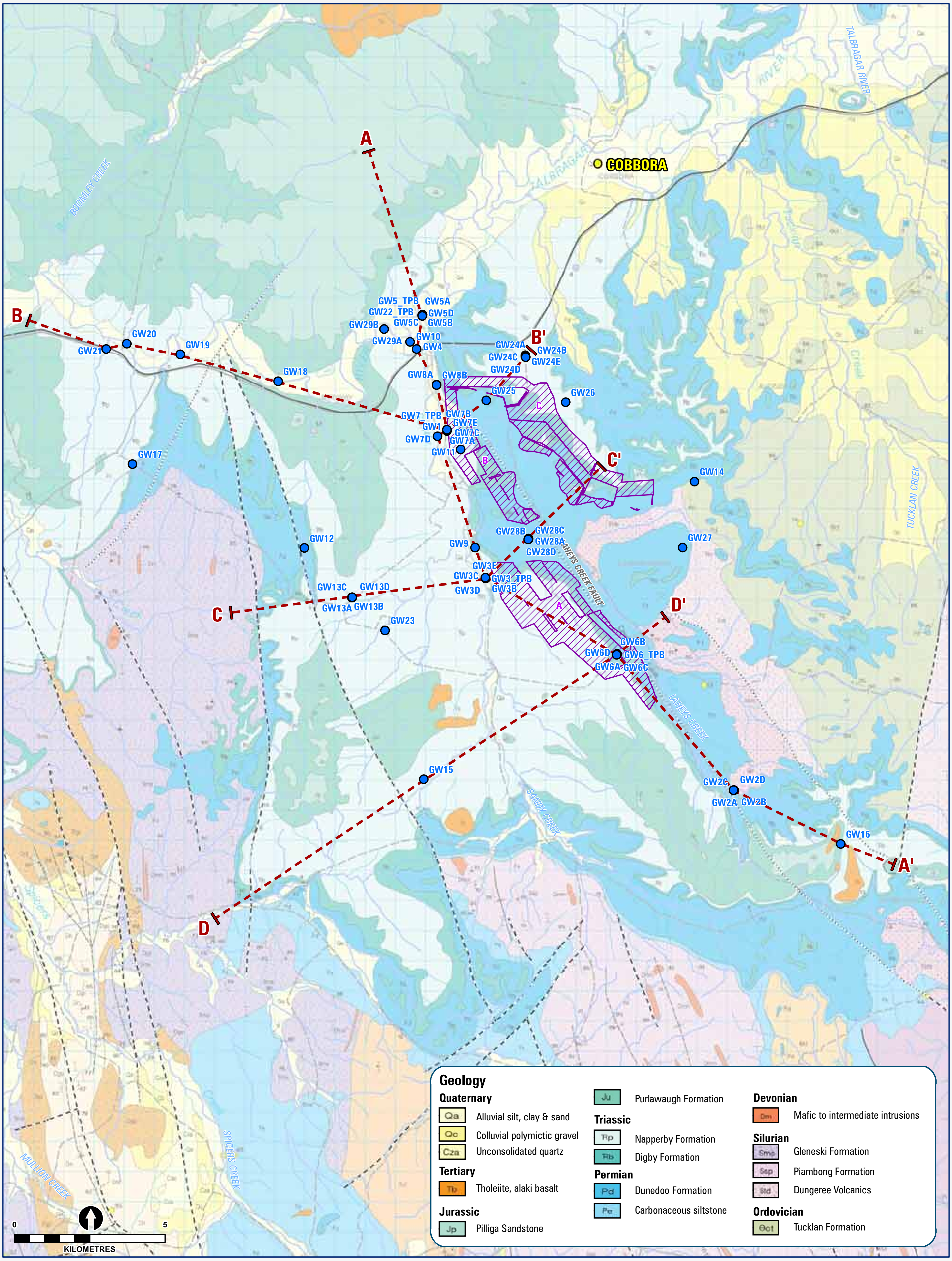


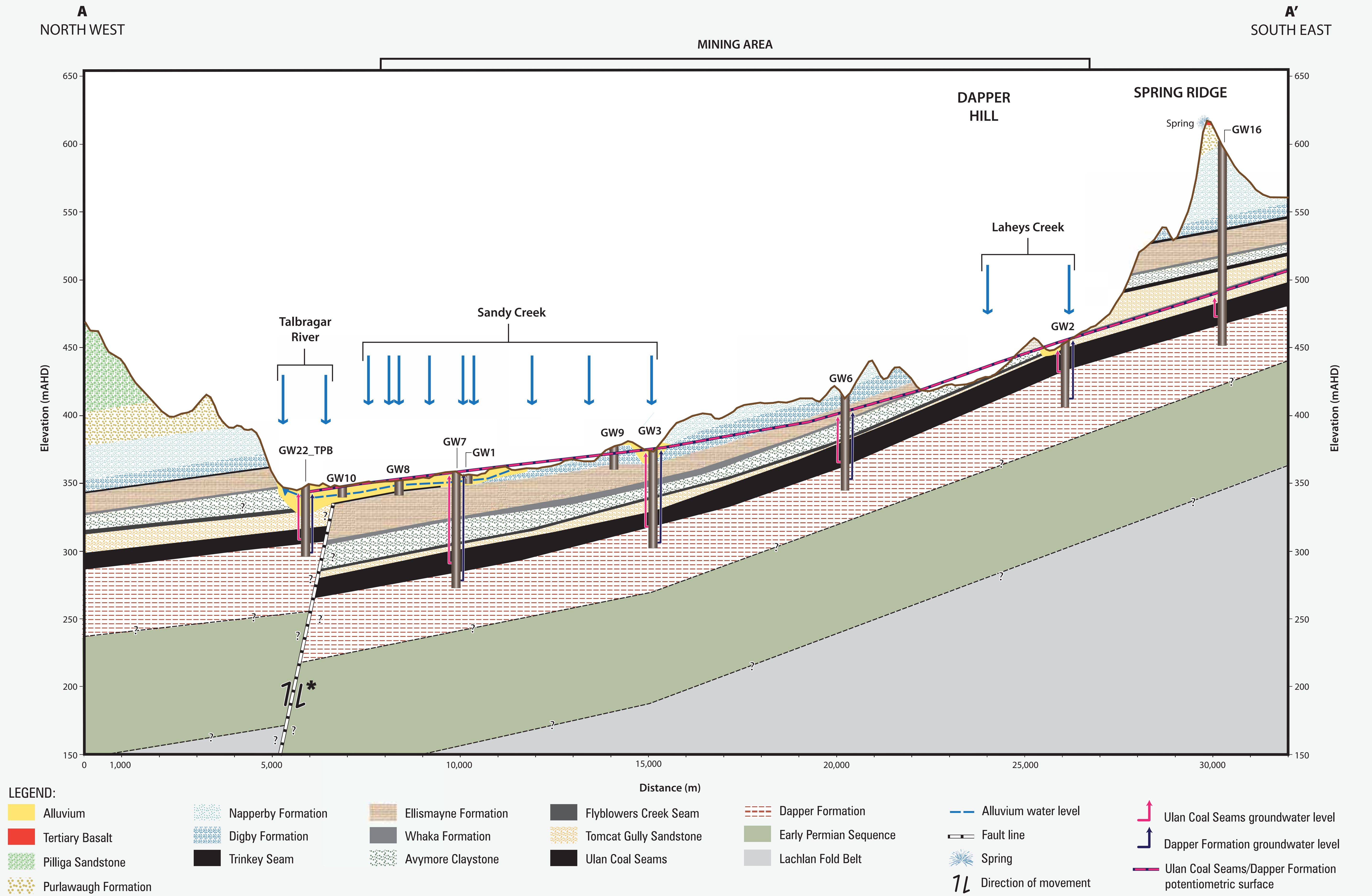
Figure 2-2: Representative stratigraphic column for the Project area (Marston, 2009)



- Piezometer sites
- Drainage lines
- Fault - approximate
- Fault - concealed
- Proposed mining areas

Figure 2.3 Site geology and geological structures

Geologic map source: Geological Survey of New South Wales, 1999



Note: * *Interpreted extension to Laheys Creek fault.*

Figure 2.4 Conceptual hydrogeological cross-section A - A'