MALABAR COAL

MAXWELL PROJECT

APPENDIX B

Groundwater Assessment

Maxwell Project: Groundwater Assessment

In support of an EIS

FOR

Malabar Coal Limited

BY

NPM Technical Pty Ltd
trading as:
HydroSimulations

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GLOSSARY

Abbreviation	Definition
AIP	Aquifer Interference Policy
AGE	Australasian Groundwater and Environmental Consultants Pty Ltd
AGL	AGL Energy Ltd
ANC	Acid neutralising capacity
ANZECC	Australian and New Zealand Environment and Conservation Council
BGL	Below ground level
BoM	Bureau of Meteorology
BSAL	Biophysical Strategic Agricultural Land
CDM	Cumulative Departure from Mean
CHD Package	Constant head package for MODFLOW
CHPP	Coal Handling and Preparation Plant
CIC	Critical Industry Cluster
cm	Centimetre(s)
CVFD	Control Volume Finite Difference
DEM	Digital Elevation Model
DGS	Ditton Geotechnical Services
DGV	Default Guideline Value
DMR	Department of Mineral Resources
DO	Dissolved oxygen
DoI Water	Department of Industry - Water
DP&E	NSW Department of Planning and Environment
Drawdown	The localised lowering of groundwater level. Drawdown is also used interchangeably with depressurisation to refer to depression of the potentiometric surface (including in some cases where physical dewatering does not occur).
DRN	Drain package for MODFLOW
EC	Electrical conductivity (salinity)
EIS	Environmental Impact Statement
EL	Exploration Licence
ENRS	Environment and Natural Resource Solutions
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999
EVT	Evapotranspiration package for MODFLOW
FD	Finite Difference

Abbreviation	Definition
GDA	Geocentric Datum of Australia
GDE	Groundwater Dependent Ecosystem
GHB	General Head Boundary
GWMP	Groundwater Management Plan
HITS	Hunter Integrated Telemetry System
HVEC	Hunter Valley Energy Coal Pty Ltd
HVO	Hunter Valley Operations
IESC	Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development
km	Kilometres
Kx	Horizontal hydraulic conductivity
Kz	Vertical hydraulic conductivity
L	Litres
L/s	Litres per second
m	Metres
mAHD	Metres above Australian Height Datum
MDBC	Murray Darling Basin Committee
MER	Mackie Environmental Research Pty Ltd
mg	Milligrams
ML	Megalitres
mm	Millimetres
MSEC	Mine Subsidence Engineering Consultants Pty Ltd
Mtpa	Million tonnes per annum
NAF	Non-acid forming
NARCliM	NSW and ACT Regional Climate Modelling
NGIS	National Groundwater Information System
NHMRC	National Health and Medical Research Council
NSW	New South Wales
PAF	Potentially acid forming
pH	Parts hydrogen (unit of acidity/alkalinity)
RCH	Recharge package for MODFLOW
RIV	River package for MODFLOW
RMS	Root mean square

Abbreviation	Definition
ROM	Run-of-mine
SEARs	Secretary’s Environmental Assessment Requirements
SILO	Scientific Information for Land Owners
Ss	Specific storage
Sy	Specific yield
TDS	Total dissolved solids (salinity)
TEM Survey	Transient Electromagnetic Survey
TVM	Time-variant materials
USGS	Un-Structured Grid
VWP	Vibrating Wire Piezometer
WRM	WRM Water and Environment Pty Ltd
WSP	Water Sharing Plan
µS	MicroSiemens

1 INTRODUCTION

Maxwell Ventures (Management) Pty Ltd, a wholly owned subsidiary of Malabar Coal Limited (Malabar), is seeking consent to develop an underground coal mining operation, referred to as the Maxwell Project (the Project).

The Project is in the Upper Hunter Valley of New South Wales (NSW), east-southeast of Denman and south-southwest of Muswellbrook (**Figure 1**).

Underground mining is proposed within Exploration Licence (EL) 5460 (**Figure 2**), which was acquired by Malabar in February 2018. Malabar also acquired existing infrastructure within Coal Lease (CL) 229, Mining Lease 1531 and CL 395, known as the "Maxwell Infrastructure". The Project would include the use of the substantial existing Maxwell Infrastructure, along with the development of some new infrastructure (**Figure 3**).

This assessment forms part of an Environmental Impact Statement (EIS) which has been prepared to accompany a Development Application for the Project in accordance with Part 4 of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act).

This Groundwater Assessment has been guided by the requirements of the NSW Department of Planning and Environment (DP&E) Secretary's Environmental Assessment Requirements (SEARs) for the Project (first issued on 2 September 2018 and revised on 17 January 2019), including the Commonwealth Department of the Environment and Energy assessment requirements (issued 20 November 2018). This Groundwater Assessment has also considered the advice and recommendations from Department of Industry – Water (DoI Water) (dated 20 December 2018), the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) (dated 9 November 2018) and the report by the NSW Mining and Petroleum Gateway Panel (the Gateway Panel) to accompany a Conditional Gateway Certificate for the Project issued on 20 December 2018. The Groundwater Assessment was prepared cognisant of other State Government agencies' comments included in Attachment 2 of the SEARs, which included comments by Muswellbrook Shire Council (dated 29 August 2018).

1.1 EXPLORATION AND PREVIOUS MINING

1.1.1 MAXWELL INFRASTRUCTURE (FORMER DRAYTON MINE)

Operations at the former Drayton Mine commenced in 1983. A Development Consent granted by the Muswellbrook Shire Council in 2002 (DA 163/2002) allowed for production of up to 5.5 million tonnes per annum (Mtpa) of run-of-mine (ROM) coal. On 1 February 2008, Project Approval 06_0202 was granted for the extension open cut mining operations with a maximum extraction rate of 8 Mtpa of ROM coal, and for the continued use of, and maintenance of, surface infrastructure.

The five coal seams targeted included the Broughams, Grasstrees, Thiess, Puxtrees and Balmoral seams, within the Rowan Formation of the Greta Coal Measures.

Open cut mining comprised a dragline, excavators, and haul trucks to remove mining waste, with loaders and/or excavators for coal extraction supported by a fleet of haul trucks, which transported the ROM coal to the Coal Handling and Preparation Plant (CHPP).

Open cut mining at the former Drayton Mine ceased in October 2016 under the ownership of Anglo American plc. Approval for coal extraction, under Project Approval 06_0202, lapsed on 31 December 2017. On 26 February 2018, the ownership of both the former Drayton Mine (now the Maxwell Infrastructure) and EL 5460 was formally transferred to Malabar.

1.1.2 MAXWELL UNDERGROUND

Exploration in the Project area commenced in the late 1940s, with exploration occurring in several phases since that time. In 1986, a Development Consent was granted to Mt Arthur South Coal Limited for an open cut mine in the Project area, although this consent lapsed in 1991.

EL 5460 was granted in 1998 and has been systematically explored following its grant. In total, more than 950 exploration boreholes have been drilled and approximately 75% of the area covered by 3D seismic survey. In addition, groundwater and surface water studies of the Project area were conducted by Mackie Environmental Research (MER) (1998). The MER (1998) study included regional data gathering, installation of eight piezometers into coal measures, core inspections and laboratory testing, formation hydraulic testing, monitoring of groundwater levels and computer-based groundwater flow modelling. Subsequently, MER (2001) consolidated hydrogeological data arising from the 2001 exploration drilling program targeting the deeper Woodlands Hill, Arrowfield, Bowfield, and Warkworth coal seams.

Anglo American plc made two applications in 2012 and 2015 for an open cut coal project in EL 5460, known as the Drayton South Coal Project. These applications included groundwater impact assessments and numerical groundwater modelling completed by Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) (2012, 2015).

The IESC provided initial advice to the Commonwealth Department of Sustainability, Environment, Water, Population and Communities on the first project proposal for the Drayton South Coal Project (dated 1 February 2013). The IESC provided additional advice on the Drayton South Coal Project open cut proposal at the Gateway and Assessment advice stages in February 2015 (IESC 2015-064) and June 2015 (IESC 2015-069).

The later IESC advice (IESC 2015-069) focused on the assessment of potential cumulative impacts on Saddlers Creek and the Hunter River and made recommendations for improvements to the monitoring program (Question 7 and response, IESC 2015-069).

The NSW Planning Assessment Commission (PAC) Determination Report (dated 22 February 2017) found that the Drayton South Coal Project "… would, subject to the mitigation measures proposed by the Applicant and the conditions recommended by the Department, have an acceptable impact on surface water and groundwater resources".

Malabar acquired EL 5460 in February 2018 for the purpose of developing an underground mining operation. The current conditions of EL 5460 only allow prospecting for the purposes of the assessment and potential future extraction of underground resources.

Data from previous investigations and studies within the Project area and surrounds have been used to inform this Groundwater Assessment.

1.2 PROJECT DESCRIPTION

The Project area comprises the following main domains:

- Maxwell Underground – comprising the proposed area of underground mining operations and the mine entry area within EL 5460.
- Maxwell Infrastructure – the area within existing mining leases comprising the substantial existing infrastructure (including the CHPP) and previous mining areas.
- The transport and services corridor between the Maxwell Underground and Maxwell Infrastructure – comprising a site access road, a covered, overland conveyor, power supply and other ancillary infrastructure and services.
- A potential realignment of Edderton Road.

The transport and services corridor and the potential realignment of Edderton Road would not interact with groundwater resources and are not discussed further in this Groundwater Assessment.

1.2.1 UNDERGROUND MINING

The Project would involve extraction of coal from four seams within the Wittingham Coal Measures using the following underground mining methods:

- Bord and pillar with partial pillar extraction in the Whynot Seam; and
- Longwall extraction in the Woodlands Hill Seam, Arrowfield Seam and Bowfield Seam.

Extraction would occur over a period of approximately 26 years.

Indicative mining layouts in the four seams are presented in **Figure 4**.

1.2.2 INFRASTRUCTURE AND SERVICES

The Project would include the use of the existing Maxwell Infrastructure for handling, processing and transportation of coal for the life of the Project.

A covered, overland conveyor would be constructed and operated to transport ROM coal from the mine entry area to the existing CHPP at the Maxwell Infrastructure (**Figure 2**). During the development stage of the Project, ROM coal would be transported via internal roads along a similar route as the covered, overland conveyor. This would cease when the covered, overland conveyor is constructed and commissioned.

ROM coal would be processed at the existing CHPP and then stockpiled prior to transport to the domestic market or to the Port of Newcastle for export.

1.2.3 MANAGEMENT OF CHPP REJECTS

CHPP reject material would be produced over the life of the Project, including coarse rejects and tailings. This CHPP reject material would be emplaced preferentially within the existing East Void in Mining Lease 1531 at the Maxwell Infrastructure as shown on **Figure 3**.

1.3 OTHER PROJECTS/DEVELOPMENTS IN THE REGION

As shown on **Figure 1**, several operating open cut mines/developments exist in the region, including:

- Mt Arthur Mine located immediately west of the Maxwell Infrastructure and north of the Maxwell Underground. Mt Arthur Mine is an open cut operation intersecting the Wittingham Coal Measures with a maximum open cut extraction rate of 32 Mtpa. The Mt Arthur underground was also approved in 2008 for a mining rate of up to 8 Mtpa. An underground entry and approximately 8 kilometres (km) of roadway were developed in 2009; however, Mt Arthur Underground is yet to commence underground longwall coal extraction.
- Liddell and Bayswater Power Stations (including supporting infrastructure including the Liddell Ash Dam and Plashett Reservoir) located approximately 2 km east of the Maxwell Infrastructure.
- Bengalla Mine located over 13 km to the north of Maxwell Underground and north of the Mt Arthur Mine.
- Mangoola Mine located over 14 km north-west of Maxwell Underground and Mt Arthur Mine, and the proposed Mangoola Coal Continued Operations Project that if approved, would extend open cut mining operations further north.
- Mount Pleasant Operation located over 16 km to the north of Maxwell Underground and north of Mt Arthur Mine and Bengalla Mine.
- Hunter Valley Operations (HVO) North located over 8 km south-east of the Maxwell Underground, including West Pit open cut that targets the deeper seams of the Wittingham Coal Measures (i.e. Vane Subgroup) where they occur at subcrop, and historical mining at Carrington and North Pit further south.
- HVO South located over 12 km to the south-east of the Maxwell Underground, including Riverview Pit, Cheshunt Pit and South Lemington Pits 1 and 2.
- Greater Ravensworth Area Operations (comprising Liddell Coal Operations, Ravensworth Operations and Mt Owen Complex) located over 13 km north-east of Maxwell Underground.

- Wambo Open Cut at the Wambo Mine located over 12 km south-southeast of the Maxwell Underground, along with underground mining activities and the proposed United Wambo Open Cut Coal Mine Project (a joint venture between Peabody and Glencore).
- Proposed Spur Hill Underground Coking Coal Project (Spur Hill) within EL 7429, located immediately west of EL 5460. Application for a Gateway Certificate was made in December 2013 by Spur Hill Management Pty Ltd, a subsidiary of Malabar. However, the mining lease applications have been withdrawn and it is therefore not considered in the cumulative assessment for the Project. Any future integration of the Project and Spur Hill would be subject to future assessments and approvals, including assessment of any potential cumulative impacts.

Further details on each of the mine areas are included in **Section 4.4.2**. This includes consideration of the likelihood for these mines/developments to contribute to cumulative groundwater drawdown impacts based on the groundwater regime, structural geology and distance from the Project.

In addition, within the Maxwell Infrastructure area (Mining Lease 1531), AGL Energy Ltd (AGL) has the right to take and use the East Void by means of a transfer of Mining Lease 1531 and seek planning and other required approvals to authorise disposal of ash from AGL's power stations. In this scenario, AGL would assume responsibility for the final rehabilitation of the transferred area which would be released from Mining Lease 1531. AGL is required to make its decision prior to 1 January 2023. Consultation with AGL would continue until a decision is made. In the event AGL does not elect to use the East Void that remains within Mining Lease 1531, Malabar would be responsible for the final rehabilitation consistent with statutory requirements. Therefore, this Groundwater Assessment considers only the final landform design Malabar could be responsible for, and does not include disposal of ash by AGL.

2 REGULATORY FRAMEWORK AND ENGAGEMENT

This section provides a summary of the NSW and Commonwealth groundwater-related legislation, policies, licences and guidelines relevant to the Project. A chronology of the engagement between Malabar and regulatory agencies is also presented.

2.1 NSW ENVIRONMENTAL PLANNING AND ASSESSMENT ACT 1979

The EP&A Act provides a system of environmental planning and assessment for the State of NSW. Section 4.12(8) of the EP&A Act requires that a development application for State Significant Development is to be accompanied by an EIS prepared by or on behalf of the applicant in the form prescribed by the regulations.

This Groundwater Assessment will be used in support of the EIS for the Project.

2.1.1 SECRETARY'S ENVIRONMENTAL ASSESSMENT REQUIREMENTS

The SEARs for the Project (Application SSD 18-9526) were provided by the DP&E in September 2018 and were revised on 17 January 2019 after the NSW Mining and Petroleum Gateway Panel issued the Conditional Gateway Certificate for the Maxwell Coal Project on 20th December 2018 (**Section 2.1.4**).

Supplementary requirements to the SEARs were issued on 20 November 2018 after the Commonwealth Minister for the Environment and Energy determined on 12 November 2018 that the proposed action was a 'controlled action' (**Section 2.2.1**).

A summary checklist against the relevant SEARs is presented in **Appendix C**.

2.1.2 NSW DEPARTMENT OF INDUSTRY

DP&E sought comments from relevant NSW Government departments during the development of the SEARs for the Project (**Section 2.1**). Comments relevant to this Groundwater Assessment were provided by DoI Water. Where relevant, the groundwater-related requirements have been considered in this Groundwater Assessment.

DoI Water subsequently prepared a Technical Assessment in support of the Minister for Primary Industries' Advice to the Mining and Petroleum Gateway Panel on 20 December 2018.

2.1.3 MUSWELLBROOK SHIRE COUNCIL

Comments were also provided by the Muswellbrook Shire Council in relation to groundwater, which have been considered in this Groundwater Assessment with responses provided in **Appendix C**.

2.1.4 STATE ENVIRONMENTAL PLANNING POLICY (MINING, PETROLEUM PRODUCTION AND EXTRACTIVE INDUSTRIES) 2007

Pursuant to clause 17H of State Environmental Planning Policy (Mining, Petroleum Production and Extractive Industries) 2007 (the Mining SEPP), the Gateway Panel determined the Gateway Application made by Malabar on 23 August 2018 by issuing a Conditional Gateway Certificate for the Project on 20 December 2018.

As discussed in **Section 2.1.1**, a supplementary list of environmental assessment requirements has been issued, so that considerations and recommendations of the Gateway Panel are appropriately addressed in the EIS. The groundwater-related recommendations of the Conditional Gateway Certificate are considered in this Groundwater Assessment and responses presented in **Appendix C**.

2.2 COMMONWEALTH ENVIRONMENT PROTECTION AND BIODIVERSITY CONSERVATION ACT 1999

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) is the Australian Government's central piece of environmental legislation. It provides a legal framework to protect and manage matters of national environmental significance, including (but not limited to):

- World heritage properties;
- Wetlands of international importance;
- Nationally threatened species and ecological communities; and
- A water resource in relation to coal seam gas and large coal mining (the water trigger).

The *Significant Impact Guidelines 1.3: Coal Seam Gas and Large Coal Mining Developments – Impacts on Water Resources* (Commonwealth Department of the Environment, 2013) were released to assist applicants in determining whether a development is likely to have a significant impact on a water resource.

The bilateral agreement under the EPBC Act with the NSW government notes that NSW should seek and consider expert advice from the IESC in relation to coal seam gas or large coal mining developments that are likely to have a significant impact on water resources.

The IESC is a statutory committee of leading scientists that independently advises government regulators on the impacts that coal seam gas and large coal mining development may have on Australia's water resources. The IESC information guidelines and advice for the Project are discussed in Sections 2.2.2 and 2.2.3.

2.2.1 ENVIRONMENT PROTECTION AND BIODIVERSITY CONSERVATION ACT 1999 REFERRAL

The *Significant Impact Guidelines 1.3. Coal Seam Gas and Large Coal Mining Developments – Impacts on Water Resources* were considered as part of the EPBC Act Referral for the Project in September 2018.

A delegate of the Commonwealth Minister for the Environment and Energy determined on 12 November 2018 that the proposed action is a 'controlled action' and therefore the action also requires approval under section 75 of the EPBC Act. The Minister's delegate considered the following controlling provisions to be relevant to the action:

- EPBC Act listed threatened species and communities; and
- Water resources.

The proposed action is to be assessed pursuant to the bilateral agreement with the NSW Government. Therefore, the EIS (including this Groundwater Assessment) provides an assessment of potential impacts to the controlling provisions identified by the Minister's delegate.

As discussed in **Section 2.1.1**, a supplementary list of environmental assessment requirements has been issued, so that Commonwealth matters are appropriately addressed in the EIS. A summary checklist against the SEARs requirements are presented in **Appendix C**.

2.2.2 INFORMATION GUIDELINES FOR PROPONENTS PREPARING COAL SEAM GAS AND LARGE COAL MINING DEVELOPMENT PROPOSALS (2018)

The Information Guidelines (May 2018) developed by the IESC, outline the information considered necessary to enable the IESC to provide robust scientific advice to government regulators on the water-related impacts of coal seam gas and large coal mining development proposals.

The Information Guidelines have been considered during the preparation of this Groundwater Assessment. A summary checklist against the requirements is presented in **Appendix A**.

This Groundwater Assessment has also considered supplementary explanatory notes to the Information Guidelines (including those finalised and in consultation draft) including:

- *Information Guidelines explanatory note: Uncertainty analysis – Guidance for groundwater modelling within a risk management framework* (Middlemis, H. and Peeters, L.J.M., 2018);
- *Assessing Groundwater-Dependent Ecosystems: IESC Information Guidelines Explanatory Note* [Consultation Draft] (Doody, T.M., Hancock, P.J. and Pritchard, J.L., 2018); and
- *How to Derive Site-specific Guideline Values for Physical and Chemical Parameters: IESC Information Guidelines Explanatory Note* [Consultation Draft] (Huynh, T. and Hobbs, D., 2018).

2.2.3 IESC ADVICE (IESC 2018-098: MAXWELL PROJECT EXPANSION)

The NSW Mining and Petroleum Gateway Panel requested the IESC provide advice on the Project Gateway Application on 21 September 2018. The advice drew upon the available assessment documentation, including the Preliminary Groundwater Assessment (HydroSimulations 2018) and was assessed against the Information Guidelines (May 2018). The IESC Advice (IESC 2018-098: Maxwell Project – Expansion) was issued on 9 November 2018, and relevantly noted that:

> '*Understandably, the documentation provided by the proponent is targeted at assessing impacts to important agricultural land, as is required by the Gateway Certificate Application process, and does not include the full range of information outlined in the IESC Information Guidelines for proponents preparing coal seam gas and large coal mining development proposals (Information Guidelines) (IESC 2018). Should this project proceed to a more detailed environmental assessment, the IESC would expect the documentation provide further detail on key risks relevant to ecological assets, water management, final landform management, geochemical characteristics, and related mitigation measures*.'

The full list of comments provided in the IESC Advice (IESC 2018-098: Maxwell Project – Expansion) have been noted and addressed. This Groundwater Assessment presents the significant advances since completion of the Preliminary Groundwater Assessment in support of the Gateway Application (HydroSimulations 2018). This includes additional baseline data gathered, hydrogeological conceptualisation details, numerical modelling complexity and uncertainty analyses. A checklist of the IESC comments and requirements with related responses is presented in **Appendix B**.

2.3 NSW WATER REGULATION

2.3.1 WATER MANAGEMENT ACT 2000 (AND WATER SHARING PLANS)

The primary objective of *Water Management Act 2000* is for the sustainable management and use of NSW's water resources, balancing environmental, social and economic considerations. Water Sharing Plans (WSPs) have been developed, which establish rules for sharing and trading both groundwater and surface water between competing needs and users.

The following describes the WSPs relevant to the Project area and surrounds. **Figure 5** provides a map of the Project in relation to the areas covered by the relevant WSPs and associated Water Sources and Management Zones.

Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016

The Project area extends across two groundwater sources under this WSP (see **Figure 5**), which appears to be divided along the Muswellbrook Anticline and Liddell Thrust Fault.

The Maxwell Underground and southern and western portion of the existing Maxwell Infrastructure are within the **Sydney Basin – North Coast Groundwater Source.** The northern portion of existing Maxwell Infrastructure (i.e. including the East Void and part of the North Void) is mapped as being within the **New England Fold Belt Coast Groundwater Source**. However, as discussed in **Section 4.1,** the entire Maxwell Infrastructure area intersects the Greta Coal Measures, which are part of the Sydney Basin geology (Hodgkinson et al. 2015). Across the Maxwell Infrastructure area, groundwater occurs within the one connected geological unit (Greta Coal Measures) (**Section 4.1.5**). Therefore, this groundwater assessment presents results based on the one connected water source (i.e. North Coast Groundwater Source).

There are no 'high priority' groundwater dependent ecosystems (GDEs) listed in the WSP within 20 km of the Project. The nearest high priority GDE listed in the WSP is Parnell Spring in the Wollemi National Park, 25 km to the south-southeast of the Project.

Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009

In relation to unregulated surface water, the Project is located within the **Jerrys Management Zone of the Jerrys Water Source**. A portion of the Maxwell Infrastructure area (including CHPP) is located within the **Muswellbrook Water Source**.

Alluvial water sources vary for the various creeks and rivers (see **Figure 5**), as follows:

- Saddlers Creek – groundwater associated with alluvium present from the confluence with the Hunter River to the upper catchment is within the **Jerrys Management Zone of the Jerrys Water Source**;
- Hunter River – groundwater associated with alluvium present within 40 metres (m) of the top of the high bank of the Hunter River falls within the **Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone)** discussed below.

There are no high priority GDEs listed in the WSP in the vicinity of the Project. The nearest high priority GDE listed in the WSP is Wappinguy Spring, near Merriwa, more than 50 km to the north-west of the Project (**Figure 6**).

Water Sharing Plan for the Hunter Regulated River Water Source 2016

The Hunter Regulated River Management Zone 1B (Hunter River from Goulburn River Junction to Glennies Creek Junction) is located to the south and south-west of the Project area.

2.3.2 WATER ACCESS LICENCES

Water access licences currently held by Malabar in each WSP water source are listed in **Table 2-1.**

Table 2-1 Water Licences Held by Malabar

Water Sharing Plan	Water Source	Licence	Entitlement
North Coast Fractured and Porous Rock Groundwater Sources 2016	New England Fold Belt Coast Groundwater Source	Refer Note 1	Aquifer (860 units)
North Coast Fractured and Porous Rock Groundwater Sources 2016	Sydney Basin – North Coast Groundwater Source	Refer Note 1	Aquifer (527 units)
North Coast Fractured and Porous Rock Groundwater Sources 2016	Sydney Basin – North Coast Groundwater Source	Refer Note 2	Aquifer (64 units)
Hunter Unregulated and Alluvial Water Sources 2009	Upstream Glennies Creek Management Zone of Hunter Regulated River Alluvial Water Source	WAL 18196	Aquifer (120 units)
Hunter Unregulated and Alluvial Water Sources 2009	Upstream Glennies Creek Management Zone of Hunter Regulated River Alluvial Water Source	WAL 18201	Aquifer (5 units)
Hunter Unregulated and Alluvial Water Sources 2009	Jerrys Management Zone of Jerrys Water Source	Refer Note 3	Aquifer (50 units)
Hunter Unregulated and Alluvial Water Sources 2009	Muswellbrook Water Source	WAL 30212	Aquifer (207 units)
Hunter Regulated River Water Source 2016	Hunter Regulated River Source (Zone 1A – Hunter River from Glenbawn Dam to Goulburn River Junction)	WAL 1143	Regulated River (General Security) (200 units)
Hunter Regulated River Water Source 2016	Hunter Regulated River Source (Zone 1A – Hunter River from Glenbawn Dam to Goulburn River Junction)	WAL 1220	Regulated River (General Security) (90 units)
Hunter Regulated River Water Source 2016	Hunter Regulated River Source (Zone 1A – Hunter River from Glenbawn Dam to Goulburn River Junction)	WAL 771	Regulated River (General Security) (632 units)
Hunter Regulated River Water Source 2016	Hunter Regulated River Source (Zone 1B – Hunter River from Goulburn River Junction to Glennies Creek Junction)	WAL 31439	Regulated River (General Security) (90 units)
Hunter Regulated River Water Source 2016	Hunter Regulated River Source (Zone 1B – Hunter River from Goulburn River Junction to Glennies Creek Junction)	WAL 31440	Regulated River (General Security) (9 units)
Hunter Regulated River Water Source 2016	Hunter Regulated River Source (Zone 1B – Hunter River from Goulburn River Junction to Glennies Creek Junction)	WAL 1066	Regulated River (General Security) (99 units)

Water Sharing Plan	Water Source	Licence	Entitlement
Hunter Regulated River Water Source 2016	Hunter Regulated River Source (Zone 1A – Hunter River from Glenbawn Dam to Goulburn River Junction)	WAL 769	Regulated River (High Security) (3 units)

[1] WAL 41491 and WAL 41559 were converted from 20BL111869/20BL122620. Anglo American plc wrote to DoI Water on 13 September 2017 indicating that 527 units were incorrectly assigned to the New England Fold Belt Coast Groundwater Source instead of the Sydney Basin-North Coast Groundwater Source. Malabar is consulting with relevant NSW Government agencies to resolve this administrative issue.

[2] Malabar has reached an agreement for the transfer of 64 units with existing WAL holders in the Sydney Basin – North Coast Groundwater Source.

[3] Malabar has reached an agreement for the transfer of 50 units with the owner of a WAL in the Jerrys Water Source.

2.3.3 NSW AQUIFER INTERFERENCE POLICY

The NSW Aquifer Interference Policy (AIP) is designed to provide a framework for the assessment of impacts of the taking of water under a proposed development, such as the Project. The AIP divides groundwater sources into "highly productive" and "less productive" categories based on salinity and aquifer yield as shown in **Table 2-2**.

Table 2-2 NSW Aquifer Interference Policy – Salinity and Aquifer Yield Criteria

Criteria		Salinity (Total Dissolved Solids)	
		Less than 1,500 mg/L	More than 1,500 mg/L
Aquifer Yield	More than 5 L/s	Highly Productive	Less Productive
	Less than 5 L/s	Less Productive	

Areas of potential highly productive groundwater sources were mapped by Department of Primary Industries (DPI) (2017), as shown in **Figure 7**. **Figure 7** shows that the alluvium along the Hunter River falls within the zone of "highly productive" groundwater, which is supported by baseline water quality and yield data (**Section 4.4.4**). Groundwater associated with alluvium along Saddlers Creek is also mapped within the extent. However, as previously reported by AGE (2015) and evidenced from baseline data, the alluvial groundwater is considered to fall within the category of "less productive". Groundwater associated with the Permian coal measures are also categorised as "less productive".

The AIP also specifies minimal impact considerations for both "highly productive" and "less productive" aquifers; these comprise thresholds for watertable and groundwater pressure drawdown, and changes in groundwater and surface water quality. Different minimal impact considerations are specified for "highly productive" and "less productive" groundwater for:

- water supply works;
- listed GDEs; and
- culturally significant sites.

A summary of the AIP minimal impact considerations is included as part of the Project potential impacts assessment (**Section 8.1.2**).

2.3.4 GROUNDWATER QUALITY PROTECTION POLICY

The NSW State Groundwater Quality Protection Policy (Department of Land and Water Conservation [DLWC] 1998) states that the objectives of the policy will be achieved by applying the following management principles:

1. All groundwater systems should be managed such that their most sensitive identified beneficial use (or environmental value) is maintained.
2. Town water supplies should be afforded special protection against contamination.
3. Groundwater pollution should be prevented so that future remediation is not required.
4. For new developments, the scale and scope of work required to demonstrate adequate groundwater protection shall be commensurate with the risk the development poses to a groundwater system and the value of the groundwater resource.
5. A groundwater pumper shall bear the responsibility for environmental damage or degradation caused by using groundwaters that are incompatible with soil, vegetation or receiving waters.
6. GDEs will be afforded protection.
7. Groundwater quality protection should be integrated with the management of groundwater quantity.
8. The cumulative impacts of developments on groundwater quality should be recognised by all those who manage, use, or impact on the resource.
9. Where possible and practical, environmentally degraded areas should be rehabilitated, and their ecosystem support functions restored.

These principles have been considered as part of the groundwater assessment, and discussed within the impact assessment (**Section 6**) and monitoring and mitigation measures.

2.3.5 GROUNDWATER QUANTITY MANAGEMENT POLICY

The NSW State Groundwater Quantity Management Policy (DLWC 2002a) states that the objectives of the policy are to:

- achieve the efficient, equitable and sustainable use of the State's groundwater;
- prevent, halt and reverse degradation of the State's groundwater and their dependent ecosystems;
- provide opportunities for development which generate the most cultural, social and economic benefits to the community, region, state and nation, within the context of environmental sustainability; and
- involve the community in the management of groundwater resources.

These principles have been considered as part of the groundwater assessment, and discussed within the impact assessment (**Section 6**) and monitoring and mitigation measures.

2.3.6 GROUNDWATER DEPENDENT ECOSYSTEMS POLICY

The NSW State Groundwater Dependent Ecosystems Policy (DLWC 2002b) was a component policy of the NSW State Groundwater Policy Framework Document and describes the five broad types of groundwater systems in NSW, each with associated dependent ecosystems. The groundwater systems relevant to the Project are:

- **Shallow Alluvial Groundwater Systems** – coastal rivers and higher reaches west of the Great Dividing Range (e.g. Hunter, Peel and Cudgegong Rivers' alluvium, and beds and lateral bars of the lower Macleay, Bellinger and Nambucca Rivers);
- **Fractured Rock Groundwater Systems** – outcropping and sub-cropping rocks containing a mixture of fractures, joints, bedding planes and faults that contain and transmit small and occasionally large amounts of groundwater (e.g. Alstonville Basalt, Molong Limestone and the Young Granite); and
- **Sedimentary Rock Groundwater Systems** – sedimentary rock aquifers including sandstone, shale and coal (e.g. Great Artesian Basin, Sydney Basin and Clarence Moreton Basin).

The NSW State Groundwater Dependent Ecosystems Policy (DLWC 2002b) also recognises the four Australian GDE types that can be found in NSW, namely:

- Terrestrial vegetation;
- Baseflows in streams;
- Aquifer and cave ecosystems; and
- Wetlands.

The GDEs relevant to the Project include riparian vegetation localised along the Hunter River, baseflows in Saddlers Creek and the Hunter River and aquifer ecosystems (stygofauna). No wetlands have been identified in the region. Further discussion on GDEs is included in **Section 4.6.2**.

2.3.7 STRATEGIC REGIONAL LAND USE POLICY (INCLUDING UPPER HUNTER STRATEGIC REGIONAL LAND USE PLAN)

In 2012, the NSW Government introduced the Strategic Regional Land Use Policy and subsequent Upper Hunter Strategic Regional Land Use Plan (NSW Department of Planning and Infrastructure 2012), as part of the introduction of the 'Gateway Process' for upfront assessment of the impacts of State Significant mining and coal seam gas proposals on Strategic Agricultural Land. This process is formalised through clause 50A of the NSW *Environmental Planning and Assessment Regulation 2000* and Part 4AA of the Mining SEPP. Critical Industry Clusters (CICs) and regional-scale mapping of Biophysical Strategic Agricultural Land (BSAL) is provided in the Mining SEPP, with a process for site verification of BSAL. BSAL and CIC land mapped near the Project area are presented on **Figure 8**.

The Strategic Regional Land Use Policy Guideline for Gateway Applicants (NSW Government 2013) was referred to during the preparation of the Preliminary Groundwater Assessment (HydroSimulations 2018) and this Groundwater Assessment.

Relevantly, the Upper Hunter Strategic Regional Land Use Plan (NSW Department of Planning and Infrastructure 2012) defines aquifers that have a yield rate greater than 5 litres per second (L/s) and total dissolved solids of less than 1,500 milligrams per litre (mg/L) as a 'reliable water supply'. This definition is consistent with the salinity and aquifer yield criteria in the AIP discussed in **Section 2.3.3**.

2.4 CHRONOLOGY OF ENGAGEMENT BETWEEN MALABAR AND REGULATORY AGENCIES

As described in **Section 1.1**, there has been a long history of exploration and past assessments and approvals within EL 5460 including engagement with Commonwealth, State and Local Governments. Whilst Malabar were not involved in the engagement prior to transfer of ownership on 28 February 2018, the consultation and advice made available during the course of the past assessments which included numerical groundwater modelling completed by AGE (2012, 2015) has been considered during the course of this Groundwater Assessment. This included the IESC advice on the Drayton South Coal Project open cut proposal at the Gateway and Assessment advice stages in February 2015 (IESC 2015-064) and June 2015 (IESC 2015-069). Consultation conducted specifically for this EIS is summarised in **Table 2-3**.

Table 2-3 Consultation Undertaken for the Project

Date	Consultation
23 August 2018	Gateway Application submitted to the Gateway Panel (including provision of Preliminary Groundwater Assessment [HydroSimulations 2018]).
28 August 2019	DoI Water provide comment on the SEARs.
21 September 2018	IESC Advice requested by the Gateway Panel (including provision of Preliminary Groundwater Assessment [HydroSimulations 2018]).
9 November 2018	IESC Advice for the Project Gateway Application received (IESC 2018:098).
13 November 2018	Environmental Risk Assessment Workshop held by Malabar and team of specialists which included consideration of AS/NZS ISO 31000:2018 Risk management – Guidelines (Standards Australia, 2018) and *Impact and risk analysis for the Hunter subregion* (Herron et al., 2018).
20 December 2018	Minister for Primary Industries Advice provided to the NSW Mining and Petroleum Gateway Panel on the Project (including Technical Assessment by DoI Water for the Minister for Regional Water).
20 December 2018	The Gateway Panel Report and Conditional Gateway Certificate issued for the Project.
13 May 2019	Natural Resources Access Regulator and DoI Water meeting to discuss project design, conceptual groundwater model and numerical groundwater modelling and impact assessment approach.

Consultation will continue to be undertaken with key relevant stakeholders in accordance with the Project stakeholder engagement strategy (Section 5 of the EIS).

3 CLIMATE AND SURFACE LANDSCAPE SETTING

3.1 CLIMATE

Commonwealth Bureau of Meteorology (BoM) data has been obtained and used to evaluate the climatic conditions in the Project area and surrounds. Data was obtained directly from the BoM website and through the Scientific Information for Landowners (SILO) database, developed by the BoM and the Queensland (Qld) Government and currently hosted by the Qld Department of Environment and Science. This service interpolates rainfall, evaporation and evapotranspiration (Penman-Monteith equation FAO56) records from available stations for an area within 100 km of the search coordinates, which was Latitude -32.4 Longitude 150.9. Climatic data from 01/01/1900 to 31/12/2018 was used in the rainfall analysis.

Weather monitoring has also been conducted across the Project area, with rainfall recorded at the Maxwell Infrastructure CHP AWS since 1981, at the Maxwell Underground MET03 Station from 1998 to 2008 and 2013 to 2018, and at Spur Hill from 2015 to 2018. Rainfall records from Maxwell Underground MET03 exist for 1998 to 2001, however there are apparent errors for early readings.

The locations of the rainfall stations are shown on **Figure 9** and average monthly rainfall for each location is presented in **Table 3-1**.

Table 3-1 Annual Rainfall for Site SILO Data and Mine-owned Weather Stations

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
SILO Grid Point – Rainfall (mm)	77	72	62	47	42	50	45	38	44	56	63	67	664
Maxwell Infrastructure - Rainfall (mm)	72	77	67	52	41	50	38	37	41	52	68	79	674
Spur Hill - Rainfall (mm)	50	17	39	52	45	60	23	30	29	31	64	39	479
Maxwell UG - Rainfall (mm)	45	55	45	35	16	52	19	25	30	34	47	58	461
SILO Evaporation (mm)	201	158	139	98	66	48	57	82	113	149	173	204	1489
SILO Evapotranspiration (mm)	164	131	117	82	58	42	47	66	91	124	145	166	1232
BoM Areal Actual Evapotranspiration (mm)	90	70	70	40	30	20	20	30	50	70	80	80	650

As shown in **Table 3-1**, the average annual rainfall is comparable between the SILO Grid Point and Maxwell Infrastructure CHP AWS monitoring station. The lower averages for Spur Hill and Maxwell Underground likely relate to the shorter range in historical data, reflecting a more finite time period. Based on the SILO Grid Point data, average annual rainfall is 664 millimetres (mm), with slightly higher rainfall over the summer months, from December to February.

The cumulative departure from mean (CDM) rainfall trend (also referred to as residual mass) has been generated for the SILO Grid Point for data from 1900 to 2018. The CDM from 2001 onwards is presented in **Figure 10.** Positive gradients on this curve confirm wetter conditions than normal, while negative gradients indicate dry conditions. Normal rainfall conditions are inferred during periods of fairly stable residual mass. The graph presents trends since 2001, in order to compare SILO Grid Point monthly rainfall and CDM to the Maxwell Infrastructure CHP AWS monthly rainfall. **Figure 10** shows that the area experienced a period of above average rainfall from 2007 to 2012, followed by a period of fluctuating rainfall until 2017. Since 2017 the area has experienced below average rainfall.

If rainfall recharge is a significant source of groundwater, the temporal variability in recorded groundwater levels can be expected to mimic the pattern of the CDM curve. That is, natural fluctuations in the groundwater table result from temporal changes in rainfall recharge to groundwater systems. Typically, changes in groundwater elevation reflect the deviation between the long-term monthly average rainfall and the actual rainfall, illustrated by the rainfall CDM. Groundwater hydrographs are assessed in **Section 4**.

Potential evaporation and evapotranspiration have been taken from the SILO dataset (**Table 3-1**), with an average annual rate of 1,489 mm and 1,232 mm, respectively. Potential evaporation and evapotranspiration assume an unlimited water supply, which is not reflected in the natural environment. BoM (2016) produce areal actual evapotranspiration maps that reflect the evapotranspiration that would occur over a large area of land under existing (mean) rainfall conditions. The annual average areal actual evapotranspiration (BoM 2016) is approximately 650 mm at the Project area (**Table 3-1**).

The bimodal weather plot for the site is presented in **Figure 11,** showing average monthly rainfall for the SILO Grid Point and Maxwell Infrastructure CHP AWS. The average monthly rainfall is compared to the average monthly pan evaporation and evapotranspiration (Penman-Monteith equation FAO56) from the SILO Grid point dataset, as well as the BoM (2016) areal actual evapotranspiration. **Figure 11** illustrates higher rainfall, evaporation and evapotranspiration during the summer months, and during the mid-year winter months evaporation and evapotranspiration are lowest.

3.2 TOPOGRAPHY

Topographic data is available for the site, including detailed LiDAR contours across EL 5460 and 5 m Digital Elevation Model (DEM) for surrounding areas. The surface topography directly above Maxwell Underground area varies between approximately 110 metres Australian Height Datum (mAHD) along a tributary of the Hunter River and rises up to a maximum approximately 240 mAHD on the top of the hill in the east of the Maxwell Underground area (**Figure 9**).

3.3 SURFACE DRAINAGE

The Maxwell Underground area is located within the Saddlers Creek and (to a lesser extent) Saltwater Creek surface catchments (**Figure 9**).

Within the Maxwell Underground area there are no major watercourses, but there is a drainage line (referred to as Unnamed Creek) that flows towards Saddlers Creek to the north-west and is classified as a third order stream (Strahler Stream Order). Surrounding the Project area, the surface areas are drained by Saddlers Creek and its tributaries to the west, and Saltwater Creek and its tributaries to the east. Both creeks drain toward the Hunter River in the south. Two minor gullies within the Project area also drain directly to the Hunter River in the south.

The northern areas of Maxwell Infrastructure previously drained to the Ramrod Creek catchment (WRM Water & Environment Pty Ltd [WRM] 2019). The eastern areas of the existing Maxwell Infrastructure drain to or previously drained to Bayswater Creek (prior to mining operations). Almost all the Bayswater Creek catchment comprises previously mined areas and do not drain off-site (WRM 2019). The southern areas of the Maxwell Infrastructure are located within the pre-mine Saltwater Creek and Saddlers Creek catchments. The Saddlers Creek and Saltwater Creek catchments at Maxwell Infrastructure are either previously mined areas and no longer drain off-site or remain undisturbed (WRM 2019).

At the Maxwell Infrastructure area, the Liddell Ash Dam and Lake Liddell are located 250 m and 3 km east of East Void, respectively. Plashett Reservoir is also located along Saltwater Creek, 6 km south of Maxwell Infrastructure area and 2.5 km east of the Maxwell Underground.

Each of the drainage features are discussed further below, including characteristics of the creeks, flow durations and background monitoring locations. Surface water quality is discussed in conjunction with groundwater quality in **Section 4.4.4**.

3.3.1 HUNTER RIVER

The Hunter River is located to the south of the Maxwell Underground. The high bank of the creek is around 470 m south of the closest proposed underground mine panel (Woodlands Hill Seam) at the Maxwell Underground.

Within the region, the Hunter River bed is around 20 m to 50 m wide, and the river flows in an east to south-easterly direction. The surface water is used for industrial and agricultural purposes, as well as town water supplies (WRM 2019).

Flows within the Hunter River are monitored at gauging stations under the Hunter Integrated Telemetry System (HITS) operated by WaterNSW[1]. The four nearest stream flow gauging stations to the site are listed in **Table 3-2**, with locations shown in **Figure 9**. Station 210151 is located closest to the Project area, but only has data from 2015. Station 210055 is the next closest and has data available from 1959.

[1] Formerly operated by NSW Office of Water (NOW)

Table 3-2 Hunter River Stream Flow Gauging Stations

Gauge Number and Name	Catchment Area (km^2)	Easting (MGA)	Northing (MGA)	Ave. Flow (ML/day)	Period of record	Zero-gauge elevation (mAHD)
210002 Hunter River at Muswellbrook	4,220	301170	6429172	818	1913 – current	136.24
210055 Hunter River at Denman	4,530	284705	6415039	677	1959 - current	101.99
210083 Hunter River at Liddell	13,400	304905	6403439	1,132	1969 - current	60.95
210151 Hunter River DS Saddlers	-	290670	6405964	459	2015 - current	79.64

Note: Coordinates in GDA94 Z56 *Average Flow – based on data from January 2001 to December 2018*

Stream flow statistics from 2001 to 2018 for the Hunter River gauges are presented in **Figure 12**. **Figure 12** shows that the Hunter River has perennial flows, with flows generally ranging between 100 ML/day and 1,000 megalitres per day (ML/day). Recent high flow/flood events, with flows over 2,000 ML/day, were recorded along the Hunter River in May 2001, June 2007, September 2008, June 2011 and March 2013.

Comparison between Hunter River (Station 210055) flow levels and daily rainfall (SILO Grid Point) is shown in **Figure 13**. **Figure 13** illustrates that stream levels within the Hunter River varied by ± 0.5 m between 2001 and 2019. These flow levels have remained relatively stable due to regulated releases from Glenbawn Dam.

Areas prone to flooding along the Hunter River near the Maxwell Underground have been assessed by WRM (2019), based on a flood study of the Hunter River developed by Muswellbrook Shire Council. The Maxwell Underground and mine entry area are beyond areas prone to flooding along the Hunter River.

3.3.2 SADDLERS CREEK

Saddlers Creek is an intermittent tributary of the Hunter River north-west of the Maxwell Underground and joins the Hunter River to the south-west of EL 5460. Saddlers Creek is a 4th order stream to the north of the underground mining area, and a 5th order stream downstream of Edderton Road. Saddlers Creek has been truncated in its upper reaches by previous open cut mining activities in CL 229. Prior to commencement of mining in the area, Saddlers Creek had a catchment of about 78 km^2 (NOW 2015). Approximately 15% of the pre-mining catchment no longer drains to Saddlers Creek (WRM 2019).

The Saddlers Creek river bed is generally around 5 m to 10 m wide and consists of sand, silt and scattered woody debris (Eco Logical 2019). Following a site inspection, Eco Logical (2019) reported that the creek bed is dry much of the year, with shallow (20 centimetre [cm] deep) pools of water in isolated areas (**Figure 14**).

Flows within Saddlers Creek were monitored at HITS gauging station 210043 between 1956 to 1981. Details on the stream flow gauging station are listed in **Table 3-3**, with locations shown in **Figure 9**. In November 2018, Malabar relocated the survey benchmark (old concrete block) previously used for the decommissioned Water NSW Site No. 210043. The zero-flow point for the decommissioned gauging station was surveyed at 100.23 mAHD as detailed in **Table 3-3**. **Table 3-3** also provides details on a new gauging station installed by Malabar on Saddlers Creek in September 2018, approximately 300 m upstream of the decommissioned gauging station (**Figure 9**). The zero-flow point for the new gauging station was surveyed at 100.47 mAHD.

Table 3-3 Saddlers Creek Stream Flow Gauging Stations

Gauge Number and Name	Catchment Area (km^2)	Easting (MGA)	Northing (MGA)	Ave. Flow (ML/day)	Period of record	Zero-gauge elevation (mAHD)
210043 Saddlers Creek at Bowfield	78	292813	6410996	3.4	1956 - 1982	100.23
Malabar - Saddlers Creek	-	293035	6411121	0.04	Sep 2018 – Feb 2019	100.47

Note: Coordinates in GDA94 Z56

Figure 15 shows the Discharge Rate Duration Curve for Saddlers Creek (Station 210043) from 1956 to 1982. The curve shows that Saddlers Creek, prior to changes in the catchment area, flowed about 62 percent of the time, with less than 10 percent probability of flows exceeding 1 ML/day. Comparison between the historical flow levels and daily rainfall (SILO Grid Point) in **Figure 16** illustrates that Saddlers Creek has intermittent flow, with high flows occurring in response to rainfall events. The available data indicates the majority of stream flow occurred in the summer months, from January to March, with negligible flows from July to December. Results for the new Malabar stream gauge (**Figure 17**) also show flow occurs in response to rainfall.

Saddlers Creek acts as a losing stream where the lithology within the river bed facilitates leakage (AGE 2015). However, within the lower reaches of the creek, near the confluence with the Hunter River, gaining conditions may occur.

Flood modelling of Saddlers Creek has been undertaken by WRM (2019). Comparisons with the estimated design flood levels under pre-mining conditions show that the Maxwell Underground and mine entry area are beyond the probable maximum flood (PMF) extent.

3.3.3 SALTWATER CREEK

Saltwater Creek runs to the east of the Maxwell Underground through (and downstream of) the Plashett Reservoir (also known as Plashett Lake). Flows along Saltwater Creek (where present) and its tributaries are ephemeral in nature, responding to rainfall events. A tributary to the east of the Maxwell Underground area was inspected by Eco Logical (2019), and found to feature a dry, sandy creek bed with steep 10 m high creek beds incised into weathered volcanics (**Figure 18**).

Plashett Reservoir is located 2 km east of the proposed Maxwell Underground and 5 km south of the Maxwell Infrastructure. Minor gullies drain the Maxwell Underground area to the south-east toward Saltwater Creek downstream of the Plashett Reservoir. Plashett Reservoir can store up to 65,000 ML of fresh water captured along Saltwater Creek and pumped from the Hunter River (DoI Water 2018b). The dam is prescribed under the Dams Safety Act and is used as a water supply source for AGL's Liddell and Bayswater Power Stations (DoI Water 2018b) and also supplies water to Jerrys Plains township. Additional dams and artificial lakes are also present east of Maxwell Infrastructure that support the Bayswater Power Station. This includes Liddell Ash Dam immediately east, Lake Liddell 3.3 km east and Bayswater-Liddell Freshwater Dam 1.7 km south-east (**Figure 9**).

3.3.4 RAMROD CREEK

To the north of the Maxwell Infrastructure area is the Ramrod Creek catchment. Ramrod Creek drains into the Hunter River approximately 10 km to the north-west of the Project, immediately downstream of Muswellbrook.

The pre-mining upper reaches of Ramrod Creek have been truncated at the CL 229 boundary. Recent survey by Eco Logical (2019) found the creek bed comprised silty clays and where inspected had shallow embankments (1.1 m) covered in grasses and reeds (**Figure 19**). The creek is incised into regolith material, with no alluvium mapped in the area, and is highly impacted by historical agricultural practices in the area (Eco Logical 2019). The creek was largely dry except for small shallow pools of remnant water, indicating ephemeral flows reliant on rainfall events (Eco Logical 2019).

3.3.5 UNNAMED CREEK

Within the Maxwell Underground area a minor tributary of Saddlers Creek is present, which flows in a north-westerly direction. The tributary is referred to as Unnamed Creek within this report, and has been classified as a 3rd order stream (Strahler Stream Order). Unnamed Creek is a shallow gully that has eroded through regolith material overlying the Permian coal measures at the Project area. No alluvium is mapped along Unnamed Creek, but is present along Saddlers Creek. Photographs of the upper reach of Unnamed Creek are included in **Figure 20**, taken in July 2018. As shown in the photographs, the gully is dry and water flow is likely to be intermitted and influenced by rainfall events.

3.4 RIPARIAN VEGETATION

Riparian vegetation is present along Saddlers Creek and its tributaries. The riparian vegetation present has been highly modified from its original state and typically persists as very narrow and interrupted corridors along the drainage lines (Hunter Eco 2019).

An assessment by Hunter Eco (2019) found that the riparian vegetation types present are unlikely to be completely dependent on groundwater as the canopy trees are likely to draw on surface flows in streams and gullies and shallow soil water before accessing groundwater. The understorey of these communities is similar to the surrounding grassy understorey of non-GDE vegetation and is unlikely to be groundwater-dependent (Hunter Eco 2019). GDEs associated with Saddlers Creek and the Hunter River are discussed separately in **Section 4.6.2**.

4 HYDROGEOLOGICAL SETTING AND GROUNDWATER MODEL CONCEPTUALISATION

This section provides a summary of the Project area hydrogeology and the conceptual hydrogeological model adopted for this groundwater assessment.

4.1 GEOLOGY

The hydrogeological setting at the Project area and surrounding region is based on numerous data sources. The available information was used to conceptualise the geology associated with the Project, and to develop the three dimensional (3D) numerical groundwater model. Available data includes the following:

- Site geological model;
- Geology logs and information for site monitoring bores and drill holes;
- Site specific geological and hydrogeological study reports, including:
  - Structure Report – Maxwell Project (McElroy Bryan Geological Services Pty Ltd [MBGS] 2018);
  - Alluvial Drilling Report – Maxwell Project Muswellbrook Local Government Area, NSW (Environment and Natural Resource Solutions [ENRS] 2018); and
  - AgTEM Survey Investigating Groundwater on Maxwell Underground Coal Mine prospect, near Muswellbrook, NSW (Groundwater Imaging 2018);
- Publicly available geological maps (Hunter Coalfields 100k, Jerrys Plains and Muswellbrook 25k geology maps) and reports;
- Publicly available geological and hydrogeological reports for the region, including groundwater assessment reports for the Mt Arthur Mine, Drayton Mine and Drayton South Coal Projects; and
- Hydrogeological data for existing private groundwater bores from the DoI Water groundwater database (PINEENA) and the National Groundwater Information System (NGIS).

A summary of the main stratigraphic units present at the Project and surrounding region is provided in **Table 4-1**. The Hunter Coalfields 100k mapped surface geology for the Project region is presented in **Figure 21**. Geological sections through the Maxwell Underground and Maxwell Infrastructure areas are presented in **Figure 22** to **Figure 24**.

The Maxwell Underground occurs within the Sydney Basin that comprises Late Permian aged sediments that form the Singleton Supergroup of the Hunter Coalfield. Within the Singleton Supergroup, the Project proposes to extract coal seams from the Wittingham Coal Measures, which include the Jerrys Plains Subgroup (Pswj), Archerfield Sandstone (Psws), Foybrook Formation within the Vane Subgroup (Pswr) and Saltwater Creek Formation (Pswc).

The Wittingham Coal Measures comprise interbedded sequences of siltstone, sandstone shale and coal. At the Maxwell Underground, the coal measures dip towards the south-west. The Wittingham Coal Measures subcrop to the north-east of the Maxwell Underground, along the Muswellbrook Anticline. Along the hinge of the anticline the underlying Maitland Group and Greta Coal Measures occur at outcrop. Jurassic volcanics are also mapped on the eastern side of the Maxwell Underground, and the southern end of the Maxwell Infrastructure area.

Surface lithology includes weathered bedrock (regolith) and alluvial deposits localized along creeks and rivers. A local scale map of the inferred surface geology as presented in **Figure 25** shows the extent of alluvium based on site specific data and the 1:25k Geology Map of Muswellbrook (Summerhayes 1983) and Jerrys Plains (Sniffin & Summerhayes 1987).

Table 4-1 Geology (Hunter Coalfields 100k)

Era		Stratigraphic Unit				Description
Quaternary					Alluvium (Qha)	Silty sand, sand and stream sediment.
					Colluvium (Cza)	Silty sand, pebbly sand, cobble, coarse sand and silcrete.
					Regolith	Weathered basement rock (i.e. Permian coal measures).
Triassic					Volcanics (Tvss, Tvsp)	Volcanic intrusions, including Savoy Sill (Tvss) dolerite, syenite and Plashett Sill (Tvsp) teschenite.
Permian	Late	Singleton Supergroup	Wittingham Coal Measures	Denman Formation		
				Jerrys Plains Subgroup (Pswj)	Mount Leonard Formation, Althorpe Formation, Malabar Formation	Interbedded coal measures with siltstone, sandstone and shale. Coal seams include Whybrow, Redbank Creek, Wambo and Whynot seams.
					Mount Ogilvie Formation, Mount Thorley Formation, Fairford Formation	Interbedded coal measures with siltstone, sandstone and shale. Coal seams include Blakefield, Glen Munro, Woodlands Hill, Arrowfield, Bowfield and Warkworth seams.
					Burnamwood Formation	Interbedded coal measures with siltstone, sandstone and shale. Coal seams include Mt Arthur, Piercefield, Vaux, Broonie and Bayswater seams.
				Archerfield Sandstone (Psws)		Massive coarse-grained lithic sandstone.
				Vane Subgroup (Pswv)	Foybrook Formation	Interbedded coal measures with siltstone, sandstone and shale. Coal seams include Wynn, Edderton, Bengalla, Edinglassie and Ramrod Creek seams.
				Saltwater Creek Formation (Pswc)		Sandstone and siltstone, minor coaly bands, marine siltstones intercalated towards base.
	Middle	Maitland Group		Mulbring Siltstone (Pmm)		Dark grey shale and siltstone, bioturbated and fossiliferous.
				Branxton Formation (Pmb)		Pebbly sandstone, silty sandstone and siltstone, conglomerate lenses.
		Greta Coal Measures		Rowan Formation (Pgr)		Interbedded coal measures with siltstone, sandstone and shale. Coal seams include Broughan, Grasstrees, Puxtrees and Balmoral seams.
				Skeletar Formation (Pgk)		Rhyolite, chert and white tuffaceous shale containing Glossopteris leaves.
	Early	Dalwood Group		Undifferentiated including Gyarran Volcanics (Pdz)		Rhyolite, breccia and amygdaloidal basalt with minor felsite, pyroclastics.

4.1.1 UNCONSOLIDATED SEDIMENTS

Geological mapping (Jerrys Plains and Muswellbrook 1:25k) indicates alluvium is present along the Hunter River, Saddlers Creek and Saltwater Creek. The extent and thickness of the unconsolidated sediments were assessed at the Project area from existing site monitoring bores, a transient electromagnetic (TEM) survey conducted by Groundwater Imaging Pty Ltd in May 2018 and a geomorphological study by Fluvial Systems (2019). The TEM survey tested the resistivity of ground cover to a depth of about 40 m and was verified using site geological drill and monitoring bore data. Further drilling and fieldwork was also conducted by ENRS (2018) to verify the geophysical survey results and obtain additional data on the alluvium. This included test drilling along two transects across Saddlers Creek alluvium and one transect north of the Hunter River, geological logging and monitoring bore installation. A geomorphological study was conducted by Fluvial Systems (2019), which further assisted to define the alluvium based on terrain analysis and review of the results of the TEM survey and ENRS (2018). Full results of the TEM survey are included in **Attachment B**, and field findings by ENRS (2018) and Fluvial Systems (2019) are presented in **Attachment C** and Appendix D of the EIS, respectively.

A summary of the findings on the alluvial sediments within the Project area are discussed in **Section 4.1.1.1** to **Section 4.1.1.4** below. **Figure 26** presents the interpolated structure contours and thickness contours for the alluvium and regolith material.

4.1.1.1 Hunter River

Lithological logs show that the alluvium localized along the Hunter River comprises surficial silts and clays overlying basal sands and gravels up to 20 m depth (ENRS 2018 and AGE 2015). The basal sands and gravels are thickest along the alignment of the Hunter River, thinning out along the edges of the extent of mapped alluvium. The extent of the thick sequences of permeable and 'highly productive' sands and gravels correlates with the Hunter Regulated River Alluvium Extraction Management Unit extent, developed by DPI (2009) and shown in **Figure 7** and **Figure 25**. Based on CSIRO (2015) regolith mapping, it is anticipated the 'highly productive' sands and gravels extend slightly further north, towards the confluence with Saddlers Creek, as shown in **Figure 25**. Along the edges of the extent of mapped alluvium, the stratigraphy comprises silts and clays that are largely unsaturated and therefore officially a 'less productive' groundwater source (**Figure 25**).

4.1.1.2 Saddlers Creek

The stratigraphy of the alluvium along Saddlers Creek varies along the reach due to changes in the depositional environment. Basal sands and gravels associated with a higher energy fluvial system occur at the lower reaches of the creek, at the confluence with the Hunter River. Further upslope from the Hunter River, the stratigraphy comprises about 4 m of surficial clays/silt overlying an heterogeneous distribution of sands and gravels up to 8 m thick. Within the upper reaches of the creek, the depositional sediments largely comprise clays and sandy clays. The local lithology is mapped in **Figure 25**, and geological sections along Saddlers Creek developed by ENRS (2018) based on data from test drill holes (W1-4, N1-4 and S1-3[2]) are shown in **Attachment C**.

4.1.1.3 Saltwater Creek

Alluvium is mapped along Saltwater Creek and an unnamed tributary to the east of the Project. No drill hole data is available for the location but based on photos from the aquatic ecology survey (Eco Logical 2019) the alluvium appears to comprise a sandy creek bed surrounded by steeply incised banks of colluvium and weathered basalt.

4.1.1.4 Drainage Lines

There is no alluvium mapped along other minor creeks and tributaries including Ramrod Creek, which is present north to north-west of the Maxwell Infrastructure. Ramrod Creek is approximately 3 m wide and largely comprised of silt (Eco Logical 2019). The creek has banks around 0.5 to 1.5 m high that are incised into the regolith and Permian coal measures (Eco Logical 2019). The creek is similar in nature to Whites Creek and Fairford Creek, that were assessed from a series of test pits and boreholes by AGE (2009). The investigation by AGE (2009) found that the stratigraphy in the upper reaches is comprised of silty to sandy clays that typically form an aquitard.

4.1.2 JURASSIC VOLCANICS

Areas of outcropped Jurassic volcanics are mapped in the vicinity of the Project according to regional geological mapping. This includes the Savoy Sill dolerite/syenite at the southern edge of the South Void and across the Muswellbrook Anticline. The Savoy Sill intrudes the Greta Coal Measures (MBGS 2018). There is also the Plashett Sill mapped at surface on the eastern edge of the Maxwell Underground that is up to 60 m thick (MBGS 2018).

Sills have also been mapped in the Maxwell Underground area, localized along the Whynot Seam, Arrowfield Seam, Bowfield Seam and within the interburden between the Whynot and Woodlands Hill Seams (Edderton Sill) (MBGS 2018 and Mine Subsidence Engineering Consultants Pty Ltd [MSEC] 2019). The sills are associated with dyke intrusions localized along north-south trending faults (**Figure 27**).

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[2] The prefixes in the drill hole names (i.e. 'N', 'S' and 'W') refer to north, south and west and were used to identify the general location of the drill holes relative to the Project by the drillers.

4.1.3 WITTINGHAM COAL MEASURES

The Permian aged Wittingham Coal Measures unconformably underlie the regolith and Quaternary alluvium, and have been intruded by volcanics in localized areas. Tertiary aged dykes and sills have intruded the coal measures around the Project area, with sills mapped along the Whynot Seam, Arrowfield Seam and Bowfield Seam (MSEC 2019). A cross-section of the sills associated with the coal measures is shown in **Figure 28**. The Wittingham Coal Measures comprise coal seams interbedded with siltstone, sandstone, shales and conglomerates referred to herein as interburden. The Project targets economic coal seams of the Jerrys Plains Subgroup, which is up to 400 m thick at the Project area. The structure, distribution and thickness of the Jerrys Plains Subgroup are shown on **Figure 29**.

Mining at the Project would intercept, from shallowest to deepest, the Whynot Seam, Woodlands Hill Seam, Arrowfield Seam and Bowfield Seams of the Jerrys Plains Subgroup. The seams range in thickness from 1 m to 4 m and occur between 50 m and 425 m below surface at the proposed Maxwell Underground (MSEC 2019). Local geological assessments conducted by MBGS (2018) and MSEC (2019), as well as regional geological mapping, show that the coal measures occur at subcrop to the north and east of the Project area (**Figure 21**).

4.1.4 MAITLAND GROUP

The Maitland Group conformably underlies the Wittingham Coal Measures and comprises marine sequences of interbedded sandstone and siltstone. No coal seams currently considered economic occur within the Maitland Group at the Project Area. The Maitland Group occurs at subcrop to the west of the Maxwell Infrastructure area and dips in a south to westerly direction.

4.1.5 GRETA COAL MEASURES

The Greta Coal Measures underlie the Maitland Group and unconformably underlie regolith where it occurs at subcrop and outcrop around the Maxwell Infrastructure area. The Greta Coal Measures comprise interbedded sequences of siltstone, sandstone and coal. The main economic seams in the area are associated with the Rowan Formation and include the Brougham, Grasstrees, Puxtrees and Balmoral seams. The coal seams are around 3 m to 10 m thick (AGE 2006) and were targeted at the former Drayton Mine where they occur at subcrop along the Saltwater Anticline. Due to folding along the anticline, the Greta Coal Measures dip in all directions from the Maxwell Infrastructure area (i.e. to north, south, east and west). Beneath the Maxwell Underground the Greta Coal Measures dip towards the south-west.

4.2 STRUCTURAL GEOLOGY

At the Maxwell Underground, the target coal seams occur at subcrop to the west, north and east (**Figure 27**). The structure of the coal seams is influenced by the Muswellbrook Anticline, which occurs to the north-east of the Maxwell Underground area. The Muswellbrook Anticline forms a structural divide, with the Wittingham Coal Measures absent in this area and the underlying Greta Coal Measures present at surface. Further to the east the Wittingham Coal Measures re-occur and dip towards the south-east and east around HVO West Pit.

Regional geological mapping (1:100k Hunter Coalfield Map) indicates the presence of faults within the region. The location of faults was reviewed by MBGS (2018) based on site drill data and geophysical assessment. The investigation verified that some mapped faults (i.e. Redmanvale Fault) were absent from the Maxwell Underground area and other minor faults are present. Within the Maxwell Underground area, a series of minor north-west trending faults with minor displacement (2 m to 10 m) are present (MBGS 2018). The East Graben Fault and Randwick Park Fault have also been mapped adjacent to and 1 km to the west of the Maxwell Underground area, respectively (**Figure 27**). The faults record structural displacement of between 3 m to 50 m along the Calool Syncline. North-east to south-west trending faults also occur within the Maxwell Underground area, which are largely associated with igneous intrusions (dykes) (MBGS 2018).

4.3 GROUNDWATER MONITORING NETWORK

4.3.1 MAXWELL PROJECT

The groundwater monitoring network at the Project area has been progressively installed since 1998. This includes 31 monitoring bores and seven vibrating wire piezometer (VWP) locations around the Maxwell Underground. Details on the bore network are summarised in **Table 4-2** and locations shown in **Figure 30.**

The groundwater monitoring bores around the Maxwell Underground include:

- Three bores within the Hunter River alluvium;
- Four bores within Saddlers Creek alluvium;
- Two bores within regolith material along Saddlers Creek;
- Two bores within the regolith material near Maxwell Infrastructure area;
- Two bores within the Greta Coal Measures (coal);
- One bore within the Maitland Group; and
- 17 bores within the Jerrys Plains Subgroup Permian coal measures.

Bore construction and lithological logs are available for the MB1 to MB4 bores from AGE (2015), and details are available for the MW1 to MW3 bores from ENRS (2018). Target geology for the DD series bores has therefore been inferred using the site geological model and bore depths. The network also includes four groundwater monitoring bores (GW01S/D and GW02S/D) installed for the Project around the Maxwell Infrastructure area in 2019. A fifth bore was drilled (GW03) but abandoned due to no water intersected and hard ground conditions within the dolerite intrusion.

The VWP network includes 32 sensors at seven locations, monitoring various interburden and coal seam sequences within the Jerrys Plains Subgroup. Construction details and lithological logs for the VWPs were derived from the AGE (2015) report.

Data is also available for one monitoring bore (W1102) and a series of historical open exploration holes converted to monitoring bores are present around the Maxwell Infrastructure.

Table 4-2 Monitoring Bore Construction Summary – Project Area network

SITE	BORE NAME	TYPE	EASTING	NORTHING	GROUND LEVEL (mAHD)	SCREEN INTERVAL (mBGL)	GEOLOGY	STATUS	DATA RANGE
MU	MB1 -Alluvial	MB	297933	6407459	81.01	8 – 11	Hunter River alluvium	EX	2011 – 2015
MU	MB4-Alluvial	MB	300302	6406234	81.43	10 - 18	Hunter River alluvium	EX	2011 – 2015
MU	MW3	MB	297904	6407652	81.641	2.9 – 6.9	Hunter River alluvium	EX	2018
MU	MB2-Alluvial	MB	294998	6411669	115.34	5 - 7	Saddlers Creek alluvium	EX	2011 - 2018
MU	MW2	MB	294977	6411419	119.36	4 – 9.5	Saddlers Creek alluvium	EX	2018
MU	MB3-Alluvial	MB	297269	6412850	132.72	8.5-14.5	Saddlers Creek alluvium	EX	2011 - 2018
MU	MW1	MB	297254	6412760	136.53	6 – 9	Saddlers Creek alluvium	EX	2018
MU	MB2-Regolith	MB	295004	6411675	115.43	20 - 29	Regolith	EX	2011 - 2018
MU	MB3-Regolith	MB	297328	6412729	137.34	27 - 30	Regolith	EX	2011 - 2018
MU	DD1041 - Deep	MB	296202	6409476	187.32	387.3	JPS	UN	2001 - 2018
MU	DD1041 - Shallow	MB	296202	6409476	187.32	-	JPS	UN	2001 - 2018
MU	DD1057	MB	295181	6410458	146.93	164-188	JPS – Arrowfield overburden		2003 – 2018
MU	DD1004	MB	299798	6410922	217.38	105.7	JPS – Blakefield overburden	UN	1998 – 2018
MU	DD1005	MB	298799	6410901	225.02	138.6	JPS – Blakefield overburden	UN	1998 – 2018
MU	DD1014	MB	296799	6410864	183.4	90.5	JPS – Blakefield overburden	UN	1998 – 2018
MU	DD1015	MB	298815	6409900	212.65	162.5	JPS – Blakefield overburden	UN	1998 – 2018
MU	DD1016	MB	297801	6410882	201.15	126.4	JPS – Blakefield overburden	UN	1998 – 2018
MU	DD1025	MB	298764	6411901	169.81	44.62	JPS – Blakefield overburden	UN	1998 – 2018
MU	MB4-Coal	MB	300307	6406231	81.34	42 - 47	JPS - Coal	EX	2011 - 2015
MU	DD1027	MB	301133	6410960	235.82	252.8	JPS – Edderton Seam	UN	2000 - 2018
MU	DD1030	MB	301754	6408961	160.08	282.5	JPS – Edderton Seam	UN	2000 - 2018
MU	DD1032	MB	297143	6412495	140.25	276.5	JPS – Piercefield overburden	UN	2001 - 2018

SITE	BORE NAME	TYPE	EASTING	NORTHING	GROUND LEVEL (mAHD)	SCREEN INTERVAL (mBGL)	GEOLOGY	STATUS	DATA RANGE
MU	MB1_Redbank	MB	297930	6407453	80.89	51 - 57	JPS – Redbank Creek Seam	EX	2011 - 2015
MU	MB1 - Whybrow	MB	297928	6407448	80.84	25-28	JPS - Whybrow Seam	EX	2011 - 2015
MU	DD1052	MB	296274	6408513	183.12	105-127	JPS – Whynot Seam overburden	UN	2003 - 2018
MU	DD1043	MB	295200	6409458	173.78	182-203	JPS – Woodlands Hill overburden	UN	2003 - 2018
MU	RD1189 (SD1_DD001)	VWP	299896	6412419	208.63	78.9	Woodlands Hill Seam	EX	2010
						145.5	ZZBF Seam		
						186.2	Warkworth Seam		
						230	Mt Arthur Seam		
						255.5	Piercefield Seam		
						315	Bayswater Seam		
						322	Wynn Seam		
MU	RD1192 (RBR2)	VWP	296092	6409038	177.06	61.2	Wambo Seam	EX	2010
						80	Redbank Seam		
						148.5	Blakefield Seam		
MU	BLK6R12 (RD1220)	VWP	293653	6409558	186.25	25	Whybrow Seam	EX	2011
						40.5	Redbank Seam		
						86.5	Whynot Seam		
						113.7	Blakefield Seam		
MU	VWP1 (RD1221) (RDW006A)	VWP	297926	6407444	80.96	21	Interburden	EX	2011
						40	Interburden		
						73	Interburden		
						87	Whybrow Seam		
						109.2	Whynot Seam		
						138	Blakefield Seam		
MU	RBD1 (VWP) (DD1170)	VWP	295178	6409246	169.55	24.65	Whybrow Seam	EX	2011
						33.55	Redbank Seam		
						79.5	Whynot Seam		
						103.3	Blakefield Seam		
MU	WND16 (VWP) (DD1188)	VWP	298122	6408842	130.58	33.75	Wambo Seam	EX	2011
						59.25	Whynot Seam		
						90.15	Blakefield Seam		
						110.5	Blakefield Seam		
MU	WND26 (VWP) (DD1187)	VWP	299487	6409044	163.71	77.3	Whybrow Seam	EX	2011
						84.6	Redbank Seam		
						123.45	Wambo Seam		
						144.25	Whynot Seam		
MI	F1024	OH	305761	6419755	236.70	236	Greta Coal Measures	AD	1982 - 2017
MI	F1162	OH	304256	6420755	228.20	274	Greta Coal Measures	UN	1982 - 2017
MI	F1163	OH	301045	6415695	194.70	384	Maitland Group	AD	1982 - 2017
MI	F1164	OH	304223	6420406	220.80	191	Greta Coal Measures	UN	1982 - 2017
MI	F1167	OH	305124	6421790	230.50	314	Greta Coal Measures	AD	1982 - 2017
MI	F1168	OH	305235	6420774	212.90	189	Greta Coal Measures	AD	1982 - 2017
MI	R4171A	OH	304821	6419129	229.62	138	Maitland Group	UN	1982 – erroneous
MI	R4171B	OH	304821	6419128	229.62	138	Greta Coal Measures	UN	2000 - 2012
MI	R4214	OH	304606	6416180	257.89	136	Jurassic Volcanics	UN	2005 – 2009
MI	R4220	OH	304968	6416196	228.42	119	Greta Coal Measures	UN	1985 - 2013
MI	R4224	OH	305473	6416199	202.98	133	Greta Coal Measures	UN	2005 – 2013
MI	R4241	OH	305853	6416205	195.98	150	Jurassic Volcanics	UN	2005 – 2017
MI	R4243	OH	304231	6416180	290.41	142	Jurassic Volcanics	UN	1983 - 2013
MI	R4258	OH	304364	6420217	225.10	176	Greta Coal Measures	UN	2005 – 2010
MI	W1102	MB	300984	6416044	186.70	23	Maitland Group	UN	1982 – 2017

SITE	BORE NAME	TYPE	EASTING	NORTHING	GROUND LEVEL (mAHD)	SCREEN INTERVAL (mBGL)	GEOLOGY	STATUS	DATA RANGE
MI	GW01D	MB	303387	6420692	213.22	12-15	Base regolith	EX	2019
MI	GW01S	MB	303391	6420684	213.17	29 - 32	Greta Coal Measures - Coal	EX	2019
MI	GW02D	MB	305647	6418664	202.98	8-14	Base regolith	EX	2019
MI	GW02S	MB	305647	6418664	202.98	69 - 72	Greta Coal Measures - Coal	EX	2019
MI	GW03	OH	303867	6416030	296.61	-	Dolerite	AD	-

Note: Coordinates in GDA94 Zone 56
MI – Maxwell Infrastructure
MB – Monitoring Bore
OH – Open Hole (exploration drill hole)
UN – Unknown
JPS – Jerrys Plains Subgroup
mbgl = metres below ground level
MU – Maxwell Underground
VWP – Vibrating Wire Piezometer
EX – Existing
AD – Abandoned and destroyed/collapsed

4.3.2 SURROUNDING DATA

Additional groundwater level and quality data is available within the region. This includes groundwater monitoring conducted at Mt Arthur Mine, Spur Hill and by AGL, as well as government groundwater monitoring. Through data sharing agreements, Malabar obtained information about the groundwater monitoring network and monitoring data for the Mt Arthur Mine and AGL, which has been utilized for this groundwater assessment. Details on the bore networks are summarised in **Table 4-3** and locations shown in **Figure 31.**

The groundwater monitoring bores around Spur Hill with water level or water quality data utilised for the groundwater assessment include:

- Four bores within the Hunter River alluvium;
- Three bores within the Jerrys Plains Subgroup Permian coal measures; and
- Five VWP locations with 36 sensors into the Permian coal measures and 1 sensor within an igneous sill (SHD010 – 383).

The groundwater monitoring bores around the Mt Arthur Mine with water level or water quality data utilised for the groundwater assessment include (refer **Figure 31**):

- Ten bores within the Hunter River alluvium, two of which potentially also intersect shallow coal measures;
- Two bores within the Saddlers Creek alluvium and one bore within regolith near Saddlers Creek;
- 40 bores within the Permian coal measures around Mt Arthur Mine, north-west of the Project area; and
- Seven VWP locations with 24 sensors into the Permian coal measures, one of which (PL2) is within a fault zone.

Groundwater monitoring conducted by AGL includes nine bores intersecting the shallow regolith surrounding the Liddell Ash Dam to the east of Maxwell Infrastructure area.

Table 4-3 Monitoring Bore Construction Summary – Surrounding Data

SITE	BORE NAME	TYPE	EASTING	NORTHING	GROUND LEVEL (MAHD)	SCREEN INTERVAL (MBGL)	GEOLOGY	STATUS	DATA RANGE
SH	CB1	MB	285517	6407737	-	7.4 - 10.4	Hunter River Alluvium	EX	2012
SH	RB2	MB	286111	6416085	-	8 - 11	Hunter River Alluvium	EX	2012
SH	RB4	MB	286017	6416066	-	8 - 11	Hunter River Alluvium	EX	2012
SH	N1	MB	282187	6411761	-	8.7	Hunter River Alluvium	EX	2017
SH	SHD027	MB	286915	6416031	-	214 - 226	Whynot Seam	EX	2014 - 2017
SH	SHD028a	MB	289169	6408423	-	113 - 119	Whynot Seam	EX	2014 – 2017
SH	SHD028b	MB	289173	6408421	-	60 - 69	Redbank Creek Seam	EX	2014 – 2017
SH	SHD003	VWP	287944	6417265	140.75	40	Whybrow Seam Overburden	EX	2013 - 2017
						88	Whybrow Seam		
						150	Whybrow Seam-Wambo Seam Interburden		
						183	Whynot Seam		
						250	Glen Munro Seam		
						287	Woodlands Hill Seam		
						330	Arrowfield Seam Roof		
						370	Bowfield Seam		
SH	SHD005	VWP	286139	6415822	128.34	85	Whybrow Seam Overburden	EX	2013 - 2017
						165	Redbank Creek Seam-Wambo Seam Interburden		
						185	Wambo Seam-Whynot Seam Interburden		
						202	Whynot Seam		
						262	Glen Munro Seam		
						313	Woodlands Hill Seam		
						358	Arrowfield Seam		
						430	Warkworth Seam		
SH	SHD006	VWP	288800	6408420	130.83	65	Whybrow Seam Overburden	EX	2013 - 2017
						100	Whybrow Seam-Redbank Creek Seam Interburden		
						190	Whynot Seam		
						270	Glen Munro Seam Interburden		
						327	Woodlands Hill Seam		
						370	Arrowfield Seam		
						418	Warkworth Seam		
SH	SHD010	VWP	286874	6412265	169.52	50	Whybrow Seam Overburden	AD	2013 - 2016
						90	Whybrow Seam Overburden		
						135	Redbank Creek Lower Seam		
						212	Whynot Seam-Blakefield Seam Interburden		
						225	Blakefield Seam		
						267	Glen Munro Seam		
						333	Woodlands Hill Seam		
						383	Igneous Sill (ISG1)		

SITE	BORE NAME	TYPE	EASTING	NORTHING	GROUND LEVEL (MAHD)	SCREEN INTERVAL (MBGL)	GEOLOGY	STATUS	DATA RANGE
SH	SHD017	VWP	287033	6408365	275.7	175	Newcastle Coal Measures	AU	2013 - 2016
						263	Whybrow Seam		
						310	Redbank Creek Upper Seam		
						330	Wambo Seam Roof		
						417	Blakefield Seam		
						584	Warkworth Seam		
MA	GW16	MB	294197	6422759	131.77	13	Hunter River alluvium	EX	2008 - 2018
MA	GW21	MB	296141	6424483	136.06	16	Hunter River alluvium	EX	2008 - 2018
MA	GW25	MB	298376	6425231	140.05	13	Hunter River alluvium	EX	2008 - 2018
MA	GW38A (IW4030)	MB	293831	6422377	131.57	20.6	Hunter River alluvium	EX	2008 - 2018
MA	GW39A	MB	293094	6422248	130.35	10.4	Hunter River alluvium	EX	2008 - 2018
MA	GW40A	MB	291815	6422119	128.89	13.8	Hunter River alluvium	EX	2008 - 2018
MA	GW41A (IW4029)	MB	290354	6421789	126.48	11.6	Hunter River alluvium	EX	2008 - 2018
MA	GW42	MB	295139	6423369	135.62	11	Hunter River alluvium	EX	2016 - 2018
MA	GW38A	MB	293832	6422377	131.24	34.4	Hunter River alluvium and coal measures	EX	2008 - 2018
MA	GW41A	MB	290354	6421789	125.96	34.7	Hunter River alluvium and coal measures	EX	2008 - 2018
MA	GW46	MB	298337	6413629	143.63	21	Regolith near Saddlers Creek	EX	2016 - 2018
MA	GW45	MB	298890	6413630	151.89	15	Saddlers Creek alluvium	EX	2016 - 2018
MA	GW47	MB	297409	6412974	136.51	18	Saddlers Creek alluvium	EX	2016 - 2018
MA	OD1078	MB	294495	6419259	171	63	Arrowfield	EX	2016 - 2018
MA	GW49	MB	290354	6421789	125.55	36	Arrowfield	EX	2016 - 2018
MA	BCGW18	MB	294345	6419985	158.3	11.3	Arrowfield		2008 - 2018
MA	EWPC33	MB	294253	6416846	229.35	57.4	Blakefield 3 seam	EX	2008 - 2018
MA	GW48	MB	291815	6422119	129.7	36.2	Bowfield	EX	2016 - 2018
MA	OD1078-PIEZO	MB	294495	6419259	171.05	82.8	Bowfield seam	EX	2008 - 2018
MA	OD1074-PIEZO	MB	296501	6417756	233.57	475	Bowfield seam	AD	2008 - 2010
MA	BCGW19	MB	292462	6419152	187.43	8.4	Glen Munro	EX	2008 - 2018
MA	OD1079	MB	295946	6416350	226	546	Glen Munro	EX	2016 – 2018
MA	OD1079-PIEZO	MB	295946	6416350	226	87.2	Glen Munro	EX	2008 - 2018
MA	GW6	MB	294254	6418579	196	27	Glen Munro	EX	2008 - 2018
MA	BCGW05	MB	291053	6410764	139.78	16.7	Glen Munro	AU	2008 - 2014
MA	BCGW11	MB	293117	6414779	185.8	39.1	Glen Munro	AU	2008 - 2014
MA	BCGW15	MB	290717	6412433	160.2	36.7	Glen Munro	AU	2008 - 2014
MA	BCGW22	MB	295304	6414211	143.91	0	Glen Munro	EX	2008 - 2014
MA	OD1073	MB	293000	6418750	215.21	48.8	Glen Munro + Arrowfield seams	AD	2008 - 2014
MA	OR2051	MB	293718	6417262	229.08	38.8	Glen Munro + Arrowfield seams	AD	2008 - 2014
MA	OR2051-PIEZO	MB	293718	6417262	229.08	blocked	Glen Munro + Arrowfield seams	AD	2008 - 2014
MA	GW7	MB	295635	6419594	214.4	48.8	Glen Munro seam (composite)	EX	2008 – 2018
MA	GW8	MB	296993	6419486	207.11	221.1	Hard Rock	EX	2008 - 2017
MA	BCGW12	MB	297458	6421988	153.06	33.2	Permian coal measures	AD	2008 - 2014
MA	BCGW22 (IW4026)	MB	295304	6414211	143.39	37.9	Glen Munro seam	AD	2016 - 2018
MA	GW22	MB	296930	6423998	154.05	96.3	Permian coal measures	EX	2008 - 2015

SITE	BORE NAME	TYPE	EASTING	NORTHING	GROUND LEVEL (MAHD)	SCREEN INTERVAL (MBGL)	GEOLOGY	STATUS	DATA RANGE
MA	GW23	MB	297919	6424515	181.4	54.6	Permian coal measures	EX	2008 - 2018
MA	OD1074	MB	296501	6417756	233.57	138.3	Permian coal measures	AD	2008 - 2015
MA	OD1049-SURFACE	MB	294498	6413753	156.31	106.7	Unknown	AD	2008 – 2014
MA	OD1073-PIEZO	MB	293000	6418750	215.21	74.7	Unknown	AD	2008 – 2014
MA	GW38P	MB	293831	6422384	131.16	32.6	Warkworth	EX	2008 - 2018
MA	GW39P	MB	293095	6422251	130.35	42.7	Warkworth	EX	2008 - 2018
MA	GW27	MB	301863	6418412	235.46	115.5	Permian coal measures	EX	2008 – 2018
MA	GW26	MB	301841	6418792	234.2	93.1	Permian coal measures	EX	2008 – 2018
MA	GW43	MB	294232	6418551	197.33	69	Woodlands Hill seam	EX	2008 – 2018
MA	GW44	MB	297422	6414715	211.03	133	Woodlands Hill seam	EX	2008 – 2018
MA	BCGW10	MB	293115	6414781	185.35	65.4	Woodlands Hill seam	AU	2008 - 2014
MA	OD1046-PIEZO	MB	297442	6414741	210.76	560	Woodlands Hill seam	AD	2008 - 2014
MA	OD1049-WH	MB	294498	6413753	156.31	35.1	Woodlands Hill seam	AD	2008 - 2014
MA	OD1082	MB	295485	6416726	219.51	70.1	Woodlands Hill seam	AD	2008 - 2014
MA	OD1082-PIEZO	MB	295485	6416726	219.51	blocked	Woodlands Hill seam	AD	2008 - 2014
MA	GW2	MB	299045	6413511	153.74	113	Woodlands Hill seam	EX	2008 - 2018
MA	GW3	MB	298856	6413389	151.29	120.4	Woodlands Hill seam	EX	2008 - 2018
MA	PL1	VWP	295167	6423381	135.46	205.5	Edinglassie Seam	EX	2011 – 2017
MA	PL2	VWP	295195	6423364	135.41	216.5	F4 Fault	EX	2011 – 2018
MA	PL3	VWP	295166	6423349	135.38	227	Edinglassie Seam (Hanging Wall)	EX	2011 – 2018
						241	Ramrod Creek Seam - RK4 (Footwall)		
MA	VWP04	VWP	294708	6422137	140.84	130	Vaux Seam	EX	2015 - 2018
						161	Bayswater Seam		
						201	Edderton Seam		
						262.5	Edinglassie Seam		
						285	Ramrod Creek Seam		
MA	VWP05	VWP	293997	6421606	161.4	164	Vaux Seam	EX	2015 - 2018
						192	Bayswater Seam		
						227	Edderton Seam		
						288	Edinglassie Seam		
						311	Ramrod Creek Seam		
MA	VWP06	VWP	293958	6420804	179.64	237	Vaux Seam	EX	2015 - 2018
						269	Bayswater Seam		
						304	Edderton Seam		
						366	Edinglassie Seam		
						388.5	Ramrod Creek Seam		
MA	VWP07	VWP	295657	6419563	215.95	223	Piercefield Seam	EX	2015 - 2018
						271	Vaux Seam		
						286.5	Bayswater Seam		
						326	Edderton Seam		
						418	Ramrod Creek Seam		
AGL	LB-MW01	MB	306538	6418183	191.00	11	Regolith	EX	2016 - 2018
AGL	LB-MW03	MB	305752	6417246	175.48	2	Regolith	EX	2016 - 2018
AGL	LB-MW05	MB	305949	6416021	187.40	5.5	Regolith	EX	2016 - 2018
AGL	LB-MW06	MB	306547	6415791	193.01	3.5	Regolith	EX	2016 - 2018
AGL	LB-MW08	MB	306882	6416600	188.70	10	Regolith	EX	2016 - 2018
AGL	LB-MW11	MB	308018	6417133	151.10	7.5	Regolith	EX	2016 - 2018

SITE	BORE NAME	TYPE	EASTING	NORTHING	GROUND LEVEL (MAHD)	SCREEN INTERVAL (MBGL)	GEOLOGY	STATUS	DATA RANGE
AGL	LB-MW13	MB	308079	6417341	165.77	7	Regolith	EX	2016 - 2018
AGL	LB-MW14	MB	307838	6417627	157.85	5.5	Regolith	EX	2016 - 2018
AGL	LV-MW03	MB	308246	6417857	141.10	8	Regolith	EX	2016 - 2018

Note: Coordinates in GDA94 Zone 56
SH – Spur Hill
MB – Monitoring Bore
OH – Open Hole
EX – Existing
mbgl = metres below ground level
MA – Mt Arthur Mine
VWP – Vibrating Wire Piezometer
AD – Abandoned and Destroyed/Collapsed
UN – Unknown
** Available data appears erroneous due to inconsistency between sensors and depths*

4.4 GROUNDWATER FLOW SYSTEMS

4.4.1 GROUNDWATER FLOW BEHAVIOUR

4.4.1.1 Hunter River Alluvium

The Hunter River alluvium comprises silt underlain by sands and gravels, reaching a thickness of up to 30 m. The Hunter River alluvium is classified as a highly productive groundwater source. As outlined in **Section 4.3**, there are 10 groundwater monitoring bores that intersect the Hunter River alluvium, eight upstream near the Mt Arthur Mine (GW series) and two downstream (MB series). There are also government monitoring bores along the Hunter River (i.e. GW080075 to GW080078 and GW271031). Groundwater levels range between 6.6 m and 12.0 m below surface, and groundwater elevations range between 130 mAHD in the upstream area (GW25), down to 69 mAHD near the confluence with Saltwater Creek (MB4-Alluvial) (**Figure 32**). This indicates groundwater flow within the alluvium generally follows the direction of surface water flow, in a south to south-easterly direction.

Groundwater levels within the alluvium have remained relatively stable over time, despite periods of below average rainfall (**Figure 33**). This indicates a degree of recharge to the alluvium from the Hunter River, which has regulated flows.

4.4.1.2 Saddlers Creek Alluvium and Regolith

Quaternary alluvium is present along Saddlers Creek, with the extent of alluvium greatest near the confluence with the Hunter River (**Figure 25**). The alluvium comprises permeable sands and gravels in the lower reaches of the creek, with low permeability silts and clays present within the upper reaches. The depth to groundwater within the upper reaches of Saddlers Creek (GW47, MB3-Alluvial, GW45 and MW1) ranges between 3.7 m and 10.9 m below surface, 128.2 mAHD and 140.95 mAHD (**Figure 34**). Within the lower reaches (MW2 and MB2-Alluvial) the depth to groundwater ranges between 3.3 m and 6.4 m below surface, 111.7 mAHD and 112.9 mAHD (**Figure 34**). The change in groundwater elevations shows groundwater within the alluvium flows in a southerly direction, following topography and Saddlers Creek.

The alluvium is unconfined and is likely recharged from rainfall and potentially stream flow following peak rainfall events. There is also potential for upward leakage from the Permian coal measures at the lower reaches of Saddlers Creek. **Figure 34** presents groundwater trends for bores intersecting the regolith material around Saddlers Creek (GW46, MB2-Regolith and MB3-Regolith). The data indicates water is present within the regolith material in localized areas, with levels generally ranging between 6 m and 9 m below surface. In the upper reaches of Saddlers Creek (MB3-Regolith) groundwater levels are below the alluvial levels, indicating potential recharge from the alluvium. In contrast, in the lower reaches of Saddlers Creek (MB2-Regolith) the water levels within the regolith are higher than alluvial levels and near the surface until 2015, indicating potential upward seepage to the alluvium at this location or the influence of land use practices. Hunter Eco (2019) also observed areas of ponded water along Saddlers Creek, indicating the potential presence of low permeability clays that can inhibit seepage to the underlying strata and form localized perched water bearing zones.

4.4.1.3 Jurassic Volcanics

Volcanic sills and dykes are present at the Project at surface and intruded into the Permian coal measures. Bores R4214, R4241 and R4243 located south of the Maxwell Infrastructure potentially intersect the volcanic intrusions. Groundwater levels range between 167.2 mAHD to 251.3 mAHD from 2005 to 2018, with the higher groundwater elevation at R4243 in the west, down to R4241 in the east (**Figure 35**). Despite active mining within 300 m north of the bores, groundwater levels within the bores have remained relatively stable. In contrast nearby bores within the Greta Coal Measures (i.e. R4220 and R4224) recorded a decline in groundwater levels of over 35 m in response to mining. This indicates the igneous material has a relatively low permeability. The volcanics are likely recharged from rainfall recharge and surface water storage.

4.4.1.4 Permian Wittingham Coal Measures

The Wittingham Coal Measures occur across the Maxwell Underground area and comprise interbedded sequences of sandstone, siltstone and coal. Groundwater occurrence is largely associated with the coal seams due to secondary porosity through the fractures and cleats (MER 2009). The interburden material (sandstone and siltstone) generally has a low permeability, and due to the stratified nature of the stratigraphy has a very low vertical hydraulic conductivity.

Groundwater within the Permian coal measures is confined to semi-confined with the coal measures occurring at outcrop. At the Maxwell Underground area, groundwater elevations generally range between 125.7 mAHD (DD1057) and 157.5 mAHD (DD1025), indicating general groundwater flow from the north-east to the south-west (**Figure 36** and **Figure 37**). Groundwater within the coal measures has remained relatively stable from 2012 to 2016. An exception to this is bore DD1052, which intersects the shallower overburden strata at the southern end of the Maxwell Underground area. Bore DD1052 records a general decline in levels over time despite there being no active mining or known registered landholder water supply bores in the area. The cause of the decline is unknown, but may relate to bore construction.

To the west at the Mt Arthur Mine, groundwater levels are influenced by mining, with decline in groundwater levels extending approximately 1 km to 2 km from the active mine area (**Figure 37**). Hydrographs of groundwater level trends within VWP04 and VWP05 located north of the Mt Arthur Underground are presented in **Figure 38** and **Figure 39**, respectively. The graphs illustrate the gradual decline in groundwater levels within the Permian coal measures in response to mining at the Mt Arthur Open Cut. **Figure 40** presents a comparison between groundwater levels within the Hunter River (GW39A) and within the underlying Permian coal measures (GW39P). The graph illustrates a decline in groundwater levels within the coal measures, while levels within the alluvium generally follow climate trends. This shows that within areas experiencing depressurisation in the coal measures there is limited change in alluvial groundwater trends.

4.4.1.5 Permian Maitland Group

The Maitland Group comprises low permeability siltstones and sandstones and underlies the Wittingham Coal Measures. Two bores potentially intersect the Maitland Group in the area, F1163 and W1102 that are located approximately 250 m west of the Maxwell Infrastructure. Groundwater levels within both bores generally remained at around 178 mAHD (± 1 m) since 1995 (**Figure 41**). The levels show no response to mining, despite mining being active within the underlying Greta Coal Measures until around 2003. This indicates limited hydraulic connectivity between the Maitland Group and surrounding Permian stratigraphy.

4.4.1.6 Permian Greta Coal Measures

The Greta Coal Measures comprise interbedded sequences of siltstone, sandstone and coal that occur at outcrop along the Muswellbrook Anticline and dip in all directions from the Maxwell Infrastructure area. Around the Maxwell Infrastructure area the regolith material overlying the Greta Coal Measures is largely unsaturated or only has water present at depth. In 2019, bores GW01S and GW02S were installed within the base of the weathered regolith material and indicated the presence of water over 14 m below surface. However, the regolith can be locally recharged from surface water storage facilities, such as the Liddell Ash Dam. Recent data (December 2018) for AGL bores (LB-MW01 to LB-MW13 and LV-MW03) indicate groundwater is present within the regolith between 0.8 m to 7.8 m below surface.

Several groundwater monitoring bores intersect the fresh Greta Coal Measures around the Maxwell Infrastructure area. The bores record a general decline in groundwater levels since monitoring commenced in 1982. In 2017, the bores recorded groundwater levels of between 101.0 mAHD (F1164) and 178.1 mAHD (F1024), indicating localized flow towards the pit (**Figure 42**). Recent installation of bores by AGE (2019) indicated the potentiometric level within the coal intersected north of North Void (GW01D) was at around 199.0 mAHD (14 mbgl) and at 135.3 mAHD (67.0 mbgl) east of East Void (GW02D). Within the Maxwell Infrastructure area the current land surface elevation is at about 120 mAHD in North Void and around 150 mAHD in East Void. The available data indicates that North Void is currently acting as a groundwater sink with groundwater flowing towards the pit area.

4.4.1.7 Effects of Local Geological Structures on Groundwater Movement

Previous groundwater assessments identified that the faults do not act as conduits to groundwater flow (AGE 2006, AGE 2012). The faults occur within the Permian coal measures. As the groundwater level contours for the Permian coal measures presented in **Figure 37** show no major changes in groundwater levels along fault lines, the faults do not display a significant change on the contoured groundwater heads.

4.4.2 EXISTING EFFECTS OF MINING

As discussed in **Section 1.3**, there are several mines in the region. The mines most likely to interact with groundwater intercepted as part of the Project are Mt Arthur Mine (open cut and underground) and the former Drayton Mine. This section also provides a brief description of other mines in the region (i.e. Bengalla, Mangoola and HVO) that are not considered likely to interact with groundwater intersected as part of the Project.

4.4.2.1 Mt Arthur Mine

Mining commenced in the Mt Arthur area in the late 1950s with an underground mine that continued in operation until 1964. Open cut mining began at Bayswater No. 2 in 1966 within the Greta Coal Measures. Since 1998 the pit has been used for reject emplacement by Mt Arthur Mine. Numerical groundwater modelling by AGE (2006) identified that seepage from the tailings buffered drawdown within the adjacent Drayton Mine area that also intersects the Greta Coal Measures.

Mt Arthur Mine currently operates in accordance with Project Approval (PA 09_0062) (for the Mt Arthur Coal Consolidation Project), which was granted on 24 September 2010 and subsequently modified on 26 September 2014. Project Approval (PA 09_0062) integrates prior development consents/approvals including:

- Mt Arthur North Mine (DA 144-05-2000, including 2002 modification);
- South Pit Extension Project (PA 06_0108);
- Bayswater No. 3 Mine (DA 210/93, including 1999 and 2001 modifications);
- Bayswater Rail Loading Facility and Rail Loop (DA 105-04-00); and
- Bayswater Coal Preparation Plant (DA 24/97).

Extraction of coal at the open cut operations at the Mt Arthur Mine may take place until 30 June 2026 (Condition 5, Schedule 2 of PA 06_0062). On 2 December 2008, the Mt Arthur Underground Project (PA 06_0091) was approved, and with the exception of the underground entry and roadways developed in 2009, the underground longwall mining activities have not progressed as proposed. Notwithstanding, approval for the underground mine activities remains in effect, and mining operations may take place until 31 December 2030 (Condition 5, Schedule 2 of PA 06_0091).

A groundwater assessment was conducted by AGE (2012) that captured all approved open cut and underground mining at Mt Arthur Mine, and included approved operations at Bengalla Mine. The groundwater model did not include the Drayton Mine area due to the structural geology, with the edge of the model limited to the extent of the coal seam outcrop to the east. AGE (2012) concluded that approved operations at the Mt Arthur Mine would drawdown groundwater levels within 2 km of active mine operations. AGE (2012) also found that drawdown associated with operations at Bengalla Mine, to the north of Mt Arthur Mine, would not interact with drawdown at Mt Arthur Mine. However, it is noted that some interaction was later predicted for the Bengalla Continuation Project (**Section 4.4.2.4**).

There were no reported potential impacts on GDEs as a result of the Mt Arthur Mine (AGE 2012). Drawdown at privately owned bores due to operations at Mt Arthur Mine was predicted. Less than 1 m drawdown was predicted at all privately-owned bores intersecting alluvium and used for stock water supply and irrigation. Greater than 2 m drawdown was predicted at some privately-owned bores intersecting the Permian coal measures and used for stock water supply.

4.4.2.2 *Drayton Mine (Maxwell Infrastructure)*

Drayton Mine was an open cut coal mine targeting the Greta Coal Measures where they occur at outcrop along the Muswellbrook Anticline. The mine commenced operations in 1983 and ceased in October 2016. The adjacent Bayswater No. 2 mine also intersected the Greta Coal Measures from 1968 to 1998, but has since been used for reject emplacement by Mt Arthur Mine.

A groundwater assessment was conducted by AGE (2006) for the extension of the North, South and East Voids at Drayton Mine. The model predicted groundwater inflows for the North, South and East Voids of up to 986 ML/year. Groundwater level drawdown within the Greta Coal Measures was predicted to extend up to 4 km north beyond Ramrod Creek, east up to Lake Liddell and south to Plashett Reservoir. AGE (2006) predicted that there was no baseflow contribution to Saddlers Creek within the upper reaches and therefore there would be no impacts to baseflow due to groundwater drawdown. Some baseflow contributions to Ramrod Creek (55 ML/year), Saltwater Creek (37 ML/year) and the Hunter River (146 ML/year) were modelled, but were not predicted to change due to mining or post-closure at the Drayton Mine. A slight reduction in baseflow contributions to Plashett Reservoir was predicted (approximately 110 ML/year).

AGE (2006) predicted that the final voids would act as sinks, drawing groundwater in towards the mine area. The simulated final pit lake elevation of the North Void was 160 mAHD, East Void was 149 mAHD and South Void was 157 mAHD. Within 10 years post closure, groundwater level drawdown extents reduced to around 2 km north and east, and less than 1 km south of the Drayton Mine. The extent of drawdown to the east would be buffered by the Liddell Ash Dam that potentially acts as a groundwater source and seeps approximately 292 ML/year of water into the underlying regolith and coal measures.

A scenario was also run that assumed the East Void would be filled with ash material and North Void and South Void backfilled with spoil post closure. The model predicted seepage from the void towards Lake Liddell in the event the voids were fully backfilled.

4.4.2.3 *HVO – West Pit*

HVO comprises several open cut pits, with the closest being West Pit over 8 km south-east of the Project. West Pit (formerly Howick) mines the Bayswater Seam to Hebden Seam of the Wittingham Coal Measures. These seams underlie the target coal seams at the Project area, which are not present at West Pit due to the geological structure.

A groundwater assessment was conducted for West Pit by MER (2003). MER (2003) predicted drawdown within the deeper Permian coal measures up to 1.5 km north-west of the pit, with the extent restricted by the outcrop of the coal measures. Drawdown also extended about 2 km south-west of the West Pit, but did not extend to the Hunter River alluvium, therefore no impacts on the alluvium were predicted for West Pit. Cumulative impacts associated with all mining across HVO was also captured within the HVO South Modification 5 groundwater impact assessment conducted by AGE (2016). AGE (2016) predicted drawdown within the Mt Arthur Seam, which is deeper than the Bowfield Seam, extending as far as Carrington Pit at HVO North. This is over 10 km south-east of the Maxwell Underground area.

The geological structure in the area is influenced by the Muswellbrook Anticline, which has resulted in the Wittingham Coal Measures being absent east of the Project and west of HVO. The Project targets the Jerrys Plains Subgroup down to the Bowfield Seam, which is absent in the HVO North area because of the structural geology. The predicted extent of drawdown within the deeper Vane Subgroup is over 6 km from the Project (MER 2003), and within the Jerrys Plains Subgroup (Mt Arthur Seam) is over 10 km from the Project (AGE 2016). Based on this, groundwater interaction between the two mines is not considered likely. Therefore, the mining effects of HVO have not been considered further in this assessment.

4.4.2.4 Bengalla Mine

As described in **Section 1.3**, and shown on **Figure 1**, Bengalla Mine is located to the north-west of Mt Arthur Mine and further afield on the northern side of the Hunter River, approximately 15 km from the Project.

Bengalla Mine is an open cut coal mine, located approximately 4 km west of Muswellbrook. Bengalla Mine currently operates in accordance with SSD-5170 for the Bengalla Continuation Project, which was approved in 2015. Mining operations for the Bengalla Continuation Project may take place until 28 February 2039 (Condition 5, Schedule 2 of SSD-5170).

A groundwater assessment was conducted by AGE (2013a) for the Bengalla Continuation Project. The assessment predicted that groundwater level drawdown could extend to the Hunter River within the initial years of mining. This resulted in cumulative impacts along the Hunter River north of Mt Arthur Mine. The Mining Operations Plan (Coal & Allied, 2015) identified the initial years of mining as being completed around 2016. However, there appears to be no cumulative interaction between the two pits during these initial years, up to year 4. There are no future predicted cumulative impacts between Mt Arthur Mine and Bengalla Mine. Therefore, the mining effects of the Bengalla Mine operations have not been considered further in this assessment.

4.4.2.5 Mangoola Mine

The Mangoola Mine, formerly known as the Anvil Hill Project is located about 10 km further west of Bengalla Mine. Mangoola Mine currently operates in accordance with Project Approval (PA 06_0014) (for the Mangoola Coal Project), that was last modified (MOD8) on 14 June 2017. Mining operations at the Mangoola Mine may currently take place for 21 years from the grant of the mining lease[3] for the project (Condition 5, Schedule 2 of PA 06_0014). There is a current application for the Mangoola Coal Continued Operations Project that plans to extend open cut mining to the north (further from the Project) and extend the life of the mine to 2030 (Mangoola Coal Operations Pty Ltd, 2019).

At its nearest point, the Project underground area is about 20 km south-east of the Mangoola Mine. The Mangoola Mine targets coal in the Newcastle Coal Measures (formerly known as Wollombi Coal Measures), which are absent in the Maxwell Underground area. A groundwater assessment of the approved Mangoola Mine was conducted by MER (2006). MER (2006) predicted 2 m depressurisation in the Newcastle Coal Measures and conglomerates up to 2 km from the active mine area. Due to the distance between the operations, there is no potential groundwater interaction between the Project and Mangoola Mine (as currently approved and with the proposed extension). Therefore, the mining effects of Mangoola Mine operations have not been considered further in this assessment.

4.4.2.6 Bioregional Assessment

In 2018 the Australian Government completed the Bioregional Assessment Program (© Commonwealth of Australia Bioregional Assessment Program www.bioregionalassessments.gov.auc). The bioregional assessments assessed potential impacts, particularly regional scale and cumulative impacts, from coal seam gas and open cut and underground coal mining developments.

The relevant bioregion for the Project area is the Hunter Subregion, which is part of the Northern Sydney Basin bioregion. The Hunter Subregion includes a large part of the Hunter River basin and all of the Macquarie-Tuggerah lakes basin in NSW.

A key finding of the Hunter Subregion Bioregional Assessment was that:

- an area of 1,879 km^2 potentially experiences cumulative groundwater drawdown impacts due to baseline and additional coal resource developments.

The Bioregional Assessment indicates the following for the Project area (Herron et al 2018):

- 5% chance of water table drawdown greater than 2 m under the baseline scenario.
- 5% chance of greater than 5m water table drawdown under the baseline plus 'additional coal resource development (ARD)' scenario.

[3] Mining Lease 1626 was granted on 20 November 2008.

The baseline scenario included:

- Bengalla Mine (open cut operations).
- Mt Arthur Mine (open cut operations).
- Mangoola Mine (open cut operations).
- Former Drayton Mine (open cut operations).

While the additional operations in the ARD scenario included:

- Drayton South Coal Project (open cut operations)[4].
- Mt Arthur Mine (underground operations).

The Bioregional Assessment program is based on data up to 2015, which is why the former Drayton Mine is included in baseline modelling. This, and the fact that the assessments are, by necessity, regional models mean that the results should be considered as indicators, rather than providing detailed analyses. On that point, the Bioregional Assessments website states that:

> *"Bioregional assessments will identify areas where impacts on water resources and water-dependent assets are likely to occur"*

Relevantly, the drawdown areas shown in the Bioregional Assessment, including the previously proposed Drayton South Coal Project and the Mt Arthur Mine (underground operations), does not indicate drawdown zones extending beyond the Hunter River in the north, supporting the exclusion of Bengalla Mine and Mangoola Mine from cumulative assessments as outlined above.

4.4.3 HYDRAULIC PROPERTIES

4.4.3.1 Hydraulic Conductivity – Parameter Ranges

Available data on the hydraulic properties of the main lithological units relevant to the Project are summarised in **Table 4-4**. Data has been sourced from core analysis, packer testing and slug testing conducted at the site and surrounding area (i.e. Maxwell Infrastructure, Maxwell Underground, Mt Arthur Mine and Spur Hill) and reported on by AGC (1984), MER (2007), MER (2009), AGE (2012) and Coffey Geosciences Pty Ltd (Coffey) (2013).

[4] Note: The Drayton South Coal Project previously proposed within EL 5460 is not proceeding.

Table 4-4 Hydraulic Conductivity Properties Summary of Available Field Data

LITHOLOGY	MIN (m/day)	MAX (m/day)	GEOMEAN (m/day)	COUNT	SOURCE
ALLUVIUM – HUNTER RIVER	1.3×10^{-1}	3.7×10^{2}	1.2×10^{1}	48	AGE (2012), MER 2009
PERMIAN COAL MEASURES – INTERBURDEN	1.9×10^{-7}	1.3×10^{-1}	1.6×10^{-4}	158	MER (2007), MER (2009), Coffey (2013)
BLAKEFIELD SEAM	5.0×10^{-4}	1.2×10^{-4}	1.7×10^{-2}	10	AGE (2012), MER (2009)
GLEN MUNRO SEAM	2.4×10^{-4}	8.9×10^{-2}	8.11×10^{-3}	21	AGE (2012), MER (2009)
WOODLANDS HILL SEAM	9.4×10^{-4}	1.0×10^{-1}	8.4×10^{-3}	29	MER (2007), AGE (2012), MER (2009)
ARROWFIELD SEAM	3.1×10^{-3}	1.4×10^{-1}	2.6×10^{-2}	12	MER (2007), MER (2009)
BOWFIELD SEAM	4.0×10^{-3}	5.3	1.1×10^{-1}	28	MER (2007), MER (2009)
PIERCEFIELD SEAM	4.3×10^{-4}	6.3×10^{-1}	1.4×10^{-2}	14	MER (2007), AGE (2012), MER (2009)
EDDERTON SEAM	8.0×10^{-2}	8.0×10^{-2}	8.0×10^{-2}	1	AGE (2012)
RAMROD CREEK SEAM	6.5×10^{-1}	6.5×10^{-1}	6.5×10^{-1}	1	AGE (2012)
GRETA COAL MEASURES - COAL	7.9×10^{-1}	2.0	1.2	6	AGC (1984)
SPOIL	7.0×10^{-1}	1.6	1.1	2	MER (2009), AGE (2013b)

Note: Geomean – geometric mean of the data

As shown in **Table 4-4**, there is data available for most lithological units in the region. Alluvium along the Hunter River is permeable with a hydraulic conductivity of between 1.3×10^{-1} m/day and 3.7×10^{2} m/day. No hydraulic data is available for the alluvium along Saddlers Creek, but recent drilling indicates the alluvium comprises thick sequences of clays and silts overlying basal sands and gravels in the lower reaches of the creek. It is anticipated that the lower-most end of Saddlers Creek could exhibit similar hydraulic properties as the Hunter River alluvium, but the upper reaches would exhibit lower hydraulic properties due to the predominance of clays and silts in the stratigraphy.

The Permian coal measures record relatively low hydraulic conductivity of between 2.4×10^{-4} m/day to 5.3 m/day for the coal seams and 1.1×10^{-5} m/day to 1.3×10^{-3} m/day for the interburden material. Core analysis conducted by Coffey (2013) at Spur Hill, as well as by MER (2007) and MER (2009) in the area, recorded vertical hydraulic conductivity of the Permian coal measures ranging between 1.0×10^{-7} m/day and 5.1×10^{-2} m/day (91 samples). Based on the results from Coffey (2013) the ratio between vertical and horizontal hydraulic conductivity ranged between 3 and 56, with a median value of 11 (Heritage Computing Pty Ltd 2013). Elevated hydraulic conductivity readings within the coal seams were recorded for the Bowfield Seam and Greta Coal Measures.

The high Bowfield Seam hydraulic conductivity results are largely from packer testing conducted by MER (2009) near Lemington to the south-east for samples collected at shallow depths. Similarly, the high hydraulic conductivity results for the Greta Coal Measures are limited to readings from pumping tests collected from shallow bores intersecting the thick coal seam sequences. It is generally expected that the hydraulic conductivity within the coal measures will decline with depth, due to increased pressure minimising secondary porosity through fractures and cleats. Extensive analysis of core samples and packer test results by MER (2009) identified a slight decline in hydraulic conductivity with depth, but a broad range in the spread of data within one depth interval (**Table 4-5**). Similar broad trends have been identified for the Spur Hill packer test and laboratory core test data analysed by Coffey (2013) and presented in **Figure 43** and **Figure 44**.

Table 4-5 Change in Hydraulic Conductivity with Depth (MER 2009) (m/day)

Seam description	0 to 100m depth	100 to 200m depth	200 to 300m depth
mostly dull coal	2.0×10^{-3} to 6.0×10^{-4}	6.0×10^{-4} to 1.8×10^{-4}	1.8×10^{-4} to 5.0×10^{-5}
dull coal with bright bands	2.2×10^{-2} to 6.0×10^{-3}	6.0×10^{-3} to 1.9×10^{-3}	1.9×10^{-3} to 5.4×10^{-4}
dull and bright banded coal	7.0×10^{-2} to 2.0×10^{-2}	2.0×10^{-2} to 6.0×10^{-3}	6.0×10^{-3} to 2.0×10^{-3}
bright coal with dull bands	2.2×10^{-1} to 7.0×10^{-2}	7.0×10^{-2} to 2.0×10^{-2}	2.0×10^{-2} to 6.0×10^{-3}
mostly bright coal	2.7 to 8.0×10^{-1}	8.0×10^{-1} to 2.3×10^{-1}	2.3×10^{-1} to 7.0×10^{-2}

Faulting and fracturing can also influence the hydraulic behaviour of the Permian coal measures. A targeted field investigation was conducted at the Mt Arthur Mine to investigate the behaviour of faults in the area (AGE 2012). The investigation involved installation of bores within fault zones and conducting packer testing. The investigation identified that the fault zones exhibit a lower hydraulic conductivity compared to the coal seams (AGE 2012). This is further supported by the presence of dyke intrusions localized along north-south trending faults within the Maxwell Underground area (MBGS 2018). Therefore, faults are not considered conduits to groundwater flow.

Sills have also been mapped within the coal measures at the Maxwell Underground area. As part of the site drill program 22 holes intersected faults, dykes and sills at the site. Lithological logs from the holes indicate the igneous material is described as "dolerite" and is generally hard and strong rock (MBGS 2018). There is no site specific data available on the hydraulic properties of the sills and dykes; however, literature indicates a broad range in hydraulic conductivity of 2.7×10^{-4} m/day to 2.7 m/day (Freeze and Cherry, 1979). Based on the lithological logs it is expected the dolerite dykes and sills exhibit a low permeability. However, it is noted by MER (2009) that localised enhanced groundwater storage can occur at the edges of dykes.

AGC (1984) conducted pumping tests of shallow sequences of the coal seams within the Greta Coal Measures. The testing recorded high hydraulic conductivity of 7.9 x 10^{-1} m/day and 2.0 m/day. No data is available for the interburden material within the Greta Coal Measures, but is anticipated to be similar to the interburden material within the overlying Wittingham Coal Measures.

Spoil material is also present within the backfilled pits, comprising a mix of Permian interburden and overburden material that is generated as waste in the mining process. Testing of spoil in the region estimated a hydraulic conductivity of around 0.7 m/day and 1.6 m/day (MER 2009; AGE 2013b).

4.4.3.2 Storage Properties

Specific yield (together with porosity and specific storage) usually decreases with depth. Specific yields for Sydney Basin sedimentary strata in the context of drainage due to longwall subsidence generally vary between 0.005 and 0.01. The Hunter River alluvium is expected to possess a specific yield in the range of 0.05 – 0.2.

MER (2009) conducted an extensive review of available data on the hydraulic properties of consolidated coal measure strata and alluvial deposits in the Hunter region. While noting that specific yield (Sy, drainable porosity) was infrequently tested, MER provided the following values for Sy:

- < 1% to > 3% for coal seams.
- < 0.0001% (claystones) to < 2% to 3% (sandstones) in unweathered interburden.
- 5% to > 30% for alluvium, about 20% considered representative for sandy silty material.

Regolith hydraulic properties are rarely measured. Areas of dispersive clays and silty clays limit infiltration, while sandy areas show infiltration rates greater than 50 mm/hr.

4.4.4 WATER QUALITY

This section presents a summary of the water quality and beneficial use of groundwater within the different geological units across the Project area and surrounds. The key geological units include the “highly productive” alluvium (Hunter River and lower reach of Saddlers Creek), “less productive” alluvium (upper reaches of Saddlers Creek and Saltwater Creek), regolith, Jurassic volcanics and the Permian coal measures (coal and interburden). Water quality results for surface water (Hunter River, Saddlers Creek and Ramrod Creek) and spoil leachate are also discussed.

Appendix D presents a table that summarises water quality data and statistics used as part of this assessment. The water quality summary table was developed using historical monitoring data for bores at the Maxwell Infrastructure, Maxwell Underground, Spur Hill and the Mt Arthur Mine.

4.4.4.1 Salinity

Salinity is a key constraint to water management and groundwater use, and can be described by total dissolved solid (TDS) concentrations. **Figure 45** presents the TDS data associated with waters screened in the various geological horizons for monitoring bores at Maxwell Infrastructure, Maxwell Underground, Mt Arthur Mine, Spur Hill and registered bore GW080077 intersecting the Hunter River alluvium.

Surface water quality data is also included in **Figure 45**. Hunter River data was converted from government stream gauge electrical conductivity (EC) data (Stations 210002, 2100055 and 2100083) by multiplying EC by 0.67. Government stream gauge data indicates the Hunter River is generally fresh, with an average TDS of 386 mg/L, but can be brackish with a maximum recorded TDS of 899 mg/L. Saddlers Creek data was inferred from graphed historical Saddlers Creek monitoring data presented by Gilbert and Associates (2012) (**Figure 46**). Gilbert and Associates (2012) document that water within the upper reaches of Saddlers Creek has a TDS of around 6,840 mg/L, ranging between 850 mg/L and 15,600 mg/L (SW1 and SW2), while water within the lower reach (SW3) has a TDS of around 3,900 mg/L, ranging between 550 mg/L and 6,920 mg/L.

Figure 45 shows that water quality within the “highly productive” Hunter River alluvium is generally fresh, but can range between fresh to moderately saline. Average TDS is recorded at 791 mg/L but can range between 354 mg/L and 5,070 mg/L.

The “less productive” alluvium within the upper reaches of Saddlers Creek is generally moderately saline, with an average TDS of 3,408 mg/L. Water quality along Saddlers Creek can range between fresh to moderately saline with a TDS of between 302 mg/L and 6,151 mg/L, although saline samples have been observed (15,600 mg/L) (**Appendix D**).

Where water is present within the regolith material, it is generally moderately saline with an average TDS of 5,434 mg/L and can range between 1,196 mg/L and 14,941 mg/L. Similarly, the Wittingham Coal Measures generally record moderately saline water quality, with an average TDS of 2,932 mg/L for the interburden and 2,658 mg/L for the coal. Water quality for the interburden stratigraphy is consistently moderately saline, with TDS ranging between 2,090 mg/L and 3,900 mg/L. The coal seams are more variable, recording fresh to saline water quality with TDS ranging between 149 mg/L and 9,520 mg/L. Bores EWPC33 and GW39P that recorded some samples with fresh water quality are located near a dam and the Hunter River, respectively and likely relate to local recharge sources. Bore BCGW11 intersects the coal measures between the Mt Arthur Mine and Spur Hill recorded fresh water quality sporadically. The readings contrast to other bores in the area and may relate to bore construction or condition.

Jurassic volcanics potentially contain moderately saline water based on results for bore R4241, with an average TDS of 3,627 mg/L. Water in the Maitland Group is brackish to moderately saline with an average TDS of 3,566 mg/L. The Greta Coal Measures are moderately saline with an average TDS of 2,858 mg/L that can range from 1,246 mg/L and 3,893 mg/L.

4.4.4.2 Metals

Routine groundwater sampling includes analysis of metals concentrations. Summary statistics, including the range in metals concentrations for each bore, are included in **Appendix D**. Note, metal analysis has not been reported for bores in the Jurassic volcanics, Maitland Group and Greta Coal Measures. In units sampled for metals, most reported:

- Iron concentrations in alluvium ranging from 38.2 mg/L to <0.05 mg/L;
- Molybdenum concentrations are on average 0.005 mg/L within the Hunter alluvium, ranging between 0.001 mg/L and 0.05 mg/L. Concentrations in the coal measures are on average 0.004 mg/L. Elevated molybdenum concentrations were recorded at one monitoring bore (BCGW22) of up to 0.075 mg/L;
- Aluminium concentrations below the laboratory limit of reporting of 0.01 mg/L in over 70% of samples, with occasional readings at or slightly above the limit of reporting;
- Arsenic concentrations below the laboratory limit of reporting of 0.001 mg/L for 70 % of samples, with occasional readings at or slightly above the limit of reporting; and
- Over 90% of antimony, cadmium, lead, mercury, selenium and beryllium samples reported concentrations below the laboratory limit of reporting.

4.4.4.3 Water Values

Groundwater quality data available for the Project area and surrounds has been compared to the government Default Guideline Values (DGV) for aquatic ecosystems and primary industries, as well as the Australian and New Zealand Environment and Conservation Council (ANZECC) (2000) guidelines for drinking water, short-term and long-term irrigation and specific guideline values for livestock watering (beef cattle). All available water quality results are presented in **Appendix D**.

The data shows all groundwater types are not considered suitable for human drinking water or freshwater aquatic systems due to elevated EC, TDS, chloride, sodium, metals (i.e. aluminium, copper and manganese). The “highly productive” alluvial groundwater may be suitable for short term irrigation (dependent on crop salt tolerance). All groundwater sources are unlikely to be suitable for long term irrigation due to elevated salinity, iron and manganese. However, it is noted that there are several registered bores potentially utilising the “highly productive” alluvium for irrigation purposes (**Section 4.6.1**).

Results for the “highly productive” alluvium along the Hunter River show that, on average, water is within the ANZECC (2000) guideline levels for stock water supply (i.e. sheep, cattle, horses, pigs and poultry). The average TDS for the “less productive” alluvium is above the ANZECC (2000) guideline level for pigs and poultry (3,000 mg/L) but on average is suitable for cattle, horses and sheep. Water within the regolith, volcanics and Maitland Group records average TDS above the ANZECC (2000) guideline level for pigs and poultry (3,000 mg/L) but on average is suitable for cattle, horses and sheep. Water within the Wittingham Coal Measures and Greta Coal Measures is considered suitable for stock water supply. This is supported by the presence of registered bores used for stock domestic supply around Spur Hill and Mt Arthur Mine (**Section 4.6.1**). Anecdotally, this water is primarily only used in drought conditions.

4.4.4.4 Tailings and Leachate Analysis

Geochemical analysis of the waste rock extracted from the Maxwell Underground area and reject emplacement material was conducted by Geo-Environmental Management (2019). Samples were collected from the coal seam roof, floor and coal from core samples for drill holes DD1132, DD1136 and DD1185 within the Maxwell Underground area. Samples of clean coal and existing coal rejects material were also collected and analysed. The analysis found that waste rock and coal is likely to be non-acid forming (NAF). The overburden and interburden material is described as acid consuming due to its buffering capacity. An exception to this was one sample from the Woodlands Hill seam roof that was potentially acid forming (PAF) – Low Concentration (LC) due to higher total sulphur concentration of 0.29 %. However, as reported by Geo-Environmental Management (2019), the overall water quality within the underground workings is unlikely to be affected by the presence of PAF-LC material due to the acid neutralising capacity (ANC) and alkaline pH of the surrounding strata.

Testing of rejects under laboratory conditions identified one sample from the Woodlands Hill seam was NAF. Three samples (Whynot, Woodlands Hill and Bowfield seams) were PAF – LC and two samples (Arrowfield and Bowfield seams) were PAF. The samples returned results for PAF due to positive net acid production potential (NAPP) values related to combined concentrations of total sulphur and sulphide. The results indicated that the coal seams had a total sulfur content of between 0.25 % and 0.86 % and sulphide concentration of between 0.07 % and 0.47 %. Further to this, a summary of surface water quality monitoring data collected from the existing Mt Arthur Tailings dam from 2008 to 2018 is presented in **Appendix D**. The results indicate water quality associated with rejects material is on average slightly alkaline with pH of 6.5, EC of 5,300 microSiemens per centimetre (µS/cm), sulphate concentration of 2,055 mg/L, molybdenum concentration of 0.002 mg/L, arsenic concentration of 0.002 mg/L and aluminium concentration of 0.45 mg/L.

As outlined in **Section 4.4.4.1** the Wittingham Coal Measures generally contain moderately saline water with EC of up to 7,720 µS/cm in interburden and up to 14,710 µS/cm in coal. The Greta Coal Measures also contain moderately saline water quality, with an EC of up to 5,810 µS/cm. There is limited water quality data available for the Greta Coal Measures, but comparison to the Wittingham Coal Measures (**Appendix D**) indicates the tailings water generally has similar EC and metals concentrations but a higher sulphate concentration.

Fly ash material is also stored within the Liddell Ash Dam to the east of the Maxwell Infrastructure area. Leachate from fly ash material can include high concentrations of calcium, magnesium and metals (Dandautiya *et al.* 2018). Recent (December 2018) water quality data for bores intersecting the regolith material around Liddell Ash Dam recorded pH of around 6.1 to 7.5, EC of up to 9,620 µS/cm, calcium concentrations of up to 716 mg/L, magnesium of up to 272 mg/l, sulphate of up to 5,240 mg/L, iron of up to 0.5 mg/L, molybdenum of up to 0.3 mg/L, aluminium of up to 0.2 mg/L, selenium of up to 0.03 mg/L and arsenic at or below the laboratory limit of 0.001 mg/L. The results indicate that water within the regolith around Liddell Ash Dam is of a poorer quality compared to water associated with the Permian coal measures and existing tailings facilities.

4.5 GROUNDWATER-SURFACE WATER INTERACTION

Figure 47 presents monthly statistics for the Hunter River between Muswellbrook and Liddell (100-year period, 1913 to 2013), conducted on 7-day moving averages to remove travel time effects (Heritage Computing, 2013). This shows that the Hunter River generally loses water along this reach (averaging around 17 ML/day). This analysis has been simplified, given the large number of ungauged tributaries and their larger catchment areas, for which inflows have not been accounted. Regardless, these data suggest that on average, for most of the time, the Hunter River loses large volumes of water to the underlying alluvium along this reach.

Hydrometric analysis of groundwater-surface water interaction was undertaken using groundwater levels in bore GW080077 and Hunter River stage elevations at the Denman gauge (#210055). The location of these sites is shown in **Figure 9** and **Figure 31**, and the analysis is presented in **Figure 48**. River water levels are consistently 2 m or more above adjacent groundwater levels, indicating a losing river surface water source with flow into the Hunter River alluvium at these locations. This is also validated by comparing alluvial and Permian rock groundwater EC against Hunter River EC that indicates the river is the dominant source of water in Hunter River alluvium at these locations. This analysis strongly supports the conclusions of other studies (Kellett *et al.*, 1989), and of the reach-scale mass balances outlined above, that the Hunter River is a losing stream to the south of the Project area.

It should be noted that the baseflow analyses of Coffey (2013) provide a qualitative and subjective estimate of baseflow, primarily along the Hunter River upstream of Muswellbrook because most gauged flows, even as far down catchment as Liddell, are primarily derived from this up-catchment area. The analyses shown in **Figure 47** and **Figure 48** strongly suggest net losing conditions along the Hunter River between Muswellbrook and Liddell.

4.6 GROUNDWATER USE

4.6.1 ANTHROPOGENIC

A search of the online WaterNSW database of registered bores was conducted by ENRS in 2018, which identified 147 registered bores within 10 km of the Project area. A bore census (ENRS 2019) was commissioned by Malabar in 2018. A summary of details from the resulting records for registered bores within 10 km of the project is presented in **Appendix E** and location of the bores is shown in in **Figure 31**.

Based on available information on the bores from WaterNSW and site information, 62 of the 147 bores are used for groundwater monitoring and testing. A summary of the purpose, depth and location/lithology of the landholder bores is included in **Table 4-6**, excluding monitoring bores. The table also includes details of an additional three unregistered shallow wells (<15 m deep) and one steel bore identified by ENRS (2019) during the bore census. The wells and bore had historically been used for stock and domestic water supply, but are currently unused.

Table 4-6 Groundwater Use

Purpose	Number	Location and Lithology
Stock Domestic	55 bores	Predominantly to west of Project, near Spur Hill and Mt Arthur Mine, with 13 located within the mapped extent of Hunter River alluvium and two Malabar-owned wells (GW202453 and GW202452) within the mapped extent of Saddlers Creek alluvium.
Irrigation	8 wells	All within mapped extent of alluvium and most along Hunter River ("highly productive" alluvium)
Irrigation/stock/ domestic	14 registered wells, 3 unregistered wells and 1 registered bore	All within mapped extent of alluvium and most along Hunter River ("highly productive" alluvium)
Municipal water supply	1 bore	At Jerrys Plains - 5 km south of Project, south of the Hunter River.
Industrial/waste disposal/dewatering	3 bores	Maxwell Infrastructure area, HVO and at Jerrys Plains.
Unknown	3 bores	South of Hunter River.
Total	85	-

As shown in **Table 4-6**, the bores that are used for stock domestic supply and intersect the Permian coal measures are located around Spur Hill and Mt Arthur Mine. Two wells used for stock and domestic purposes also occur to the west of the Maxwell Underground (GW202453 and GW202452, also known as Bowfield Well and Bowfield House Well, respectively). These Malabar-owned wells are located 100 m apart from each other and likely intersect the alluvium along Saddlers Creek. According to the bore census findings (ENRS 2019) the two concrete wells are around 6 m deep and are equipped with pumps. Water levels for GW202452 and GW202453 were recorded at 5.6 m and 3.1 m below ground level in August 2018, respectively.

In addition, the bore census indicated a well (Plashett Bore 1) and bore (Plashett Bore 2) located within the Maxwell Underground area on Malabar-owned land. The well is around 10 m deep and was recorded as dry in August 2018. The bore is around 40 m deep, likely intersects the Wittingham Coal Measures and recorded a groundwater level of 12 m below surface with saline quality water (EC of 8,275 µS/cm). The bore and well are currently not in use.

The remaining stock and domestic bores and all irrigation bores are within the mapped extent of the Hunter River alluvium and typically intersect the "highly productive" alluvial groundwater source.

4.6.2 GROUNDWATER DEPENDENT ECOSYSTEMS

A groundwater dependant ecosystem (GDE) is one in which the plant and/or animal community is dependent on the availability of groundwater to maintain its structure and function. This section discusses potential GDEs relevant to the Project, vegetation and stygofauna.

4.6.2.1 Vegetation

The nearest 'high priority' GDE listed in the Water Sharing Plan for the Hunter Unregulated and Alluvial Water Source 2009 (version current for 14 January 2018) to the Project area is Wappinguy Spring, near Merriwa, more than 50 km to the north-west. Hence there are no known risks as a result of the proposed mine development to such 'high priority' GDEs (**Figure 6**).

Similarly, there are no 'high priority' GDEs listed in the Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016 (version current for 1 July 2016) within 20 km of the Project. At the time of writing the nearest 'high priority' GDE to the Project area is Parnell Spring in the Wollemi National Park to the south-southeast. There is no known risk of mine development to such 'high priority' GDEs.

The BOM hosts the National Atlas of Groundwater Dependent Ecosystems (GDE Atlas, accessible through the BOM website: http:\\www.bom.gov.au).

The GDE Atlas comprises maps that show the location of both known and potential GDEs across Australia, as well as ecological and hydrogeological information for each GDE. The GDE layers in the Atlas include GDEs identified in previous studies, and potential GDEs derived through new spatial analysis using existing feature layers and products developed from analysis of remotely sensed data.

GDEs derived in the analysis are mapped according to the following classifications:

- High potential for groundwater interaction.
- Moderate potential for groundwater interaction.
- Low potential for groundwater interaction.

Figure 49 shows a map of potential GDEs derived from the GDE Atlas for the Project area and surrounds. There are no areas of high or moderate GDE potential within the Project area. Areas of moderate or high GDE potential within the broader model area are restricted to reaches along the Hunter River and other rivers and creeks to the west and south of the Hunter River.

None of the creeks north of the Hunter River, such as Saddlers Creek and Ramrod Creek have mapped moderate or high GDE potential areas. There are areas of low GDE potential within the Project area, along Saddlers Creek and Saltwater Creek.

According to the GDE Atlas glossary, GDEs with 'Low potential for groundwater interaction' are defined as having the following properties:

- Ecosystems that are unlikely to be interacting with groundwater.
- Either groundwater is unlikely to be present, or if groundwater is present, the ecosystem is unlikely to be using it.
- Either all datasets suggest groundwater interaction is unlikely, or the most reliable dataset suggests that groundwater interaction is unlikely.

Vegetation mapping was conducted for the Project by Hunter Eco (2019). The mapping showed the majority of the Maxwell Underground area was covered with native perennial grassland due to historical land clearing. Remnant and regrowth forest and woodland occur in isolated areas, generally localised along riparian corridors.

Riparian vegetation has been mapped along Saddlers Creek, which is predominantly made up of dry sclerophyll woodland but also includes small remnant stands of Swamp Oak (*Casuarina glauca)*. Swamp Oak has not been identified as a high priority or threatened ecosystem (Hunter Eco 2019). Along Unnamed Creek within the Maxwell Underground area the vegetation includes Slaty Box Shrubby Woodland in the upper reaches and Fuzzy Box Woodland and a small area of White Box (Red Gum Shrubby Forest) and Swamp Oak Forest near the confluence with Saddlers Creek. During the field survey Hunter Eco (2019) noted that the stands of Swamp Oak occurred in areas of ponded water. This indicates the presence of surficial clays that may be forming localised perched aquifers along Saddlers Creek.

Individual River Red Gum (*Eucalyptus camaldulensis*) trees have also been previously recorded as present in the lower reaches of Saddlers Creek, near the confluence with the Hunter River. However, recent field verification by Hunter Eco indicated the trees are not present in this area.

Along Saddlers Creek the remnant stands of Swamp Oak are considered consistent with a GDE (Hunter Eco 2019).

The observation of ponded areas along Saddlers Creek also indicates the potential for localized perched aquifers along the creek due to the presence of low permeability clays inhibiting seepage to the underlying strata. Also, as reported in **Section 4.4.1.2**, along Saddlers Creek the groundwater within the alluvium ranges between 3.7 m and 10.9 m below surface in the upper reaches, and 3.3 m and 6.4 m in the lower reaches (**Figure 50**). Therefore, the vegetation potentially utilizes groundwater within the alluvium. However, a recent study in NSW by Doody *et al.* (2015) found that river red gums are likely more reliant on soil moisture within the upper layers of the soil profile. The trees reduce their sapwood area and water usage during periods of low rainfall and streamflow, which increases when water becomes readily available again.

4.6.2.2 Stygofauna

Stygofauna surveys have been conducted at the site and surrounding area, testing groundwater within the Permian coal measures and alluvium. Field programs were conducted in 2011 and 2018. The programs involved sampling of bores intersecting Permian coal measures across EL 5460, and bores intersecting alluvium along the Hunter River and Saddlers Creek (Eco Logical 2015 and Eco Logical 2019).

The surveys found (Eco Logical 2015 and 2019):

- No stygofauna were identified within samples collected from the Permian coal measures in 2015;
- Stygofauna were identified as present in the Hunter River and Saddlers Creek alluvium in 2018, namely;
    - one known stygofauna taxon (*Syncarida: Notobathynella sp. crustacean*) from the Hunter River alluvium;
    - two likely stygofauna taxa (*Cyclopoida: diacyclops* and *Ostractoda crustaceans*) in the Hunter River and Saddlers Creek alluvium; and
    - two potential, but unlikely, stygofauna taxa in the Hunter River (*Acarina mite*) and Saddlers Creek alluvium (*Oligochaete worm*).
- None of the known and potential stygofauna taxa are listed as threatened under the EPBC Act or NSW *Biodiversity Conservation Act 2016*.
- None of the known and potential stygofauna taxa collected are endemic to the Project area, as all are widespread along aquifers associated with the Hunter River or associated tributaries.

4.7 GROUNDWATER MODEL CONCEPTUALISATION

A conceptual model of the groundwater regime has been developed based on the review of the hydrogeological data for the Project area and surrounding regions.

The Project lies within the Hunter Coalfields, which comprises Permian aged coal measures that have been folded into a syncline structure that strikes in a north to south direction. The geology of the Project area comprises the stratified sequences of the Wittingham Coal Measures and Maitland Group that dip to the south-west at the Maxwell Underground area. These units are underlain by the Greta Coal Measures that occur at outcrop at the Maxwell Infrastructure area to the north-east.

The Maxwell Underground mining would include the Whynot Seam (bord and pillar), as well as longwall extraction of the Woodlands Hill, Arrowfield and Bowfield Seams of the Wittingham Coal Measures. The Wittingham Coal Measures occur at subcrop west, north and east of the Maxwell Underground area. The coal seams to be extracted are deepest near the Hunter River, generally over 100 m below surface (**Figure 29**). Surficial cover includes the alluvium along the Hunter River, Saddlers Creek, and Saltwater Creek, as well as regolith strata comprising weathered *in situ* sediments. The main hydrogeological features at the Project area include:

- Alluvium associated with the Hunter River;
- Alluvium associated with Saddlers Creek and regolith; and
- Permian strata that host the coal measures.

A summary of the conceptualisation of the main hydrogeological features are discussed in **Section 4.7.1** to **Section 4.7.3**. Discussion on the groundwater response to the Project is included in **Section 4.7.4**.

4.7.1 HUNTER RIVER ALLUVIUM

The Hunter River alluvium comprises surficial silts and clays overlying basal sands and gravels. The hydraulic properties of the alluvium vary due to the variable lithologic composition, with field tests indicating horizontal hydraulic conductivity can range between 1.3 x 10^{-1} m/day and 3.7 x 10^{2} m/day along the Hunter River. Groundwater occurs within the alluvium at depths of around 5 m to 10 m below surface, generally over 2 m below the base of the Hunter River. This indicates that the Hunter River generally has losing conditions, where surface water seeps into the underlying alluvium. Regional groundwater flow within the alluvium is a subdued reflection of topography, with groundwater flowing in a south-easterly direction consistent with the alignment of the Hunter River.

Recharge to the Hunter River alluvium is considered to be mostly from regulated stream flow or flooding (losing streams), with direct infiltration of rainfall also occurring rapidly where there are no substantial clay barriers in the shallow sub-surface. On a regional scale, discharge from the alluvium is via evapotranspiration from vegetation growing along creek beds and minor short duration baseflow events after significant rainfall/flooding. There is also potential for downward seepage to the underlying Permian coal measures. Water quality data for the alluvium indicates it can be fresh to brackish, and is mostly suitable for stock water supply and irrigation, but is not suitable for drinking water and freshwater aquatic ecosystems.

The bore census (**Section 4.6.1**) indicates alluvial groundwater along the Hunter River is used by local landholders, predominantly for irrigation and stock water supply. Ecological studies identified that riparian vegetation along the Hunter River potentially utilises groundwater within the alluvium, but likely relies more on surface water flows. Stygofauna sampling indicated the presence of stygofauna within the Hunter River alluvium.

4.7.2 SADDLERS CREEK ALLUVIUM AND REGOLITH

The Saddlers Creek alluvium comprises surficial silts and clays overlying a heterogenous distribution of clays, silts, sands and gravels. The occurrence of sands and gravels is predominantly within the lower reaches of Saddlers Creek, near the confluence with the Hunter River. The hydraulic properties of the alluvium near the confluence is expected to be similar to that of the Hunter River alluvium, while the stratigraphy further upslope is expected to be lower yielding due to the dominant silts and clays.

Spatially, the alluvium is variably saturated. Localised perched water tables are also evident where waterbodies continue to hold water throughout the dry period (e.g. pools along Saddlers Creek) occurring where clay layers slow the percolation of surface water. Where groundwater is present, it occurs at depths of around 3 m to 10 m below surface.

Saddlers Creek has intermittent flow, with flows occurring in response to rainfall events. When flowing, Saddlers Creek generally exhibits losing conditions, where surface water seeps into the underlying alluvium. Within the lower reaches of the creek there is also potential upward seepage from the underlying Permian coal measures.

Discharge is via evapotranspiration from vegetation growing along the creek. There are also possible minor short duration baseflow events after significant rainfall/flooding within the lower reaches of the creek. Water quality data for the alluvium along Saddlers Creek is generally moderately saline, and is mostly suitable for stock water supply, but is not suitable for irrigation, drinking water and freshwater aquatic ecosystems.

In areas near Saddlers Creek, water has been detected within the regolith material at depths of around 6 m to 9 m below surface. The presence of water may be locally influenced by land use practices (i.e. water storage areas), and outside of these areas the regolith material is largely unsaturated. Water quality data for the regolith indicates it is generally moderately saline.

4.7.3 PERMIAN COAL MEASURES

In the Permian strata, groundwater is encountered in the coal seams and in the sandstone/siltstone units of lower permeability. The coal seams are the main groundwater bearing units within the Permian sequences, with low permeability interburden generally confining the individual seams. The coal seams are dual porosity in nature with a primary matrix porosity and a secondary (dominant) porosity provided by fractures (joints and cleats). Hydraulic conductivity of the coal decreases slightly with depth due to increasing overburden pressure reducing the aperture of fractures. However, there is also spatial variability in hydraulic conductivity due to other factors such as the presence of igneous intrusions. Vertical movement of groundwater (including recharge) is limited by the confining interburden layers, meaning that groundwater flow is primarily horizontal through the seams with recharge primarily occurring at subcrop. Faults are mapped within the region, however, studies have indicated they do not act as conduits to groundwater flow. Regionally, groundwater within the Permian coal measures flows in a southerly direction. Review of water quality data indicates water within the Wittingham Coal Measures is generally moderately saline. Groundwater within the Wittingham Coal Measures is only considered suitable for some stock, with the type of stock dependent on the TDS range (i.e. beef cattle or sheep). The bore census identified registered water supply bores that likely target the coal measures and are principally used for stock water supply.

4.7.4 GROUNDWATER RESPONSE TO THE PROJECT

Understanding of the conceptual groundwater regime for each of the main hydrogeological features is discussed below. A series of groundwater model conceptual cross sections are also presented, showing:

- North – South conceptual cross section, Maxwell Underground, before mining (**Figure 51**);
- North – South conceptual cross section, Maxwell Underground, including mining (**Figure 52**);
- North – South conceptual cross section, Maxwell Infrastructure, 2020 (**Figure 53**);
- North – South conceptual cross section, Maxwell Infrastructure, 2046 (**Figure 54**);
- East – West conceptual cross section, Maxwell Infrastructure, before CHPP reject emplacement in East Void, 2020 (**Figure 55**); and
- East – West conceptual cross section, Maxwell Infrastructure, CHPP reject emplacement in East Void complete, 2046 (**Figure 56**).

The sections illustrate the main expected changes to the groundwater regime in response to the Maxwell Underground, these include:

- Depressurisation and drawdown of subsurface water pressures/levels due to mine inflows (dewatering) extending some distances (e.g. laterally) from underground mining areas, altering flow patterns and groundwater storage.
- Fracturing of overlying strata above underground mining areas leading to alteration of nearer-surface groundwater flow patterns and aquifer storage.
- Drawdown of the water table, potentially reducing or interrupting flows in surface streams and reducing bore groundwater levels.

For the proposed Maxwell Infrastructure area, **Figure 55** and **Figure 56** illustrate the proposed CHPP reject emplacement regime and subsequent change in groundwater conditions around the East Void.

5 GROUNDWATER SIMULATION MODEL

Numerical modelling was undertaken to evaluate the interaction of the Project with the groundwater regime. The objectives of the predictive modelling were to:

- determine the groundwater inflow to the mine workings as a function of mine position and timing;
- simulate and predict the extent and area of influence of dewatering and the level and rate of drawdown at specific locations; and
- assess areas of potential risk, where groundwater impact mitigation/control measures may be necessary.

The key to numerical modelling is the adequate conceptualisation of the groundwater regime, and calibration of the model against observed data. The conceptual model provides a representation of the current understanding about the groundwater system within the region as a basis for representing that system by a numerical model**.** Examples of conceptual model sections within the region are presented in this report in **Figure 51** to **Figure 56**.

The conceptual model represents how the groundwater regime operates based on available data and experience. **Section 4** details the conceptual understanding of the hydrogeological regime at the Project.

Section 5.1 and **Section 5.2** present how the conceptualisation has been developed as a numerical groundwater model, and **Section 5.3** presents how the model replicates observed data (calibration).

5.1 MODEL DESIGN

This section provides a summary of the design and development of the numerical groundwater model.

5.1.1 MODEL COMPLEXITY AND SOFTWARE

Numerical modelling has been undertaken using Geographic Information Systems (GIS) in conjunction with MODFLOW-USG, which is distributed by the United States Geological Survey (USGS). MODFLOW-USG is a relatively new version of the popular MODFLOW code (McDonald and Harbaugh, 1988) developed by the USGS. USGS MODFLOW has been the most widely used code for groundwater modelling in the past and has long been considered an industry standard.

MODFLOW-USG represents a major revision of the USGS MODFLOW code and the MODFLOW-SURFACT code previously used by consultants, in that it is based on a control volume finite difference (CVFD) formulation, rather than the traditional MODFLOW's rectilinear finite difference (FD) scheme. 'USG' is an acronym for Un-Structured Grid, that is it supports a variety of structured and unstructured model grids, including those based on cell shapes such as prismatic triangles, rectangles, hexagons, and other cell shapes (Panday *et al*., 2013). For the model adopted in this report, use is made of Voronoi cells generated using a proprietary code developed by HydroAlgorithmics. The CVFD method allows a model cell to be connected to an arbitrary number of adjacent cells, which is not the case with a standard FD scheme.

The MODFLOW-USG code has a number of other advantages. Firstly, they allow finer grid resolution to be focused solely in areas of a model that require it (e.g. along mining trenches), as opposed to refinement over the entire grid, significantly decreasing cell count and consequently model runtimes. Secondly, spatial areas not required in the model may be omitted rather than deactivating cells or retaining "dummy" layers (e.g. for layer pinch-outs). Thirdly, flexible meshes allow cell boundaries to follow important geographical or geological features, such as watercourses and faults, and therefore provide a better representation of the hydrogeological system. Finally, the orientation of the flow interfaces between cells may vary, allowing preferential flow directions to be modelled with better accuracy.

Additionally, MODFLOW-USG, as was the case with MODFLOW-SURFACT, is able to simulate variably saturated flow and can handle desaturation and re-saturation of multiple hydrogeological layers without the "dry cell" problems of traditional USGS MODFLOW. This is relevant to models which simulate layers, such as surficial regolith, which frequently encounter variably saturated conditions during depressurisation and desaturation under mining conditions.

5.1.2 MODEL EXTENT AND MESH DESIGN

The model domain is shown in **Figure 57**. The region is discretised into 24 layers for a total of 954,744 Voronoi-shaped cells (**Figure 58**). The model domain has been designed to be large enough to prevent boundary influence on model mining drawdowns. The model extends beyond the subcrop trace of the deepest coal seam that is likely to be mined by the Project and/or surrounding mines in the future.

The HydroAlgorithmics software 'AlgoMesh', used to generate the Voronoi cells, can export MODFLOW-USG files in addition to other formats. In particular, AlgoMesh allowed the following special features:

- A regular (aligned) square grid of cells was enforced in the Project's proposed longwall areas, rotated in line with the longwalls, and in those of the Mt Arthur Underground Project.
- A regular (aligned) square grid of cells was enforced in the East Void, part of the Maxwell Infrastructure, where CHPP reject emplacement is proposed to take place.
- A regular hexagonal grid of cells was enforced within the Maxwell Infrastructure and Mt Arthur Mine open cut pits.

- Polylines along mapped rivers and creeks were used to ensure the mesh conformed to mapped drainage networks, and to enforce variable spatial detail along streams (e.g. greater detail along streams closest to the Project).
- The Hunter Coalfields 1:100k mapped alluvial and colluvial boundary was also used as input to AlgoMesh to enforce finer Voronoi cell resolution along the mapped edge, based on the alluvial extents of the Hunter River and Saddlers Creek.

Model grid resolution applied in key areas of interest is as follows:

- 50 m in the Project longwalls, and 150 m in Mt Arthur Underground Project longwalls;
- 50 m in the East Void CHPP reject emplacement in the Maxwell Infrastructure area;
- 100 m in the North and South Voids in the Maxwell Infrastructure;
- 150 m in the rehabilitated and waste emplacement area in the former Drayton Mine (now Maxwell Infrastructure) and in the Sublease CL 229 (Part of Mt Arthur Mine close to the Maxwell Infrastructure);
- 200 m and 150 m in the existing and proposed open cut areas of the Mt Arthur Open Cut and Saddlers Pits respectively;
- a maximum of 100 m along the Hunter River, Saddlers Creek, Ramrod Creek and other streams close to the Project, but with finer resolution where an accurate reflection of stream geometry required it; and
- 300 m at Lake Liddell, Plashett Reservoir, Liddell Ash Dam and minor water reservoirs.

5.1.3 MODEL LAYERS

The 24 model layers used to represent the regional stratigraphy are outlined in **Table 5-1**, and are based on the conceptual hydrogeology described in **Section 4**.

In the model, topography within EL 5460 relies on LiDAR data provided by Malabar; the remaining model extent has topography defined by the Australia Wide DEM-H (Geoscience Australia, 2011) with 1 second resolution.

Model layers (lateral and vertical extents) have been defined using data available from the following sources:

- Malabar site geological model;
- site-specific geological studies, including *Structure Report – Maxwell Project* (MBGS 2018), subsidence assessment (MSEC 2019), alluvium drilling and AgTEM field investigation (ENRS 2018; Groundwater Imaging 2018);
- site geological drill hole and bore logs;
- NGIS/PINEENA groundwater bore database;
- State geological mapping, including 1:25k Geology Map of Muswellbrook (Summerhayes 1983) and Jerrys Plains (Sniffin & Summerhayes 1987), as well as 1:100k Hunter Coalfields;
- CSIRO (2015) regolith mapping for unconsolidated sediments; and
- Hunter Coalfield Geology Model - Sydney Gunnedah Model (Oliveira 2018).

Because it is not practical to represent every individual coal seam ply in a regional groundwater model, a "combined thickness" totalling the individual seam thicknesses for each relevant seam has been simulated. Site-specific information regarding the Wittingham Coal Measures was available from the site geological model and geological modelling for the Spur Hill. In addition, layer surfaces around Mt Arthur Mine were based on the Mt Arthur Mine numerical groundwater model surfaces and reported average seam thickness (AGE 2013b).

Model layer 1 was assigned to capture the variability in unconsolidated sediments mapped at various sites and across the model domain, as discussed in **Section 4.1**. Hydraulic parameter zonation within layer 1 is shown in **Figure 58**, that depicts various values of hydraulic conductivity and rainfall recharge, as well as other boundary conditions. The zones include:

- highly productive alluvium along the Hunter River and the lower reach of Saddlers Creek (confluence with Hunter River);
- less productive alluvium along Saddlers Creek, Saltwater Creek and other minor tributaries;
- less productive alluvium/colluvium along the upper reaches of Saddlers Creek; and
- regolith.

The hydraulic properties and rainfall recharge for the zones are discussed in **Section 4.4**.

Table 5-1 Model Layer Assignment

LAYER	LITHOLOGY	LUMPED UNITS
1	Alluvium, regolith (unconsolidated) and volcanics	Zoned based on mapped surface geology
2	Historical mined areas (waste rock)	-
3	Whybrow overburden	Jerrys Plains Subgroup - including overburden and Whybrow Seam
4	Whynot overburden	Malabar Formation including overburden, Redbank Creek Seam and Wambo Seam
5	Whynot Seam	-
6	Blakefield overburden	-
7	Blakefield Seam	-
8	Glen Munro overburden	-
9	Glen Munro Seam	-
10	Woodlands Hill overburden	-
11	Woodlands Hill Seam	-
12	Arrowfield overburden	-
13	Arrowfield Seam	-
14	Bowfield overburden	-
15	Bowfield Seam	-
16	Piercefield overburden	-
17	Piercefield Seam	-
18	Edderton overburden	Vane Subgroup/Foybrook Formation including Wynn Seam
19	Edderton Seam	-
20	Ramrod Creek overburden	Vane Subgroup/Foybrook Formation including Bengalla Seam and Edinglassie Seam
21	Ramrod Creek Seam	-
22	Maitland Group	Mulbring Siltstone and Branxton Formation
23	Rowan Formation	Combined interburden and coal, including Broughan, Grasstrees, Puxtrees and Balmoral seams mined at the former Drayton Mine
24	Basement	Skeletar Formation and basement

5.1.4 GEOLOGICAL FAULTS

The Project intersects Permian aged coal measures that are folded along the Muswellbrook Anticline and Calool Syncline. Detailed site geological investigations (MBGS 2018) identified fewer faults are present in the area than previously mapped. Faults in the area have also been categorized more as barriers to flow rather than conduits to groundwater flow (AGE 2013b). This correlates to findings by MBGS (2018) that identified that local north-east to south-west trending faults at the Maxwell Underground are largely associated with dyke intrusions around 2 m wide. The faults/dykes are localized within the Maxwell Underground area (**Figure 27**), therefore their presence may influence the timing of groundwater inflows from the Permian coal measures, but is unlikely to influence regional groundwater trends and Project impacts. Therefore the dykes have not been included within the Basecase numerical groundwater model, but have been explored within the sensitivity analysis.

As discussed in **Section 4.1**, sills have also been mapped within the Maxwell Underground area and occur along the target coal seams. The sills have been captured within the numerical model within layers 5, 6, 13 and 15, as shown in **Figure 59.**

5.2 MODEL STRESSES AND BOUNDARY CONDITIONS

The model domain and boundaries shown in **Figure 58** have been selected to incorporate any potential receptors (i.e. surface water bodies or GDEs) that could be adversely affected by mining. Following is detailed information on each of the modelled boundary conditions. Values used as initial conditions for the steady-state calibration model are presented.

5.2.1 REGIONAL GROUNDWATER FLOW – BOUNDARY CONDITIONS

The model perimeter is set as a 'no-flow' boundary by default, except where regional groundwater flow is likely to enter or leave the active model area in which case a general head boundary (GHB) is specified. No-flow boundaries (inactive cells) are shown in **Figure 58** in the southeastern and northeastern corners of the model area. These areas represent groundwater divides in the form of ridge lines (geomorphic divide) and river channels.

The GHB boundary condition was used to represent the regional flow into and out of the model area primarily in the west, north and south. Groundwater will enter the model where the head set in the GHB is higher than the modelled head in the adjacent cell, and leave the model when the water level is lower in the GHB. The GHB heads were assigned based on the most recently calibrated head values from the Gateway model (HydroSimulations 2018) and recorded water levels at NSW government bores.

Conductance is calculated using the modelled hydraulic conductivity of the layer in which the GHB sits, multiplied by the cell's vertical area along the boundary, and divided by the distance to an external source of water. It is therefore variable in the model due to variable cell-sizes.

5.2.2 WATERCOURSES

This Groundwater Assessment follows the Strahler stream classification system, where watercourses are given an “order” according to the number of tributaries associated to each watercourse (1st order being the top of the catchment, with the order increasing by one when streams of equivalent orders meet).

Not all creeks and rivers have been built into the model mesh, as this would require complexity in the model that is not justified from the available data. Major rivers and streams (Stream Order 4 and 5) have been built into the model, this includes the Hunter River, Saddlers Creek, Ramrod Creek and Saltwater Creek. Creeks and rivers throughout the model domain were modelled using MODFLOW’s River (RIV) package. RIV is a form of the head dependent boundary condition which is appropriate for a stream which partially penetrates a layer and can receive water from an aquifer (gaining stream) or pass water to an aquifer (losing stream).

Head dependent boundary conditions require dimensional information regarding the boundary within a given cell, a boundary head and a conductance term, C (L^2/ T), where:

$$C = KA/B$$

and K is hydraulic conductivity of the boundary material

A is the area of the boundary

B is the thickness or width of the boundary (e.g. vertical stream bed thickness)

Table 5-2 lists the parameters used in the model.

The river and creek widths were estimated using aerial photography and are consistent with previous modelling (Heritage Computing 2013). The conductance values assigned to each river and creek are based on a constant bed thickness of 1 m, with a clayey hydraulic conductivity property ranging from 1.0 x 10^{-6} m/day to 6.0 x 10^{-3} m/day (also consistent with Heritage Computing 2013).

Steady-state river stage elevations on the Hunter River and Goulburn River were based on the long-term average from government gauging stations (210002, 210055, 210151, 210031). For the transient simulation, river stage levels were varied monthly based on the historical monthly average levels from government gauging stations.

Steady-state river stage elevation for Saddlers Creek followed the long-term average from the historical monitoring gauge station (210043) and the water stage height data recently recorded from the Malabar Saddlers Creek station. During historical transient simulation, Saddlers Creek stage varied based on the monthly average of 210043 station and Malabar station. Where data was absent, stream levels were interpolated based on rainfall for the month.

Table 5-2 River Package Parameters

Boundary	Water depth (m)	Width (m)	Conductance (m^2/day)	Vertical hydraulic conductivity (m/day)
Hunter River	SS simulation - Long -term Average (= 0.89) TR simulation - Historical Monthly Average	20	6	3.0 x 10^{-3}
Goulburn River	SS simulation - Long-Term Average (= 1.35) TR simulation - Historical Monthly Average	10	3	6.0 x 10^{-3}
Saddlers Creek	SS simulation Long -term Average (= 0.058) TR simulation - Historical Monthly Average	5	0.6	1.7 x 10^{-3}
Ramrod Creek	0	2	0.6	6.0 x 10^{-3}
Other Creeks	0	2	0.6	6.0 x 10^{-3}
Lake Liddell	2	300	0.6	1.0 x 10^{-6}
Plashett Reservoir	2	300	0.6	1.0 x 10^{-6}
Liddell Ash Dam	5	300	0.6	1.0 x 10^{-6}
Other reservoirs	2	300	0.6	1.0 x 10^{-6}
West Pit	55	60	0.1	3.0 x 10^{-5}

SS = Steady-state. TR = Transient

Third order streams such as Unnamed Creek that are eroded drainage features within the regolith material were not included in the RIV package. These features can be modelled as drains with the RIV package. However, to more conservatively estimate the saturated extent of regolith material, these drainage features were not included in the model.

Water reservoirs were modelled using the RIV package to replicate surface water and groundwater interactions using a constant head (CHD package) and the conductivity component to control leakage to the groundwater system. The following reservoirs were included in the model, with stage elevations assigned based on current site topography:

- Lake Liddell – assigned a constant stage elevation of 127 mAHD.
- Plashett Reservoir – assigned a constant stage elevation of 126 mAHD.
- Liddell Ash Dam – assigned a constant stage elevation of 177 mAHD.
- Bayswater-Liddell Freshwater Dam – assigned a constant stage elevation of 188 mAHD.
- West Pit Void (SW13) at Mt Arthur Mine - assigned a constant stage elevation of 211 mAHD from 2001 to 2018, and fully backfilled in the recovery as per mine closure plan.

5.2.3 MAXWELL INFRASTRUCTURE AREA

5.2.3.1 Tailings Emplacement

At Mt Arthur Mine, tailings (or fine rejects) are stored within the historical Bayswater No. 2 pit. Bayswater No. 2 mined the Greta Coal Measures from 1968 to 1998 and has since been used for tailings emplacement. The tailings material was placed over spoil within the base of the pit, and has a maximum approved fill level of 280 mAHD. As part of the Project, CHPP rejects are also proposed to be emplaced within East Void at the Maxwell Infrastructure area, to a maximum fill level of 175 mAHD, and with a decant pond to the north set at 150 mAHD. A cross section depicting the Maxwell Infrastructure area and rejects emplacement is included in **Figure 53**.

Layer 2 of the model was designed to capture the approved fill level of Mt Arthur Tailings and proposed fill level for East Void. Properties in layer 2 were updated using the time-variant materials (TVM) package to represent the low permeability tailings material. Horizontal and vertical hydraulic conductivity of 8.64×10^{-3} m/day, specific yield of 0.1 and specific storage of 1.0×10^{-4} assigned. Surface water consultants WRM (2019) conducted water balance modelling and predicted the rate of seepage from the Mt Arthur Mine tailings emplacement. To replicate the water content of the tailings material the RIV package was assigned over the emplacement area with a 1 m stage height and bed conductance equivalent to 8.64×10^{-3} m/day.

5.2.3.2 Water Storage and Existing Voids

As part of the Project design it is proposed that water be stored within the Maxwell Infrastructure area at South Void, East Void and North Void during mining operations.

The calibrated groundwater model was used to quantify the volume of groundwater seeping into the void areas. This was estimated at 3 ML/year on average and less than 11 ML/year maximum. These rates were considered negligible for the purposes of the site water balance modelling conducted by WRM, which also factored in seepage from the surrounding spoil. The surface water storage levels over time predicted by WRM were used in the groundwater model, applied using the CHD package.

5.2.4 RAINFALL RECHARGE

Recharge is a form of constant flux boundary condition in MODFLOW, managed by the RCH package, treated by Groundwater Vistas (GWV) as a property. As such, RCH requires a flow rate for each stress period, applied to the topmost model layer or uppermost active model layer.

As outlined in **Section 5.1.3** and shown in **Figure 58**, stratigraphy represented in layer 1 varies spatially and is categorized as different zones regarding their hydraulic properties, and thus capacity to transmit water to the Permian layers. These zones have been used for the rainfall recharge zones.

Rainfall recharge has been imposed as a percentage of actual rainfall from the SILO Grid Point observations (for transient calibration) or long-term average rainfall (for steady-state calibration and prediction simulations) across 6 zones:

- Highly Productive Alluvium [R101].
- Alluvium – Less Productive [R102].
- Alluvium Upslope – Saddlers Creek [R103].
- Regolith [R104].
- Void [R105].
- Jurassic volcanics [R106].

The recharge rates were determined during the steady-state calibration (**Section 5.3.3**). Additional recharge rates were assigned into the model during calibration and predictive periods to account for mined areas and voids. Spoil infiltration was set at 5% taking effect 5 years after mining has stopped.

Within the model domain, there is also likely to be a degree of enhanced recharge along the Hunter River alluvium due to irrigation. There was insufficient data to assign additional recharge to specific areas along the Hunter River. However, it is noted that the model calibration resulted in a higher recharge along the Hunter River alluvium that may in part capture this influence.

5.2.5 EVAPOTRANSPIRATION

Evapotranspiration is a form of head dependent flux boundary condition in MODFLOW, managed by the EVT package, which is treated by GWV as a property. Evapotranspiration can be applied to the topmost model layer or the uppermost active model layer. The EVT package only includes evapotranspiration from the saturated zone. The EVT package requires maximum rate and extinction depth values. The evapotranspiration rate maximum is for the water table at the top of the uppermost model layer and decreases linearly as the water table height drops below the surface until it equals zero at the extinction depth. The extinction depth is the depth below which evapotranspiration will not occur, defined, for example, by a plant rooting zone depth.

For the steady-state calibration, the extinction depth in the model was set to 2 m, and the maximum evapotranspiration rate was set to the annual average BOM Areal Actual Evapotranspiration (BoM 2016) value of 650 mm/year.

The pan evaporation within the Maxwell Infrastructure area was estimated to 1,489 mm/year (SILO Evaporation 2016). The average pan evaporation to lake (open water body) evaporation conversion coefficient was assumed to be 0.7, giving a maximum evaporation rate of 1,042 mm/year (0.00285 m/day) when waterbodies develop in the North, East and South Voids.

MODFLOW-USG also allows an external EVT file to change the ET surface to a specified elevation over time. The change in ET surface has been applied at the Maxwell Infrastructure in order to enhance the conceptualisation of the water inflow and outflow within the void areas. As mining progresses and waste rock emplacement occurs at the former Drayton Mine (Maxwell Infrastructure) during the calibration period, ET surface elevations change from the top of layer 1 to the bottom of the pit (bottom of layer 2). ET surface elevation is then assigned back to the top of layer 1 at the East Void when and where emplacement of CHPP rejects starts in 2021.

5.2.6 GROUNDWATER USE

As outlined in **Section 4.6**, there is limited groundwater usage in the region, largely due to the availability of surface water along the regulated Hunter River. At the Maxwell Underground area there is no significant groundwater extraction apart from small-scale stock and domestic use. Therefore, abstraction from water supply bores has not been represented within the groundwater model.

5.2.7 MINING

The MODFLOW Drain (DRN) package was used to simulate mine dewatering in the model for the Project and the surrounding mines. Drain boundary conditions allow a one-way flow of water out of the model. When the computed head drops below the stage of the drain, the drain cells become inactive. This is an effective way of theoretically representing removal of water seeping into a mine over time, with the actual removal of water being via pumping and evaporation.

Drain progression for the Maxwell Underground was developed based on annual mine progression files provided by Malabar. The drain cells applied for the surrounding mines were interpolated from mine schedule information available from EIS documentation and aerial photography (open cut). The modelled mine progression for open cut and underground is presented in **Figure 60** and **Figure 61**.

For open cut mining, Hawkins (1998) and MER (2009) indicate that spoil and waste rock are more permeable than the undisturbed strata. Completed open cut mining areas are backfilled with waste overburden as the extraction proceeds. Within the groundwater model, backfill was given uniform hydraulic conductivity of 1 m/day, specific yield of 0.2 and rainfall recharge set to 1% of average rainfall. In the transient calibration and prediction model, backfill properties were applied two years behind the mine face.

The underground mining at the Project and surrounding mines is simulated in the model as MODFLOW Drain (DRN) cells, with drain cells applied in the coal seam layer and several overlying layers to represent fracturing. The DRN cells represent the fracture network with drains aligned vertically (stacked). The purpose of this is to approximate the connectivity between the host strata and the fracture network above the mined model cell.

The effects of multi-seam subsidence on the fracture height calculations have been estimated for the Project in consultation with a geotechnical/subsidence expert (i.e. Ditton Geotechnical Services). The height of fracturing for each mined seam was calculated from the average mining height, cover depth and panel width for each seam, and in each multi-seam mining zone the total of the mined seam thicknesses has been adopted as the effective mining height. The approach adopted to determining the height of fracturing is considered conservative; full details on the stacked drain approach and how fracture heights were calculated are included in **Appendix J**.

The drain cells within the underground areas are kept on until the end of mining. At the start of the recovery period for the underground mine areas, the stacked drains were replaced by an equivalent porous medium with enhanced hydraulic properties (using the TVM package of MODFLOW-USG) that gave similar mine inflow to that being experienced at the end of mining.

5.2.8 MODEL SIMULATION TIMING

Both steady-state and transient calibration models have been developed:

- Steady-state model of average pre-2001 conditions (**Section 5.3.1**).
- Transient model calibration based on temporal pre-mining data at monthly time intervals from January 2001 to December 2018 (**Section 5.3.2**).
- Predictive model used to simulate effects on the groundwater regime over the life of the Project (**Section 5.4**).
- Recovery model used to simulate post-mining conditions for a period of 1,000 years after completion of the Project (**Section 5.5**).

5.3 MODEL CALIBRATION

Calibration was conducted in a staged approach, with recharge and hydraulic conductivity for layer 1 zones calibrated in the steady-state model and hydraulic conductivity and storage properties calibrated in the transient model. Details on the steady-state and transient calibration models and performance are included in **Section 5.3.1** and **Section 5.3.2**. Details on the calibrated parameters are included in **Section 5.3.3**.

Calibration was undertaken using the automated calibration utility PEST and manual calibration. The bounds of the calibration for hydraulic conductivity were set in consideration of available site data for each of the geological units, as discussed in **Section 4.4.3**. The range in storage properties was set based on realistic bounds as reported by Rau *et al.* (2018).

5.3.1 STEADY-STATE CALIBRATION

Steady-state calibration was undertaken using PEST (Doherty, 2010) with 106 groundwater head targets. Manual parameter adjustment was then undertaken to ensure the calibrated parameters were consistent with the conceptual understanding of the hydrogeological system. Steady-state calibration focused on both hydraulic conductivity and recharge. Vertical hydraulic conductivity was calibrated as a factor of horizontal conductivity (Kz/Kx). Reduced vertical hydraulic conductivity is typically observed due to sedimentary layering throughout the sequence, and by aggregation of strata in a numerical model.

Groundwater targets were utilized in the groundwater model where:

- Valid information on bore construction or geology information was available for the site; and/or
- Data was collected prior to 2001 or reasonably around 2001 to reflect baseline condition at the start of the model.

Groundwater heads targets used for the steady-state calibration were weighted as 1 in the calibration where reliable data was available on the construction of the bore and the data collected. Some data points were weighted down (i.e. to 0.5) where there was limited detail available about the bore (i.e. GW8, GW22, GW23 and OD1074), where the reading was interpolated from public domain reports and/or where the earliest available reading occurred after 2001. Details on each of the observation points, the weights and residuals are presented in **Appendix G**.

5.3.1.1 Statistics

Figure 62 presents the observed and simulated groundwater levels graphically as a scattergram for the steady-state calibration. Steady-state residuals for each of the observation points have been spatially mapped in **Figure 63** and are tabulated in **Appendix G**.

The industry standard method to evaluate the calibration of the model is to examine the statistical parameters associated with the calibration. This is done by assessing the error between the modelled and observed (measured) water levels in terms of the root mean square (RMS). A RMS is expressed as:

$$\mathrm{RMS} = \left[1/n \sum (h_o - h_m)_i^{\,2}\right]^{0.5}$$

where: n = number of measurements

h_o = observed water level

h_m = simulated water level

RMS is considered to be the best measure of error, if errors are normally distributed. The RMS error calculated for the calibrated model is 7.95 m.

The acceptable value for the calibration criterion depends on the magnitude of the change in heads over the model domain. If the ratio of the RMS error to the total head change in the system is small, the errors are only a small part of the overall model response. The total measured head change across the model domain is 130.5 m; therefore, the ratio of RMS to the total head loss (Scaled MRS) is 6.09%. This indicates a good calibration and is within the Australian guidelines indicator of 10% Scaled RMS (Murray Darling Basin Committee [MDBC], 2001; Barnett *et al*., 2012).

The residuals within the Maxwell Underground area indicate that the model reasonably replicates the initial condition within this area of interest. Predicted groundwater levels were around 10 m higher than observed at two observation points (DD1004 and DD1015) within the Project area. This may be due to localised dyke structures in these areas influencing trends within the immediate mine area, but not influencing the regional groundwater trends.

Groundwater levels around Maxwell Infrastructure and Mt Arthur Mine also vary slightly in response to mining. This is likely due to differences between actual historical pre-stripping and mine activities that have not been fully captured in the steady-state model.

5.3.1.2 Steady State Calibration Mass Balance

The water balance for the steady-state simulation is presented in **Table 5-3**.

Table 5-3 Steady-State Model Mass Balance

COMPONENT	INFLOW (ML/DAY)	OUTFLOW (ML/DAY)
RECHARGE (RCH)	11.6	-
ET (FROM GW) (EVT)	-	41.0
SW-GW INTERACTION RIVERS (RIV)	8.4	1.1
REGIONAL GW FLOW (GHB)	31.1	8.8
MINES (DRN)	-	0.1
STORAGE	-	-
TOTAL	51.1	51.0
% ERROR	0.0	

The water balance for the steady-state model records low drain inflows. Drains have been applied in the steady-state model for the historical mining within the Greta Coal Measures (Bayswater No. 2 and Drayton Mine Centre Pit) and within the Wittingham Coal Measures at Belmont, McDonald and Saddlers pits (**Appendix G**). The low inflows relate to the layer structure, with localized pinched out layers, and assumptions in the starting heads. Drain inflows improved in the transient calibration with comparison to actual mine inflows.

5.3.1.3 Predicted Pre-Mining Groundwater Conditions

The predicted pre-mining groundwater levels for the unconsolidated (layer 1) and Bowfield Seam (Layer 15) are presented in **Figure 64**, which shows:

- The unconsolidated layer is saturated with groundwater heads ranging from 90 mAHD to 140 mAHD along the Saddlers Creek alluvium and with groundwater levels ranging from 70 mAHD to 130 mAHD in the Hunter Alluvium.
- The Bowfield Seam presents a north-east to south-west hydraulic gradient with groundwater levels ranging from 130 mAHD to 150 mAHD across the Project area. Groundwater heads in the Mt Arthur Mine area have a similar hydraulic gradient with flux direction toward the Hunter River alluvium; groundwater heads across this area have a range from 140 mAHD within the outcrop area to 180 mAHD toward the Hunter River alluvium.

In summary, the initial conditions succeed in replicating the higher groundwater levels along the outcrop areas, across the Project area and at the Bowfield Seam outcrop.

5.3.2 TRANSIENT CALIBRATION

Automated calibration utility PEST and manual calibration were used to match the available transient water level data. There were 8,857 target heads established for 117 sites and 10 inflow targets were assigned across three mine sites (Maxwell Infrastructure, Mt Arthur Underground and Mt Arthur Open Cut).

Groundwater level and quality trends were observed for each bore as part of the conceptualisation (**Section 4.4**), in order to understand the quality of data to be represented in the groundwater model. From that process the geology of different bores was updated, and the quality of different datasets identified. **Section 4.3** includes the updated details on each of the monitoring bores in the region.

Groundwater heads targets were chosen following the same procedure as the steady-state calibration. Groundwater heads targets used for the transient calibration were weighted as 1 in the calibration where reliable data was available on the construction of the bore and the data collected. Some data points were weighted down (i.e. 0.1 to 0.5) where there was limited detail about the bore available or where readings were potentially influenced by other factors, such as recent drilling of the bore. Details on each of the targets, the average weighting and average residual are presented in **Appendix H**.

Hydraulic conductivity parameters for the surficial layer (layer 1) and recharge calibrated in the steady-state model were held constant for transient calibration. During the transient calibration, changes were made to hydraulic conductivity for the deeper layers (layer 2 to 24), specific storage (Ss) and specific yield (Sy).

5.3.2.1 Statistics

Resulting calibration statistics for the transient simulation are shown in **Table 5-4**. The model scaled RMS is 4.3% and is considered a good fit using statistical targets suggested by MDBC (2001) and Barnett *et al*. (2012).

Table 5-4 Transient Calibration Statistics

Statistic	Value
Residual Mean (m)	-2.5
RMS Error (m)	7.0
Scaled RMS Error (%)	4.3

Figure 65 presents the observed and simulated groundwater levels graphically as a scattergram for the initial and historical transient calibration (2001 to 2019). Overall the observed data shows a reasonable to good fit with the model simulation. An almost linear relationship exists between simulated and observed groundwater heads for the Drayton South mine bores and government monitoring bores. Greater variability between simulated and observed groundwater levels is presented for the Spur Hill VWPs, Mt Arthur Mine bores and Maxwell Infrastructure bores, but still within the linear +/-20m error margin. The spatial distribution of residuals is shown on **Figure 66**. This figure alongside the data in **Appendix H** indicates there was no consistent over- or under-prediction of groundwater heads at the target bore locations. The groundwater levels at bores surrounding the Hunter River and Saddlers Creek generally match well.

Over the indicative extent of underground development simulated groundwater levels are lower than observed in some areas, which may relate to the localized influence of dykes and sills. Predicted groundwater levels are higher than observed at the northern end of North Void at Maxwell Infrastructure and show limited response to mining over time (refer to **Appendix I**). This is due to the bores intersecting the more permeable coal seams at these locations. The coal seams show greater response to groundwater level drawdown in response to mining compared to the lower permeability interburden sequences. At this location the model was simplified to capture the combined interburden and coal seams within the Rowan Formation for layer 23. The model captures the observed groundwater level drawdown within the combined units surrounding the pit, in response to mining.

The scattergram and residuals show that the model over-predicts the drawdown at Mt Arthur Open Cut at one bore, GW8 (**Figure 65**). Until 2013, simulated groundwater levels match the decreasing trend of observed groundwater level as mining progresses. Within more recent years the groundwater level response indicates mining has not progressed as far or deep as previously reported and captured within the model.

Calibration hydrographs, showing the fit between modelled and observed groundwater levels are presented as **Appendix I**. These results support the findings above.

5.3.2.2 Transient Calibration Mass Balance

The water balance for the transient simulation is presented in **Table 5-5**, averaged over the duration of the calibration period. The mass balance error, that is, the difference between calculated model inflows and outflows at the completion of the transient calibration, was 0.04%. This value indicates that the model is relatively stable and achieves an accurate numerical solution.

Table 5-5 Transient Model Mass Balance

	INFLOW (ML/DAY)	OUTFLOW (ML/DAY)
RECHARGE (RCH)	12.8	-
EVAPOTRANSPIRATION (FROM GW) (EVT)	-	42.7
RIVERS AND DAMS (RIV)	11.4	1.2
REGIONAL GW FLOW (GHB)	30.7	8.4
MINES (DRN)	-	2.8
STORAGE	10.4	12.5
TOTAL	67.6	67.5
% ERROR	0.04	

The water budget indicates that recharge to the groundwater system within the model averages 12.8 ML/day, with approximately 1.2 ML/day being discharged via surface drainage. The model predicted 42.7 ML/day lost to evapotranspiration in areas where the water table is within 2 m of the land surface. This number is high due to evaporation from several large waterbodies within the model domain (i.e. Plashett Reservoir and Lake Liddell).

The model predicts surrounding mines capture 2.8 ML/day of groundwater. The predicted inflows to mine areas were compared to measured inflows (where available). Predicted average annual pit inflows to the voids at the Maxwell Infrastructure, Mt Arthur Open Cut and along the drift development at Mt Arthur Underground are shown in **Table 5-6** shows reasonable fit between observed and modelled mine inflows in most mine areas. There is a slight over-estimation of inflows to Mt Arthur Open Cut from 2013 to 2018, which likely relates to assumptions in mine progression over this period.

Table 5-6 Transient Calibration – Mine Inflows

Mine	Area	Year	Measured Inflow (ML/d)	Simulated Inflow (ML/d)
Drayton	North Void	*2008**	0.55	0.72
Drayton	East Void	*2008**	1.1	2.2
Drayton	South Void	*2008**	0.45	0.18
Mt Arthur	Open Cut	2011	1.15	0.56
Mt Arthur	Open Cut	2013	1.37	6.08
Mt Arthur	Open Cut	2014	1.58	0.91
Mt Arthur	Open Cut	2015	1.78	3.05
Mt Arthur	Open Cut	2016	1.89	4.63
Mt Arthur	Open Cut	2018*	2.33	3.47
Mt Arthur	Underground	2010	0.011	0.044
**predicted value from Drayton Extension AGE (2006) and Mt Arthur Coal Open Cut Modification (AGE 2013b)*		**predicted value*		

5.3.2.3 Starting Heads (2019)

The predicted groundwater levels for model Layer 1 (alluvium/regolith/volcanics) and the Layer 15 (Bowfield Seam) are presented on **Figure 67** and **Figure 68** for the end of the transient calibration period. **Figure 67** presents the simulated depth to the water table alongside modelled groundwater levels. The simulated groundwater levels indicate that the saturated extent of Layer 1 is largely confined to the alluvium and follows the same downstream trajectory as the Hunter River. Similarly flows within the tributaries move along the alluvium towards their respective confluences with the Hunter River. The depth to the groundwater table shows that over the extent of the alluvium the water table is typically between the surface and 20 m depth. Mining related drawdown due to operations at Saddlers Pit indicates the water table as being approximately 100 to 400 m below ground surface in this area.

The groundwater levels within the Bowfield Seam, presented on **Figure 68**, show the desaturation of Saddlers Pit due to mining. This desaturation induces drawdown that extends beyond the pit to within 2 km of the mining operations. A localised groundwater mound is observed at the MacDonald and Belmont pits to the west of the Saddlers Pit, reflecting groundwater level recovery and in-pit water storage at this location.

5.3.3 CALIBRATED PARAMETERS

5.3.3.1 Hydraulic Conductivity and Storage

Table 5-7 summarises the calibrated values for horizontal and vertical hydraulic conductivity plus specific yield and specific storage.

Table 5-7 Calibrated Hydraulic Properties

Layer	Zone	Kx [m/d]	Kz [m/d]	Kx/Kz	Sy	Ss [m^{-1}]
1	Alluvium - Hunter River	15.0	15.0	1.00	1.00×10^{-1}	N/A
1	Alluvium - Less Productive	1.0	0.39	2.59	4.96×10^{-2}	N/A
1	Alluvium - Upslope	0.10	0.02	5.41	2.51×10^{-2}	N/A
1	Regolith	0.50	0.06	8.15	2.00×10^{-3}	N/A
1	Jurassic volcanics	6.53×10^{-7}	3.66×10^{-7}	1.78	1.00×10^{-4}	N/A
2	Maxwell Infrastructure	2.00×10^{-3}	2.00×10^{-3}	1.00	9.95×10^{-3}	1.00×10^{-6}
3	Whybrow overburden	1.84×10^{-3}	1.28×10^{-3}	1.43	8.55×10^{-3}	9.99×10^{-6}
4	Whynot overburden	1.09×10^{-4}	1.51×10^{-5}	7.22	9.66×10^{-3}	1.00×10^{-5}
5	Whynot Seam	1.04×10^{-2}	9.70×10^{-4}	10.7	3.08×10^{-2}	1.00×10^{-5}
5	Tertiary volcanics	9.83×10^{-7}	9.83×10^{-7}	1.00	1.00×10^{-4}	1.00×10^{-6}
6	Blakefield overburden	1.26×10^{-5}	1.26×10^{-6}	10.0	1.39×10^{-2}	1.00×10^{-5}
6	Tertiary volcanics	9.13×10^{-7}	9.13×10^{-7}	1.00	1.00×10^{-4}	9.96×10^{-7}
7	Blakefield Seam	1.39×10^{-1}	4.29×10^{-2}	3.23	3.12×10^{-2}	1.00×10^{-6}
8	Glen Munro overburden	6.31×10^{-5}	6.31×10^{-5}	1.00	1.32×10^{-2}	1.01×10^{-6}
9	Glen Munro Seam	1.00×10^{-3}	1.00×10^{-4}	10.0	3.01×10^{-2}	1.00×10^{-6}
10	Woodlands Hill overburden	1.01×10^{-4}	3.52×10^{-5}	2.87	1.01×10^{-2}	1.01×10^{-6}
11	Woodlands Hill Seam	1.00×10^{-3}	1.00×10^{-4}	10.0	2.96×10^{-2}	1.00×10^{-6}
12	Arrowfield overburden	1.36×10^{-5}	4.35×10^{-6}	3.13	9.63×10^{-3}	1.04×10^{-6}
13	Arrowfield Seam	4.35×10^{-3}	4.35×10^{-4}	10.0	2.87×10^{-2}	1.00×10^{-6}
13	Tertiary volcanics	1.01×10^{-6}	1.01×10^{-6}	1.00	1.00×10^{-4}	9.99×10^{-7}
14	Bowfield overburden	2.40×10^{-5}	2.40×10^{-5}	1.00	7.42×10^{-3}	1.14×10^{-6}
15	Bowfield Seam	3.56×10^{-3}	2.60×10^{-3}	1.37	2.63×10^{-2}	1.03×10^{-6}
15	Tertiary volcanics	9.29×10^{-7}	9.29×10^{-7}	1.00	1.00×10^{-4}	9.99×10^{-7}
16	Piercefield overburden	7.25×10^{-5}	5.68×10^{-5}	1.28	3.49×10^{-3}	1.71×10^{-6}
17	Piercefield Seam	1.00×10^{-2}	1.00×10^{-3}	10.00	2.84×10^{-2}	1.00×10^{-6}
18	Edderton overburden	4.06×10^{-5}	1.45×10^{-5}	2.80	2.93×10^{-3}	1.04×10^{-6}
19	Edderton Seam	1.70×10^{-2}	2.40×10^{-3}	7.09	2.62×10^{-2}	9.98×10^{-7}
20	Ramrod Creek overburden	1.93×10^{-4}	6.69×10^{-5}	2.88	2.25×10^{-3}	9.89×10^{-7}
21	Ramrod Creek Seam	2.18×10^{-2}	1.72×10^{-2}	1.27	1.96×10^{-2}	9.97×10^{-7}
22	Maitland Group	6.75×10^{-5}	6.75×10^{-5}	1.00	1.00×10^{-4}	9.96×10^{-7}
23	Rowan Formation	2.00×10^{-3}	2.00×10^{-3}	1.00	1.50×10^{-2}	1.00×10^{-6}
24	Skeletar Formation	6.36×10^{-7}	6.36×10^{-8}	10.0	5.00×10^{-3}	1.00×10^{-6}

5.3.3.2 Recharge

Table 5-8 illustrates the range in recharge values for the model domain, as a percentage of annual rainfall. The recharge ranges for the Hunter River alluvium and regolith material is comparable between this model and previous models. The recharge within the less productive alluvium is lower within the model compared to previous models. This was based on the presence of surficial clays identified along the creek lines (ENRS 2018) that would inhibit recharge as identified as part of the conceptualisation (**Section 4.7**). These recharge rates will be further explored within the uncertainty analysis (**Section 7**).

Table 5-8 Rainfall Recharge Ranges

	Calibrated Recharge (% Annual Rainfall)	AGE 2013b Modelled Recharge (%)	AGE 2015 Modelled Recharge (%)
Alluvium - Hunter River	5	10	5.2
Alluvium - Less Productive	0.4	1 (low gradient)	4.0
Alluvium - Upslope	0.1	-	-
Regolith	0.06	0.4 (high gradient)	0 – 1.4
Jurassic volcanics	0.05	-	-

5.4 PREDICTIVE MODELLING

5.4.1 MODELLING APPROACH

The potential effects of the Project were assessed by making comparisons between baseline predictive runs and stressed predictive runs (with the Project simulated as outlined later in this report section). This allows the simulated impact of the development on the hydrogeological environment to be isolated from other model processes (such as changes in groundwater levels due to changes in recharge and/or groundwater use).

Three main predictive model scenarios were run:

1. Null Run: A baseline scenario with no Project and no Mt Arthur Mine (i.e. a 'no-mining' or 'null' run as per Barnett *et al.*, 2012). This enables assessment of the cumulative effects of the Project along with those of the Mt Arthur Mine.

2. Approved: A baseline scenario with the Mt Arthur Mine and no Project[5]. This enables assessment of the incremental effect of the Project when compared to the third scenario below.

3. Approved plus Project: A predictive scenario with the Mt Arthur Mine and the Project in operation.

[5] Also called the Basecase model

All models used the calibrated historical period, as described in **Section 5.3**, as a run-in precursor to the predictive simulation period; that is, initial heads for all predictive and baseline runs were derived from the end of the calibrated historical model.

5.4.2 MODEL IMPLEMENTATION

A summary of the model timing and mining for the underground is presented in **Figure 60.** Model timing for the previous mining activities and proposed activities at the former Drayton Mine (now the Maxwell Infrastructure) is presented in **Figure 61**.

A description of how mining stresses were applied to the model is provided in **Section 5.2.7**.

5.4.3 PREDICTIVE MODEL MASS BALANCE

The water balance for the predictive simulation is presented in **Table 5-9**, averaged over the duration of the model period of 18 years from January 2001 to December 2018. The mass balance error was 0.01%, indicating the model is relatively stable and achieves an accurate numerical solution.

Table 5-9 Predictive Model Mass Balance - Approved

	INFLOW (ML/DAY)	OUTFLOW (ML/DAY)
RECHARGE (RCH)	12.1	-
ET (FROM GW) (EVT)	-	43.1
RIVERS AND DAMS (RIV)	20.7	1.6
REGIONAL GW FLOW (GHB)	30.7	8.4
MINES (DRN)	-	1.1
STORAGE	8.1	15.0
TOTAL	74.8	74.8
% ERROR	0.01	

The water budget indicates that recharge to the groundwater system within the model averages 12.1 ML/day, with approximately 1.6 ML/day being discharged via surface drainage. The model predicted 43.1 ML/day lost to evapotranspiration in areas where the water table is within 2 m of the land surface. This number is high due to evaporation from several large waterbodies within the model domain (i.e. Plashett Reservoir and Lake Liddell). The model predicts Mt Arthur Mine captures 1.1 ML/day of groundwater.

The water balance for the predictive simulation with the approved plus Project is presented in **Table 5-10**, averaged over the duration of the model period. The mass balance error was 0.01%, indicating the model is relatively stable and achieves an accurate numerical solution.

Table 5-10 Predictive Model Mass Balance – Approved Plus Project

	INFLOW (ML/DAY)	OUTFLOW (ML/DAY)
RECHARGE (RCH)	12.1	-
ET (FROM GW) (EVT)	-	43.3
RIVERS AND DAMS (RIV)	22.4	1.6
REGIONAL GW FLOW (GHB)	30.7	8.4
MINES (DRN)	-	3.0
STORAGE	9.7	16.5
TOTAL	78.0	77.9
% ERROR	0.01	

The water budget indicates little to no change in recharge, surface water discharge and evapotranspiration between the approved and the approved plus project model runs.

The model predicts that, with the Project, an additional 1.9 ML/day on average would be captured by the Project.

5.4.4 SIMULATED MINE INFLOW

Groundwater inflows to the Maxwell Underground have been extracted from the predictive models. These inflows are presented in **Figure 69**. Groundwater inflows to the Maxwell Underground are predicted to peak in Year 12 with peak inflows predicted at a rate of around 2.9 ML/day (1,085 ML/year). From Year 12, this rate reduces slightly over the life of the mine, to an average of around 2.3 ML/day (849 ML/year).

5.5 RECOVERY MODELLING

At the completion of mining, drain cells were removed and the model simulated post-mining conditions. A transient model was created to ascertain post-mining inflows.

A 1,000 year recovery simulation was run, with all drain cells removed, thus allowing the groundwater levels in the coal seams and the overlying water-bearing strata to recover. Model cells within the underground area had the DRN package turned off and parameters changed to reflect mined-out areas and goaf effects. Within the mined seams, the hydraulic conductivity was increased to 10 m/day (horizontal and vertical) and the specific yield set at 0.1. The properties within the layer overlying longwall panels were also changed to replicate increased permeability, with a hydraulic conductivity of 7.0 x 10^{-5} m/day to 1.0 x 10^{-3} m/day (increasing with depth) and specific yield of 0.034. The deformed specific yield (increased porosity) was calculated based on the difference of the total seam thickness of 9.65 m and the predicted subsidence of 5.60 m (MSEC, 2018), equaling 4.05 m of cavity/air zone.

Model cells located within the final voids in open cut areas were assigned a high horizontal and vertical hydraulic conductivity (1,000 m/day) and storage parameters (specific yield of 1.0, specific storage of 5.0 x 10^{-5} m^{-1}), to simulate free water movement within the void. The percentage of the rainfall becoming recharge across the spoil was set to 1 % of annual rainfall recharge and the evaporation/EVT rate was set at 0.00178 m/day. No recharge or evaporation was applied where the CHD package was active. The final landform design is captured in the structure of the model layer (top of Layer 1), and the EVT surface was assigned across the top of layer 1 for the recovery model, with an extinction depth of 2 m. The groundwater model was run for 1,000 years in order to simulate local and regional groundwater level recovery.

Modelling of recovery within the Maxwell Infrastructure area was conducted using a similar approach to the predictive model during mining (**Section 5.2.3**). Post mining the water levels varied from the predictive period (active mining) due to changes in water transfers and cessation of water storage post mining. The recovery of water levels within the final voids within the Maxwell Infrastructure area as predicted by WRM (2019) includes:

- North Void: start at 140 mAHD and recover up to 166 mAHD.
- South Void: start at 171 mAHD and recover down to 166 mAHD.
- East Void: start at 150 mAHD and recover up to 166 mAHD.

Pit lake level recovery rates from the surface water model were reinstated to the groundwater model using a series of constant heads over time (CHD package). This ensured consistency between the surface water and groundwater studies.

5.6 MODEL PERFORMANCE

5.6.1 MODEL CONFIDENCE LEVEL CLASSIFICATION

Groundwater modelling has been conducted in accordance with the Australian Groundwater Modelling Guidelines (Barnett *et al*. 2012), the MDBC Groundwater Flow Modelling Guideline (MDBC 2001) and the released IESC Explanatory Note for Uncertainty Analysis (IESC 2018). These are mostly generic guides and do not include specific guidelines on special applications, such as underground coal mine modelling.

The 2012 guide has replaced the model complexity classification of the previous guideline by a "model confidence level" (Class 1, Class 2 or Class 3 in order of increasing confidence) typically depending on:

- **Available data** (and the accuracy of that data) for the conceptualisation, design and construction.
- **Calibration procedures** that are undertaken during model development.
- **Consistency between the calibration and predictive analysis**.
- **Level of stresses** applied in predictive models.

Table 5-11 (based on Table 2.1, Barnett *et al*. 2012) summarises the classification criteria and shows a scoring system allowing model classification.

Based on **Table 5-11**, the groundwater model developed for this Groundwater Assessment may be classified as primarily Class 2 (effectively "medium confidence"), which is an appropriate level for this Project context.

The IESC Explanatory Note (IESC, 2018) points out the need to integrate geological complexity in the development of a modelling study that is history-matched to head and discharge data to reduce the source of uncertainty associated with geological structure. As such, the EIS modelling study has vertically and laterally refined the model grid to better accommodate the geology structure at the mines in the vicinity of the Project and at the Maxwell Infrastructure to enhance confidence in model prediction.

The IESC Uncertainty analysis – *Guidance for groundwater modelling within a risk management framework* (2018) identifies four key sources of scientific uncertainty affecting groundwater model simulations:

- Structural/conceptual.
- Parameterisation.
- Measurement error.
- Scenario uncertainties.

These four sources of scientific uncertainty have been qualitatively assessed, and are presented in **Table 5-12.**

5.6.2 PEER REVIEW

An external peer review was conducted by Dr Frans Kalf, who has over 40 years of experience in hydrogeological investigations and groundwater modelling. The review was in accordance with the Australian Groundwater Modelling Guidelines (Barnett *et al.* 2012).

The overall peer review report for the groundwater assessment is presented in Attachment 6 of the EIS.

Table 5-11 Groundwater Model Classification Table

Class	Data		Calibration		Prediction		Indicators		TOTAL
	Not much		Not Possible		Timeframe>>calibration		Timeframe>10x		
	Sparse		Large error statistics		Long stress periods		Stresses>5x		
	No metered usage	✓	Inadequate data spread		Transient prediction but steady state calibration		Mass balance>1% (or single 5%)		
1	Remote climate data		Targets incompatible with model purpose		Bad verification		Properties<>Field		**1**
							Bad discretisation		
							No review		
	Some	✓	Partial performance		Timeframe>calibration	✓	Timeframe=3-10x	✓	
	Poor coverage		Long-term trends wrong		Long stress periods	✓	Stresses=2-5x	✓	
	Some usage info		Short time record		New stresses not in calibration	✓	Mass balance<1%		
2	Baseflow estimates	✓	Weak seasonal replication		Poor verification		Properties<>Field measurements	✓	**9**
			No use of targets compatible with model purpose				Some key coarse discretisation	✓	
							Reviewed by hydrogeologist		
	Lots		Good performance stats	✓	Timeframe~calibration		Timeframe<3x		
	Good aquifer geometry	✓	Long-term trends replicated		Similar stress periods		Stresses<2x		
3	Good usage info		Seasonal fluctuations OK	✓	Similar stresses to those in calibration		Mass balance<0.5%	✓	**9**
	Local climate info	✓	Present day data targets	✓	Steady state prediction consistent with steady state calibration		Properties ~Field measurements		
	K measurements	✓	Head and flux targets		Good verification		Some key coarse discretisation		
	Hi –res DEM	✓					Reviewed by modeller	✓	

Table 5-12 Qualitative Assessment of Model Uncertainty

Type	Part	Status	Comment
Structural/ Conceptual Geology/ Structure	Grid	Fit for purpose	Model has unstructured Voronoi grid that includes detailed cell refinement around site and along drainage features.
	Layer 1	Fit for purpose	Top of layer 1 based on LiDAR data at site and DEM outside of site. Alluvium thickness based on site drill data where available, and CSIRO (2015) regolith depth mapping elsewhere.
	Layer 3 to 21	Fit for purpose	Wittingham Coal Measures at site based on detailed geological model, which captures minor fault displacements in coal measures. Outside of site the layering was based on geological model at Spur Hill and mapped/reported geological surfaces from AGE (2013b) report for Mt Arthur. Other areas based on the Hunter Coalfield Geology Model - Sydney Gunnedah Model (Oliveira 2018).
	Layer 22	Fit for purpose	Maitland Group based on Hunter Coalfield Geology Model - Sydney Gunnedah Model (Oliveira 2018) and designed to align with overlying layers. No active mining in the layer.
	Layer 23	Some limitations but fit for purpose	Greta Coal Measures were simplified and grouped as one unit rather than separate layers to represent coal seams and interburden. Grouping of the coal measures was undertaken due to limited data available to develop specific coal seam layers, and due to the cessation of mining in this area. The Project design includes final voids at the location and recovery in the voids is included in the groundwater assessment. The Greta Coal Measures at Drayton Mine largely comprise interburden material, with combined coal seam thickness of 22 m compared to around 110 m of interburden (AGE 2006). Some bores in the area intersect the permeable coal seams and recorded a groundwater level response to historical mining. The grouping of the units influences the ability of the model to calibrate to the specific bores, as groundwater level drawdown within the combined interburden/coal unit is more subdued than that observed in a thin coal seam. However, the grouped unit still enabled prediction of groundwater level drawdown around the mine area in the calibration model. This then enabled the model to predict groundwater level recovery of the final voids, and results can be verified against previous detailed modelling of the area by AGE (2006).
	Sills	Fit for purpose	Sills were included within the model based on detailed site geological mapping by MBGS (2018). Model was tested and run with and without the sills present, and it was found that the predicted groundwater levels at the Project area improved within inclusion of the sills in the model design.
	Dykes	Some limitations but fit for purpose.	Dykes are present within the Project area. The dykes were too thin (approx. 2 m wide) to be incorporated in the grid design of the regional model. The dykes appear to be mapped within the immediate mine area and may influence local groundwater trends at the Project, but unlikely to influence impact predictions and regional groundwater trends. The influence of faults on the model predictions was tested as part of the sensitivity analysis.

Type	Part	Status	Comment
	Faults	Some limitations but fit for purpose	Faults have previously been mapped in the region, but detailed geological mapping at site indicates the faults are less extensive than previously mapped. Detailed fault investigation by AGE (2013b) for Mt Arthur Mine found faults are more likely to act as barriers to flow than conduits. To manage the level of complexity in the model and be conservative in predictions, the model did not include barriers to flow, and allows for groundwater level drawdown to extend across areas of mapped faults. The influence of faults on the model predictions has been tested as part of the sensitivity analysis with the dykes.
Parameterisation	Hydraulic Conductivity	Fit for purpose	Extensive field testing of hydraulic conductivity (horizontal and vertical) has been conducted at the site and immediate surrounds for most lithological units represented in the model. Model parameters calibrated in line with field data ranges and in consideration of model parameters used in the region. There is limited data on the hydraulic properties of the alluvium along Saddlers Creek. However, detailed drilling conducted along Saddlers Creek provides details on the lithology in the area.
	Storage properties	Fit for purpose	Limited site data available for the storage properties, but values matched to align with parameters used at surrounding mines and within accepted bounds promoted by Rau *et al* (2018).
	Recharge	Fit for purpose	Recharge parameters were zoned based on surface geology and calibrated in the steady state calibration. Recharge in the transient calibration was represented based on actual monthly rainfall to capture seasonal variability. Recharge parameters were compared to parameters used for neighbouring operations and were largely in line. Recharge for the less productive alluvium was lower compared to previous models. This was based on new data for the Project from field drilling, which recorded the presence of surficial clays along the creek that would inhibit recharge.
Measurement Error	Observation Data quality	Fit for purpose	As part of the conceptualisation the quality of data was reviewed, including review of groundwater level and quality trends to verify target lithology. All available information about the observation bores is included in the main report. Where the source of data was uncertain (i.e. no bore construction details or lithology), this data was omitted or weighted down in the calibration process. A summary of how each observation point was weighted is shown in **Appendix G** and **Appendix H**.
	Spatial spread	Fit for purpose	Observation targets are available for most model layers across the model domain. Some coal seams and interburden sequences within the Wittingham Coal Measures do not have specific observation targets as shown in **Table 4-4**. However, there is sufficient data for other similar sequences to allow adequate model calibration.
	Temporal spread	Fit for purpose	Groundwater levels have been recorded on a daily to quarterly basis across the network. Groundwater level readings are available from 1982 to 2018, capturing responses to rainfall/flood events and mining in the region over the calibration period.

Type	Part	Status	Comment
Scenario Uncertainties Future stresses/ conditions	Calibration	Fit for purpose	Steady State calibration and Transient Calibration from January 2001 to December 2018 (18 years) with monthly stress periods.
	Predictive	Fit for purpose	Predictive model January 2019 to January 2047 (27 years) with annual stress periods. Model predictive time frame is less than 3 times the duration of transient calibration. Temporal discretisation varies to calibration, in order to align with mine plan design timing.
	Sensitivity		Sensitivity analysis included a range of scenarios to test various conceptualisations, including: • RCH: Above and below average rainfall recharge. • Faults/dykes acting as groundwater barriers. • GHB: Test influence of GHB on model predictions, with cells conductance reduced by an order of magnitude.
	Uncertainty Analysis		Uncertainty analysis has been conducted by stochastic modelling using an adapted Monte Carlo method with modern software packages. AlgoCompute (HydroAlgorithmics, 2018; Merrick, 2017) was used as the platform for executing the model runs in parallel, with multiple realisations evaluated simultaneously, each being allocated to a single CPU core of a virtual machine in the cloud. Model-independent uncertainty quantification software HGSUQ (Miller *et al.*, 2018) was used to generate the Monte Carlo parameter realisations and orchestrate the model runs within the AlgoCompute environment. The uncertainty analysis quantified the variability in predictions with changes in: • Hydraulic conductivity for all layers. • Storage properties - specific yield and specific storage for selected layers. • Maxwell Underground drain conductance.

6 GROUNDWATER IMPACT ASSESSMENT

This section describes the numerical model predictions and impacts of the Project, including:

- drawdown in groundwater levels in the alluvium and coal measures as a result of the Project (**Section 6.1**);
- change in alluvial and surface water resources availability (**Sections 6.2** and **6.3** respectively);
- water licensing requirements (**Section 6.4**);
- impact on supplies from private bores (**Section 6.5**); and
- potential impacts on groundwater dependent ecosystems (**Section 6.7**).

6.1 DRAWDOWN AND DEPRESSURISATION

Mining results in depressurisation of the coal seams and fractured overburden/interburden within the immediate area of mining activities. Depressurisation, that is depression in the potentiometric surface, propagates away from the mining area based on the hydraulic properties of the surrounding strata.

Depressurisation, or depression of the potentiometric surface, does not necessarily result in physical drawdown within constrained units (such as the deeper Permian groundwater system).

6.1.1 DRAWDOWN AND DEPRESSURISATION – PROJECT

Predicted water table contours at the end of mining are presented in **Figure 70** and **Figure 71** without and with the Project, respectively. The figures show a slight decline in groundwater elevations within the Maxwell Underground area.

Figure 72 to **Figure 77** show the maximum predicted drawdown due to the Project for the combined water table (all layers), as well as predicted depressurisation within individual model layers. This includes drawdown within the unconsolidated sediments (Layer 1), and depressurisation within the Whynot Seam (Layer 5), Woodlands Hill Seam (Layer 11), Arrowfield Seam (Layer 13) and Bowfield Seam (Layer 15). Key results are summarised as follows:

- **Figure 73** shows along Saddlers Creek there is up to 8 m of maximum predicted drawdown within the saturated alluvium within two localized areas, while up to 4 m of maximum drawdown is predicted along Saltwater Creek. Less than 2 m of maximum drawdown was also predicted for the regolith along Unnamed Creek within the Maxwell Underground area.
- **Figure 73** shows no drawdown above the AIP criteria of 2 m was predicted within the "highly productive" alluvium along the Hunter River.

- The extent of maximum predicted depressurisation of the Permian coal measures (**Figure 74** to **Figure 77**) is limited to the north and east of the Project area due to the structural geology (i.e. coal seam subcrop). Depressurisation is also attenuated in magnitude and spatial extent in an upward direction through the strata from the mined seams. This is due to the relatively low vertical strata hydraulic conductivity in the Permian layers.
- The cone of depression is steepest around the active underground mine area. In all coal seam layers, the magnitude of the depressurisation is generally less than 20 m at a distance of 4.7 km from the edge of the proposed underground footprint.
- Depressurisation within the coal measures largely occurs during the recovery period. The extent of drawdown is influenced by conservative assumptions in the recovery model, including averaged rainfall recharge.

6.1.2 DRAWDOWN AND DEPRESSURISATION – CUMULATIVE

Approved coal mines within the region operate below the water table and therefore extract groundwater and create a cumulative depressurisation effect on the groundwater system. The numerical groundwater model was used to assess the cumulative drawdown associated with existing and approved mining at Mt Arthur Mine.

The maximum groundwater depressurisation due to cumulative effects was calculated by comparing results between the Null and the Approved plus Project model scenarios. **Figure 78** to **Figure 83** show the maximum predicted cumulative drawdown for the combined water table (all layers), as well as depressurisation within individual model layers. This includes drawdown within the unconsolidated sediments (Layer 1) and depressurisation with the Whynot Seam (Layer 5), Woodlands Hill Seam (Layer 11), Arrowfield Seam (Layer 13) and Bowfield Seam (Layer 15). The results show:

- Predicted maximum drawdown along Saddlers Creek is largely due to the Project, with no additional predicted impact from future approved operations at the Mt Arthur Mine.
- No cumulative drawdown in excess of 2 m predicted within the Hunter River “highly productive” alluvium.
- No connection in groundwater depressurisation within the shallow Permian coal measures (Layer 3 to Layer 5) between the Project and mining at Mt Arthur Mine.
- As expected, the greatest cumulative depressurisation occurs in the deeper coal seams that are mined at the two mine areas (i.e. from Layer 11 to Layer 15). However, the extent of depressurisation in the coal seams is limited to the north and east by the outcrop of the coal seams.

6.2 PREDICTED INCIDENTAL TAKE OF WATER FROM THE ALLUVIUM

The change in alluvial water resources was determined by comparing water budgets for alluvial zones using versions of the numerical model that contained and excluded the Project. Due to a lag in groundwater drawdown migration, the results include both the predictive and recovery period.

The main alluvial resources in the area include:

- alluvium regulated under the Hunter Unregulated and Alluvial Water Sources:
  - the Jerrys Water Source (Jerrys Management Zone), which covers the Saddlers Creek and Saltwater Creek alluvium;
  - the Hunter Regulated River Alluvial Water Source (Upper Glennies Creek Management Zone), which covers much of the Hunter River alluvium; and
- alluvium associated with the Hunter Regulated River Water Source, which includes alluvium in the immediate vicinity of the Hunter River channel.

Figure 84 shows the change in flow between the alluvium and the Permian coal measures due to the Project during the predictive and recovery model periods. **Figure 84** shows that the Project is predicted to reduce upward leakage from the Permian coal measures to the overlying alluvium in localized areas along Saddlers Creek and the Hunter River. This can be considered beneficial as it reduces the inflow rate of higher salinity groundwater from the Permian to the overlying alluvium.

Along Saddlers Creek and Saltwater Creek the reduction in upward seepage from the Permian coal measures to the alluvium is on average 6 ML/year and peaks at 12 ML/year during active mining. Post mining the reduction in upward seepage peaks at 25 ML/year, but reduces back to 9 ML/year at equilibrium. The location of drawdown associated with the reduction in upward seepage along Saddlers Creek and Saltwater Creek is shown on **Figure 85**. There is no predicted drawdown in layer 1 along Unnamed Creek.

Alluvium along the Hunter River also shows a slight decline in upward seepage from the Permian coal measures to the overlying alluvium due to the Project, with reduced seepage predicted of up to 5 ML/year during mining and up to 19 ML/year post mining along the zone of “highly productive” alluvium associated with the Hunter Regulated River Water Source. There is also a reduction in seepage predicted to occur within the Hunter River alluvium regulated under the Hunter Unregulated and Alluvial Water Sources – Upper Glennies Creek Management Zone of up to 3 ML/year during mining and up to 11 ML/year post mining. Due to increased recharge to the Hunter River alluvium, the predicted reduction in seepage would result in less than 0.5 m of maximum drawdown along the Hunter River alluvium. The predicted reduction in seepage is considered negligible in the context of the high rates of recharge to the Hunter River alluvium.

6.3 PREDICTED STREAM FLOW EFFECTS

Figure 85 shows the change in predicted net river baseflow for Saddlers Creek, Saltwater Creek and the Hunter River during and post mining. **Figure 85** shows that there is no change in baseflow along Saddlers Creek and Saltwater Creek. This corresponds with the predicted area of groundwater drawdown in Layer 1 (**Figure 73**) that shows groundwater drawdown within the saturated alluvium is localized within the upper reaches of Saddlers Creek. This area of the creek exhibits losing conditions (refer **Section 4.4** and **Section 4.5**), therefore no expected reduction in baseflow contributions. Flows along Saddlers Creek are also intermittent, which means reduced availability of surface water to recharge the alluvium. Similarly flows along Unnamed Creek, a tributary of Saddlers Creek, at the Project area are ephemeral. Groundwater levels are predicted to be around 2 m to 6 m below surface with no expected reduction in baseflow contributions to Unnamed Creek.

The predicted drawdown along the Hunter River extends near the Hunter River alignment, resulting in up to 0.55 ML/year of potential increased leakage from the Hunter River to the underlying alluvium. This degree of flow reduction in response to the Project is considered negligible in light of observed historical flow rates in the Hunter River and the regulation of its flow. The volume is also well within the predicted volume of reduced seepage from the Permian coal measures to the "highly productive" alluvium along the Hunter River, of up to 19 ML/year. Impacts associated with the indirect interception of alluvial groundwater and surface water flow along a specified area are related. Therefore, to avoid double accounting of water indirectly intercepted, the volume of baseflow change should be accounted for under the larger predicted take of groundwater within the "highly productive" alluvium under the Hunter Regulated River Water Source – Zone 1B.

6.4 WATER LICENSING

The AIP requires all water taken by aquifer interference activities to be accounted for within the extraction limits set by the relevant water sharing plan.

As discussed in **Section 2.3**, water sharing plans relevant to the Project are:

- *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016.*
- *Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009.*
- *Water Sharing Plan for the Hunter Regulated River Water Source 2016.*

The predicted annual groundwater volumes required to be licensed over the life of the Project and post mining are summarised in **Table 6-1**. Attachment 8 of the EIS presents the project licensing requirements in the context of Malabar's existing entitlements (including consideration of historical water determinations and relevant carry over provisions).

Table 6-1 Groundwater Licensing Summary

	Source	During Mining		Post-Mining		Post-Mining Equilibrium
		Avg (ML/year)	Max (ML/year)	Avg (ML/year)	Max (ML/year)	(ML/YEAR)
Hunter Unregulated and Alluvial Water Sources WSP	Jerrys Water Source - Jerrys Management Zone (Saddlers Creek and Saltwater Creek)	6	12	20	25	9
	Hunter Regulated River Alluvial Water Source – Upstream Glennies Creek Management Zone	7	15	28	35	12
Hunter Regulated River Water Source	Hunter Regulated River Water Source – Management Zone 1B – Hunter River from Goulburn River Junction to Glennies Creek Junction	2	5	14	19	6
North Coast Fractured and Porous Rock WSP	Sydney Basin North Coast Groundwater Source	750	1,085	-	-	-
		3*	11*	-	-	-
	New England Fold Belt Coast Groundwater Source	-	-	-	-	-

Note: ** Predicted groundwater inflows to existing Maxwell Infrastructure area*

6.5 DRAWDOWN AT PRIVATELY-OWNED WATER SUPPLY BORES

No bores in the "highly productive" Hunter River alluvium or the Saddlers Creek alluvium are predicted to experience cumulative drawdowns greater than 2 m.

One privately-owned bore (GW029660) is predicted to experience cumulative drawdown greater than 2 m as a result of the Project and Mt Arthur Mine (including both open cut and approved underground operations) (**Table 6-2** and **Figure 86**). The bore has an existing water column of 35 m and therefore the yield of the bore is unlikely to be materially affected by the Project.

As outlined in **Section 6.1**, the maximum depressurisation due to the Project is predicted to occur within the recovery period. The predicted impact to GW029660 is due to the conservative assumptions within the recovery model (including averaged rainfall recharge and allowing groundwater level drawdown to extend across areas of mapped faults, which would likely act as barriers to flow in practice).

Two bores (GW029647 and GW029648) on the MH & RK Wolfgang property apparently intersect the shallow Permian coal measures, at depths of 36.6 m and 31.1 m and are thought to be dry given the predicted water table is approximately 20 m below the base of the bores. Whilst cumulative depressurisation of approximately 3 m is predicted to extend beneath the bores, the bores would be unaffected if they are already dry.

Groundwater monitoring will continue to be conducted over the life of the Project to confirm the actual extent of groundwater impacts and to validate the predictions, particularly with regard to drawdown effects on private bores. As part of operational and mine closure planning, the proponent will implement 'make-good' provisions for any bore that experienced or is predicted to experience greater than 2 m drawdown and an associated reduction in yield due to the Project (e.g. rather than natural climatic variability).

Table 6-2 Predicted Drawdown at Privately-owned Water Supply Bores

Bore ID	Use	Bore Depth (mbgl)	Baseline Water Level (mbgl)	Predicted Water Level (mbgl)	Water column (m)	Maximum Drawdown Due to Project (m)	Maximum Cumulative Drawdown (m)
GW029660	Stock	74.7	39.6	22.2	35.1	2.3	3.7

Notes: *Baseline Water Level – water level recorded in recent years from the bore census or public domain documents*
Predicted Water Level – predicted water level for the location from the end of the calibration model (Dec 2018)

6.6 DRAWDOWN AT MINE-OWNED WATER SUPPLY BORES

Five BHP-owned water supply bores accessing less productive hard rock groundwater systems are predicted to have over 2 m drawdown due to cumulative impacts (**Table 6-3** and **Figure 86**). All affected bores intersect the Permian coal measures and are located north to north-west of the Project area, near Mt Arthur Mine. All have a listed purpose of stock and domestic purposes and are constructed to depths of between 33 m and 91 m below surface.

The bore with the highest maximum drawdown of 13.5 m due to the Project is BHP-owned bore GW049223 located along Saddlers Creek. The bore is a 127 mm diameter PVC bore with a recorded yield of 1.04 L/s that is used for stock water supply (ENRS 2019). Four other bores on BHP-owned land are predicted to experience 1.8 m to 4.3 m drawdown due to the Project (GW032512, GW032077, GW031859 and GW031622).

Table 6-3 Predicted Drawdown at Mine-owned Water Supply Bores

Bore ID	Use	Bore Depth (mbgl)	Baseline Water Level (mbgl)	Predicted Water Level (mbgl)	Water column (m)	Maximum Drawdown Due to Project (m)	Maximum Cumulative Drawdown (m)
GW049223	Stock	67.1	-	1.9	65.2*	13.5	13.5
GW031622	Stock	91.4	30.5	40.0	60.9	3.9	10.2
GW031859	Stock	61	22.9	17.1	38.1	4.3	8.7
GW032077	Stock	53.3	28.7	42.6	13.9	3.1	11.6
GW032512	Stock	33.5	-	14.2	19.3*	1.8	17.6

Notes: *Baseline Water Level – water level recorded in recent years from the bore census or public domain documents*

Predicted Water Level – predicted water level for the location from the end of the calibration model (Dec 2018)

** Anticipated water column based on predicted water level where observed levels are not available.*

6.7 IMPACT ON GROUNDWATER DEPENDENT ECOSYSTEMS

As outlined in **Section 4.6.2**, high potential GDEs were mapped in the GDE Atlas along the Hunter River, correlating with riparian vegetation. Along Saddlers Creek the GDE Atlas indicates only low potential for groundwater interaction. However, field surveys conducted across the site (Hunter Eco 2019) indicated the presence of Swamp Oak along Saddlers Creek that potentially have some reliance on groundwater. The Swamp Oak is not identified as a high priority ecosystem (Hunter Eco 2019). As Swamp Oak is found up to the high bank of the creek, Hunter Eco (2019) is of the view that these trees would primarily access streamflow and soil moisture rather than deeper groundwater.

Reliance on groundwater is correlated to the depth to groundwater, with trees generally unable to access groundwater over 10 m below surface. Hunter Eco (2019) expects that the maximum root depth for Swamp Oak would be about 4.5 m. **Figure 67** presents the predicted depth to water across all geological units for current (2019) conditions and the saturated extent within Layer 1. **Figure 67** shows most shallow groundwater is captured within model Layer 1. Maximum predicted drawdown in Layer 1 is presented in **Figure 73** for Project only impacts and **Figure 79** for cumulative impacts. **Figure 73** shows the Project could cause up to 8 m of drawdown within the alluvium along Saddlers Creek where the Swamp Oak has been mapped as being present.

Hydrographs from the predictive and recovery model runs have been extracted for Layer 1 for four areas where Swamp Oak has been mapped along Saddlers Creek; the locations of the points are shown in **Figure 87**. The hydrographs are presented in **Figure 88** to **Figure 91** and show the timing associated with groundwater level change for the Approved only model scenario and the Approved plus Project model scenario (cumulative). The results show that the groundwater drawdown in the alluvium largely occurs post mining. The drawdown in the alluvium remains sustained over time due to the assumptions in the recovery model with constant averaged rainfall and Saddlers Creek modelled as dry. This results in reduced potential recharge to the alluvium compared to conditions that have been observed along Saddlers Creek (see **Section 4.4**), providing a conservative estimate of impacts.

As discussed in **Section 4.6.2** stygofauna have also been identified within the alluvium along the Hunter River and Saddlers Creek. The species of stygofauna in the two locations were identified as being the same. This is likely due to the hydraulic connection between the Saddlers Creek alluvium and down-slope Hunter River alluvium (**Section 4.4**). There is no significant drawdown predicted along the Hunter River; however drawdown of up to 8 m has been conservatively predicted in areas within the alluvium along Saddlers Creek. The consequences of this drawdown are reduced due to the connected nature of the alluvium and mobile nature of stygofauna populations. In addition the drawdown relates to a predicted reduction in upward seepage from the Permian coal measures to the alluvium along Saddlers Creek. This reduction is likely to improve the water quality in the alluvium, thereby improving the environment for stygofauna.

6.8 POST-MINING EQUILIBRIUM

The predictive models simulate the operational mining period, followed by a further post-mining recovery period of 1,000 years. As outlined in **Section 6.1** to **Section 6.3**, there is a delay in the timing of maximum groundwater depressurisation and impacts associated with the Project. These maximum impacts occur around 100 – 200 years post closure. Within the recovery period there is also a change in activities conducted within the Maxwell Infrastructure area. During the recovery period, water and tailings storage is ceased and groundwater levels within the final voids recover over time. As discussed in **Section 5.5**, the groundwater model was used to estimate groundwater inflows to the existing final voids at the Maxwell Infrastructure. WRM used these estimates to run a high-resolution surface water model recovery within the voids (North, South and East voids) over time. For consistency between the two studies, this recovery was then incorporated into the groundwater model as a series of constant heads over time.

To illustrate the change in groundwater levels over time, water table contours (all layers combined) are presented for 100 years post mining (**Figure 92**), 200 years post mining (**Figure 93**) and 1,000 years post mining (**Figure 94**). **Figure 92** and **Figure 93** show the recovery of groundwater levels within the Permian coal measures within Maxwell Underground and Mt Arthur Mine. By 1,000 years post mining (**Figure 94**) groundwater levels and flow directions have recovered back towards pre-mining conditions within the Maxwell Underground area.

Figure 96 shows the depth to water table at 1,000 years post mining. The figure illustrates that the groundwater levels are over 30 m below surface at the northern and southern sides, and over 20 m below surface on the eastern side of Maxwell Infrastructure area. As also shown in **Figure 96,** groundwater levels around Maxwell Infrastructure area show that North Void and South Void act as partial groundwater sinks, drawing groundwater from the *in situ* strata towards the mined area.

Groundwater levels around East Void are more subdued to the east but also indicate the void will act as a sink, largely due to localized recharge from the Liddell Ash Dam driving a slight gradient towards the void (**Figure 96**). On the western side of East Void there is a saddle of *in situ* (un-mined) Greta Coal Measures down to an elevation of 260 mAHD that separates the Maxwell Infrastructure from the Mt Arthur Coal Bayswater Pit final void (**Figure 56**). Within the Maxwell Infrastructure area the groundwater levels are predicted to equilibrate at around 166 mAHD and remain below the *in situ* strata to the west.

6.9 POTENTIAL IMPACTS ON GROUNDWATER QUALITY

The Project is predicted to reduce upward leakage from the Permian coal measures to the overlying alluvium in localized areas along Saddlers Creek and the Hunter River (**Section 6.2**). These results demonstrate that as the Permian coal measures become depressurised, flow from the Permian to the alluvium decreases. This can be considered beneficial as it over time reduces the inflow rate of higher salinity groundwater from the Permian to the overlying alluvium. Accordingly, the Project is considered to have negligible adverse impact on groundwater quality in the alluvium.

The results for the predictive and recovery model indicate:

- Maxwell Underground would remain a sink towards which groundwater would flow during mining and post-mining.
- North Void and South Void at the Maxwell Infrastructure would largely act as groundwater sinks with groundwater levels within the void area lower than levels within the adjacent *in situ* (unmined) Greta Coal Measures.
- East Void at the Maxwell Infrastructure area was also predicted to act as a groundwater sink. However, the flow gradient was is more subdued and largely influenced by localized recharge from the Liddell Ash Dam.

Figure 95 shows the predicted groundwater level change post mining, and **Figure 96** shows the predicted depth to water table and groundwater levels at 1,000 years post mining. Discussion on the potential impact on water quality at Maxwell Underground and Maxwell Infrastructure areas is included below.

6.9.1 MAXWELL UNDERGROUND WATER QUALITY CHANGE

Within the Maxwell Underground, the salinity of mine water inflows will be controlled by the groundwater salinity within the strata above and around the mine workings and fracture zone, from which inflows will originate. Because strata groundwater salinity varies spatially (vertically and horizontally), the bulk inflow salinity will reflect a mixture of groundwaters of variable salinity over time, as dictated by fracture zone heights (i.e. which strata are depressurised in response to mining), and the spatial variability of host strata salinity within and around the progressively mined areas. As outlined in **Section 4.4.4**, groundwater within the coal measures is generally moderately saline to saline with an average TDS of 2,932 mg/L for interburden and 2,658 mg/L for coal. Geochemical analysis conducted by Geo-Environmental Management (2019) found that the overburden and coal samples were largely NAF. An exception to this was one sample from the Woodlands Hill seam roof that was PAF-LC. However, as reported by Geo-Environmental Management (2019), the overall water quality within the underground workings is unlikely to be affected by the presence of PAF-LC material due to the ANC and alkaline pH of the surrounding strata. It is therefore anticipated that groundwater quality within the Maxwell Underground area will remain in line with baseline data with no change in the beneficial use of water within the Permian coal measures during or following the Project.

6.9.2 MAXWELL INFRASTRUCTURE WATER QUALITY CHANGE

As outlined in **Section 1.2** and **Section 5.2.3**, the Project design for the Maxwell Infrastructure includes temporary storage of water in North Void, East Void and South Void during active mining. In addition, East Void will be used for rejects emplacement up to a maximum fill level of 175 mAHD and has a decant pond to the north at an elevation of 150 mAHD.

The final void water level within the Maxwell Infrastructure area is predicted to be around 166 mAHD (WRM, 2019). This predicted level of 166 mAHD remains over 30 m below groundwater levels within the *in situ* material to the north of North Void, as shown in **Figure 95** and **Figure 96**, and as recorded at bore GW01D (**Section 4.4**). Therefore the northern end of the Maxwell Infrastructure area is likely to act as a sink, drawing groundwater towards North Void.

Similarly South Void is predicted to have a final steady state pit lake level of approximately 166 mAHD (WRM, 2019) and would remain lower than groundwater levels in the *in situ* strata to the south, acting as a sink.

For East Void, the model predicts pit lake recovery up to 166 mAHD at East Void (WRM, 2019), and **Figure 96** shows a low gradient of flow from Liddell Ash Dam towards the void. As shown in **Figure 96** the groundwater levels next to the void are over 20 m below surface, within the Greta Coal Measures that dip towards the east. At the western side of the Maxwell Infrastructure area the equilibrated water level of 166 mAHD is below the existing height of unmined Greta Coal Measures present down to 260 mAHD that separates it from the Mt Arthur Mine Bayswater Pit final void. **Figure 96** shows that groundwater levels are around 100 m below surface in this area, **Figure 56** also illustrates this in cross section. The depths to water decrease to the west within the Bayswater Pit final void area; however, this may relate to the assumed final landform design for Mt Arthur Mine. Hydraulic connection between the Maxwell Infrastructure area and the Bayswater Pit is likely to be limited by the presence of the *in situ* strata and the structure of the geology.

Overall, the final voids within the Maxwell Infrastructure area are predicted to act as groundwater sinks, and are therefore unlikely to impact on water quality within the surrounding stratigraphy. As discussed above, the gradient towards the final voids is lowest on the eastern side of East Void, near the Liddell Ash Dam. **Section 4.4.4.4** identified that, based on laboratory analysis, rejects material at site can be PAF due to the total sulphur content. Consistent with this, available water quality data from the existing Mt Arthur Mine tailings dam indicates the tailings water generally has similar EC and metals concentrations to groundwater in the Permian coal measures, but a higher sulphate concentration. However, water within the tailings generally has lower concentrations of metals and sulphate compared to water within the regolith around the Liddell Ash Dam. Therefore, while no seepage is predicted from the eastern side of East Void, in addition to this the water quality within the void area is likely to be of a better quality compared to current water quality in the area.

7 SENSITIVITY AND UNCERTAINTY ANALYSIS

Due to the low risk of the Project as indicated by Basecase model predictions and sensitivity analysis, uncertainty analysis was performed using scenario analysis. This is one of three recommended methods of undertaking uncertainty analysis as advocated in the IESC guidelines for uncertainty analysis (Middlemis and Peeters, 2018).

Using this approach, the aim of uncertainty analysis is to assess the predictive models' simulated Project mining effects with regard to their sensitivity to selected model parameters. A series of alternate predictive models has been run in addition to those described in **Section 5.4.1**, with the objective to rank the input parameters in terms of their influence upon model predictions. The model parameters were adjusted to encompass the range of likely uncertainty in key parameters. This was achieved by changing and assessing the following:

- ± 1 order of magnitude change in horizontal hydraulic conductivity (Kx) for all geological units;
- ± 1 order of magnitude change in vertical hydraulic conductivity (Kz) for all geological units;
- ± 1 order of magnitude change in specific storage (Ss) for all geological units, with values within the range of expected values based on Rau *et al.* (2018);
- An increase in coal seam drain conductance by 300 % (to 0.3 m^2/d);
- Rainfall recharge:
    - NSW and ACT Regional Climate Modelling (NARCliM) projection for near future (2020 to 2039) – simulation of median (+ 3 %), highest (+16 %) and lowest (-13 %) predicted changes to average rainfall;
    - NARCliM projection for far future (2060 to 2079) – simulation of median (+8 %) predicted changes to average rainfall;
- Boundary conditions (GHB); and
- Dykes within Maxwell Underground area.

Within the Basecase model a coal seam drain conductance of 0.1 m^2/d was applied based on the best match to observed groundwater inflows to existing underground operations (**Section 5.2.7**). For the purpose of the uncertainty analysis this was increased by 300 % to 0.3 m^2/d in order to understand the sensitivity of the model predictions to increased hydraulic connectivity within the underground mine area.

In order to assess the sensitivity of proposed mining to alluvial and baseflow take, a series of model scenarios modifying rainfall recharge were run. To assess how major climatic changes might affect model predictions, rainfall recharge sensitivity analyses were performed using the NARCliM data for the Hunter Region (NSW Office of Environment and Heritage, 2014). There are 12 individual NARCLiM simulations that predict changes to average annual rainfall from assumed climate trends. This information allows a more comprehensive comparison of simulations at locations within NSW. This Project study has examined the three scenarios for the median, highest and lowest predicted changes to average annual rainfall for the near future (2020 to 2039) and one scenario simulating median predicted changes to average annual rainfall in the far future (2060 to 2079).

Model sensitivity to GHB conditions was also assessed. This scenario acts to confirm that prescribed boundary conditions are not influencing model water balances and in turn predicted impacts to groundwater.

The final analysis involved simulating a series of low permeability dykes mapped at site scale over the mine footprint (see **Figure 27**). This was done to assess the influence these low permeability features could have on simulated drawdown extents.

The uncertainty in the model predictions in terms of groundwater level depressurisation extent, alluvial groundwater take and river leakage is discussed in the following sections.

7.1 SENSITIVITY OF GROUNDWATER DEPRESSURISATION EXTENT

The variation in aquifer parameters also results in variation in the predicted extent of depressurisation. **Figure 97**, **Figure 98** and **Figure 99** show the extent of 2 m predicted depressurisation for each modelled sensitivity run in Layers 1, 5 and 15, respectively.

These figures highlight that drawdown is close to the Basecase for most of the scenarios with only the changes to vertical and horizontal hydraulic conductivity (that resulted in uncalibrated models) presenting an improbable extreme extent of drawdown.

Figure 97 shows the sensitivity of the predicted 2 m maximum groundwater drawdown extent for the Project only in Layer 1, representing alluvium, regolith and basalt. The results show that predicted groundwater drawdown is largely contained within the alluvium surrounding Saddlers Creek and Saltwater Creek. Drawdown was predicted to occur in the regolith of the Maxwell Infrastructure area in two of the NARCliM Near Future recharge sensitivity scenarios; the median and highest predicted rainfall changes. The sensitivity scenario implementing the greatest predicted change to rainfall recharge led to the peak drawdown extent in this area. An increase in drain conductance had no visible influence on the predicted extent of drawdown in Layer 1.

Predicted depressurisation of model Layer 5 for each sensitivity scenario is presented in **Figure 98**. The results are more varied than those depicted for Layer 1, however predicted drawdown is generally similar to the Basecase scenario. The greatest drawdown extent of Layer 5 was found to occur in the NARCliM highest and lowest predicted change to average annual rainfall sensitivity scenario, as well as the scenario that enhanced vertical hydraulic conductivity (Kz) by one order of magnitude. The lowest and highest NARCliM changes to rainfall recharge have a similar extent to the Basecase drawdown over the mine footprint; however, these scenarios predict greater drawdown extent to occur on the regolith that separates Saddlers and Saltwater Creeks. The influence of low permeability dykes and boundary conditions on model predictions was also tested with a reduction in the GHB conductance. The dyke, drain conductance and GHB scenarios resulted in a reduction in the predicted extent of depressurisation, indicating the Basecase model design is conservative.

The predicted drawdown extents for model Layer 15 are presented on **Figure 99**. The results show that the sensitivity runs are close to the Basecase. The greatest differences from the Basecase predicted drawdown extents were simulated from the increased and decreased Kz scenarios.

7.2 SENSITIVITY OF ALLUVIAL GROUNDWATER TAKE

Predicted alluvial take was calculated for each sensitivity scenario to assess whether adjusted parameters led to changes in predicted take compared to the Basecase model. These results are presented in **Table 7-1**. This table presents predicted take for the Highly Productive Hunter River alluvium and Less Productive alluvium, as well as Jerrys Management Zone alluvium (Saddlers Creek and Saltwater Creek alluvium). The results are presented as the proportional change in average predicted take compared to the Basecase model, meaning a factor of 1.00 indicates a match to the Basecase. A negative value indicates the predicted take in the sensitivity run is lower than predicted in the Basecase run and vice versa.

The greatest change in predicted take for both the highly and less productive Hunter River alluvium was predicted where horizontal hydraulic conductivity was changed by an order of magnitude. It should be noted the Basecase model horizontal hydraulic conductivity for alluvium is conservatively high and the sensitivity range includes parameters outside of expected field ranges (**Section 4.4.3**). Despite this, the predicted change in interception of alluvium along Saddlers Creek and Saltwater Creek declined with changes in hydraulic conductivity. This indicates the predicted impacts along Saddlers Creek and Saltwater Creek are conservative.

The influence of changes in recharge were tested using the NARCliM ranges for the Hunter Region. As shown in **Table 7-1** increases and decreases in recharge resulted in a general decline in the predicted interception of alluvial groundwater. The scenario simulating reduced rainfall recharge using the NARCliM estimate of lowest predicted change to average annual rainfall showed reductions in predicted take from the Hunter River alluvium zones. This is likely due to the reduced rainfall causing a gradient reversal between the alluvium and groundwater underlying the Hunter River alluvium, causing groundwater to instead feed into the unconsolidated sediment. The scenario with the highest predicted change in recharge resulted in a slight rise in predicted take along the Hunter River alluvium. This likely relates to increased water availability (i.e. increased saturated extent) in localized areas.

The scenario implementing decreased GHB conductance led to the lowest estimate of alluvial take from Saltwater Creek. The inclusion of low permeability dykes also resulted in a reduction in the predicted interception of alluvial groundwater in all alluvial zones.

Table 7-1 Sensitivity scenarios – predicted alluvial take due to Project

Sensitivity Run	Hunter Alluvium (Hunter Regulated - Zone 1B)	Hunter Alluvium (Hunter Unregulated - Upper Glennies)	Jerrys Water Source - Jerrys Management Zone (Saddlers Creek and Saltwater Creek)
Basecase	1.00	1.00	1.00
Decreased GHB conductance	-0.96	-0.77	-0.88
NARCliM Far Future - median predicted change to average annual rainfall	-0.69	-0.90	-0.80
NARCliM Near Future - median predicted change to average annual rainfall	-0.55	-0.60	-0.77
NARCliM Near Future - lowest predicted change to average annual rainfall	-1.19	-1.52	-0.83
NARCliM Near Future - highest predicted change to average annual rainfall	-0.01	0.17	-0.72
Kx increased by one order of magnitude	4.74	2.05	-0.39
Kx decreased by one order of magnitude	-0.96	-0.95	-0.87
Kz increased by one order of magnitude	-0.63	-0.70	-0.81
Kz decreased by one order of magnitude	-0.45	-0.57	-0.75
Ss increased by one order of magnitude	-0.76	-0.75	-0.80
Ss decreased by one order of magnitude	-0.66	-0.67	-0.77
Simulation of low permeability dykes	-0.56	-0.58	-0.79
Increased drain conductance	-0.31	-2.05	-0.62

7.3 SENSITIVITY OF RIVER LEAKAGE

Predicted river leakage for each sensitivity scenario was conducted to assess whether adjusted model inputs/parameters led to changes compared to the Basecase model. These results are presented in **Table 7-2** for the Hunter River and Saddlers Creek. The results are presented as the potential change in leakage from the river/creek to the underlying alluvium in ML per year. A negative number indicates baseflow contributions (upward seepage from alluvium to the river/creek).

Table 7-2 shows that the predicted river leakage is low to negligible for most scenarios, despite large changes in hydraulic and storage parameters, boundary conditions, drain conductance and inclusion of dykes. The greatest change in river leakage occurred for the NARCliM near future scenario with highest predicted rise in rainfall recharge resulting in minor baseflow contributions.

Table 7-2 Sensitivity scenarios – predicted river leakage due to Project

Sensitivity Run	Hunter River Leakage (ML/year)	Saddlers Creek Leakage (ML/year)
Basecase	0.55	0.00
Decreased GHB conductance	0.12	0.00
NARCliM Far Future - median predicted change to average annual rainfall	0.14	0.00
NARCliM Near Future - median predicted change to average annual rainfall	-0.05 (baseflow)	0.00
NARCliM Near Future - lowest predicted change to average annual rainfall	1.21	0.00
NARCliM Near Future - highest predicted change to average annual rainfall	-9.35 (baseflow)	-0.62 (baseflow)
Kx increased by one order of magnitude	1.64	0.02
Kx decreased by one order of magnitude	0.04	0.00
Kz increased by one order of magnitude	0.12	0.00
Kz decreased by one order of magnitude	0.28	0.00
Ss increased by one order of magnitude	0.56	0.00
Ss decreased by one order of magnitude	0.03	0.00
Simulation of low permeability dykes	0.13	0.00
Increased drain conductance	0.16	0.00

8 IMPACT CONDITIONS

8.1 AQUIFER INTERFERENCE POLICY

8.1.1 WATER TAKE

Table 8-1 compares the groundwater impact predictions for the Project against the requirements stipulated under Section 2 of the NSW AIP (NOW, 2012) and as included within the AIP Assessment Framework.

There are two levels of minimal impact considerations specified in the AIP. If the predicted impacts are less than the Level 1 minimal impact considerations, then these impacts will be considered as acceptable. Where the predicted impacts are greater than the Level 1 minimal impact considerations then the AIP requires additional studies to fully assess these predicted impacts. If the additional studies show that the predicted impacts do not prevent the long-term viability of the relevant water-dependent asset, then the impacts will be considered to be acceptable.

The modelling indicates potential for drawdown at four private bores and five mine-owned bores to exceed the Level 1 minimal impact criteria of 2 m. As discussed in **Section 6.5**, the proponent will implement 'make-good' provisions for any bores that experience greater than 2 m drawdown and an associated impact on yield due to the Project.

Table 8-1 AIP Requirements

AIP Requirement		Proponent Response
1	Described the water source (s) the activity will take water from?	Based on the AIP, the groundwater system impacted by the Project can be separated into two systems, as follows: • porous and/or fractured consolidated sedimentary rock of the Permian coal measures; and • groundwater within alluvium associated with the Hunter River and Saddlers Creek alluvium.
2	Predict the total amount of water that will be taken from each connected groundwater or surface water source on an annual basis as a result of the activity?	Refer to Section 6.4 for licensing requirements.
3	Predicted the total amount of water that will be taken from each connected groundwater or surface water source after the closure of the activity?	Refer to Section 6.4 for licensing requirements (including post-mining).
4	Made these predictions in accordance with Section 3.2.3 of the AIP? (page 27)	Based on 3D numerical modelling.
5	Described how and in what proportions this take will be assigned to the affected aquifers and connected surface water sources?	Refer to Section 6.4 for licensing requirements (including post-mining).
6	Described how any licence exemptions might apply?	Not applicable.
7	Described the characteristics of the water requirements?	No additional external water supply is required for the Project (WRM, 2019).

AIP Requirement		Proponent Response
8	Determined if there are sufficient water entitlements and water allocations that are able to be obtained for the activity?	Discussion of water access licence availability is provided in Attachment 8 of the EIS.
9	Considered the rules of the relevant water sharing plan and if it can meet these rules?	Discussion of the relevant water sharing plan rules is provided in Attachment 8 of the EIS.
10	Determined how it will obtain the required water?	Discussion is provided in Attachment 8 of the EIS.
11	Considered the effect that activation of existing entitlement may have on future available water determinations?	Discussion of the Project water licensing requirements relative to existing entitlements is provided in Attachment 8 of the EIS.
12	Considered actions required both during and post-closure to minimise the risk of inflows to a mine void as a result of flooding?	Refer to Surface Water Assessment for further information.
13	Developed a strategy to account for any water taken beyond the life of the operation of the Project?	Relevant entitlements under the Project water access licences would be retired at the completion of the Project to account for groundwater take during the recovery of the groundwater system post mining.
	Will uncertainty in the predicted inflows have a significant impact on the environment or other authorised water users? Items 14-16 must be addressed if so.	
14	Considered any potential for causing or enhancing hydraulic connections, and quantified the risk?	Numerical groundwater modelling conducted using a conservative 'stacked drain' approach to replicate potential enhanced hydraulic connections to the active mine area.
15	Quantified any other uncertainties in the groundwater or surface water impact modelling conducted for the activity?	A sensitivity and uncertainty analysis has been completed to identify parameters that demonstrate most substantial changes in the predictions.
16	Considered strategies for monitoring actual and reassessing any predicted take of water throughout the life of the Project, and how these requirements will be accounted for?	Ongoing monitoring and verification of modelling recommended.
SECTION 3.2.3 OF AIP		
	For State Significant Development or mining or coal seam gas production, is the estimate based on a complex modelling platform that is:	
	Calibrated against suitable baseline data, and in the case of a reliable water source, over at least two years?	Steady state and transient calibration conducted with 18 years of data, as reported in **Section 5.3**.
	Consistent with the Australian Modelling Guidelines?	Conducted in accordance with guidelines as outlined in **Section 5** and external peer review conducted as documented in main EIS report (Attachment 6).
	Independently reviewed, robust and reliable, and deemed fit-for-purpose	Progressive external peer review conducted by Kalf and Associates (Dr Frans Kalf) – report included in Attachment 6 of the EIS.
1	Establishment of baseline groundwater conditions?	Baseline conditions established based on historical data for the site and surrounding region collected from 1982. Baseline conditions presented in **Section 4** and model's performance at matching baseline conditions presented in **Section 5**.
2	A strategy for complying with any water access rules?	Discussion of the relevant water sharing plan rules is provided in Attachment 8 of the EIS.

AIP Requirement		Proponent Response
3	Potential water level, quality or pressure drawdown impacts on nearby basic landholder rights water users?	One private landholder bore and five mine-owned bores intersecting the Permian coal measures predicted to have cumulative drawdown of over 2 m and a proportion of drawdown contributed by the Project. Depressurisation is also predicted at two private bores that are predicted to be dry under existing conditions.
4	Potential water level, quality or pressure drawdown impacts on nearby licensed water users in connected groundwater and surface water sources?	One private landholder bore and five mine-owned bores intersecting the Permian coal measures predicted to have cumulative drawdown of over 2 m and a proportion of drawdown contributed by the Project. Depressurisation is also predicted at two private bores that are predicted to be dry under existing conditions.
5	Potential water level, quality or pressure drawdown impacts on groundwater dependent ecosystems?	Drawdown predicted within Saddlers Creek alluvium where potential GDE (Swamp Oak) identified. Further details are provided in the ecology report (Hunter Eco 2019).
6	Potential for increased saline or contaminated water inflows to aquifers and highly connected river systems?	As discussed in **Section 6.9** it is unlikely that the Project will result in an adverse change in groundwater quality. Within Maxwell Infrastructure the final voids are predicted to act as groundwater sinks, drawing groundwater towards the historical pit area.
7	Potential to cause or enhance hydraulic connection between aquifers?	During active mining the height of connective cracking was predicted to reach surface or near surface in areas immediately above the Maxwell Underground. However, the connective cracking remains within the extent of mapped Permian coal measures and regolith (weathered coal measures) with no connective cracking expected to interact with other aquifers (i.e. alluvium).
8	Potential for river bank instability, or high wall instability or failure to occur?	Refer to Surface Water Assessment.

8.1.2 MINIMAL IMPACT CONSIDERATIONS

This section provides discussion of potential impacts of the Project (**Section 6**) in terms of the AIP minimal impact considerations for the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone) (**Table 8-2**).

Based on the findings of the groundwater modelling and assessment, the Project meets the Level 1 minimal impact consideration classification of the AIP for ‘highly productive’ groundwater associated with the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone).

Based on available data, the unconsolidated alluvial sediments associated with Saddlers Creek within the Jerrys Management Zone of the Jerrys Water Source are classified as a 'less productive' groundwater source (**Section 2.3.3**). Notwithstanding, the alluvial sediments associated with Saddlers Creek are conservatively assessed against the AIP 'highly productive' in **Table 8-3**.

The Permian porous rock groundwater sources within the Sydney Basin – North Coast Groundwater Source are also classified as 'less productive'.

These water sources are assessed against the AIP minimal impact considerations in **Table 8-2** to **Table 8-4**.

Table 8-2 Summary of Aquifer Interference Policy Assessment – Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone)

Aquifer	Alluvial Water Source: Hunter Regulated River Water Source (Upstream Glennies Creek Management Zone)
Category	Highly Productive Groundwater Source
Level 1 Minimal Impact Consideration	Assessment
Water Table 1. Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 m water table decline cumulatively at any water supply work.	The nearest high priority groundwater dependent ecosystem listed in the *Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009* to the Project area is Wappinguy Spring, near Merriwa, more than 50 kilometres (km) to the north-west. As such, it would not be affected by drawdown from the Project. There are no listed high priority culturally significant sites in the *Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009*. No water supply work within the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone) would incur more than 2 m drawdown due to the Project. **The Project meets the Level 1 minimal impact consideration classification.**
Water Pressure 1. A cumulative pressure head decline of not more than 40% of the "post-water sharing plan" pressure head above the base of the water source to a maximum of a 2 m decline, at any water supply work.	This criterion is not applicable as only unconfined conditions are present in the alluvial water source, therefore, only the above watertable consideration is relevant. **The Project meets the Level 1 minimal impact consideration classification.**

Aquifer	Alluvial Water Source: Hunter Regulated River Water Source (Upstream Glennies Creek Management Zone)		
Category	Highly Productive Groundwater Source		
Level 1 Minimal Impact Consideration		Assessment	
Water Quality 1. (a) Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity. 1. (b) No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity. 1. (c) No mining activity to be below the natural ground surface within 200m laterally from the top of high bank or 100m vertically beneath (or the three-dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source that is defined as a "reliable water supply". 1. (d) Not more than 10% cumulatively of the three-dimensional extent of the alluvial material in this water source to be excavated by mining activities beyond 200m laterally from the top of high bank and 100m vertically beneath a highly connected surface water source that is defined as a "reliable water supply".		There would be no change to beneficial use categories of the alluvial water source as a result of the Project or any predicted increase in the salinity of the Hunter River. No mining activity within the specified proximities to the alluvial water source is proposed. No excavation of the highly productive alluvial sediments associated with the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone) is proposed. **Level 1 minimal impact consideration classification.**	

Table 8-3 Summary of Aquifer Interference Policy Assessment – Alluvial Water Source: Jerrys Water Source (Jerrys Management Zone)

Aquifer	Alluvial Water Source: Jerrys Water Source (Jerrys Management Zone)		
Category	Less Productive Groundwater Source (conservatively assessed against Highly Productive criteria)		
Level 1 Minimal Impact Consideration		Assessment	
Water Table 1. Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 m water table decline cumulatively at any water supply work.		The nearest high priority groundwater dependent ecosystem listed in the *Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009* to the Project area is Wappinguy Spring, near Merriwa, more than 50 km to the north-west. There are no listed high priority culturally significant sites in the *Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009*. No water supply within the Jerrys Water Source (Jerrys Management Zone) would incur drawdown in excess of the criteria. There are no alluvial water sources associated with the Muswellbrook Water Source mapped in the vicinity of the Project. **The Project meets the Level 1 minimal impact consideration classification.**	

Aquifer	Alluvial Water Source: Jerrys Water Source (Jerrys Management Zone)
Category	Less Productive Groundwater Source (conservatively assessed against Highly Productive criteria)

Level 1 Minimal Impact Consideration	Assessment
Water Pressure 1. A cumulative pressure head decline of not more than 40% of the "post-water sharing plan" pressure head above the base of the water source to a maximum of a 2 m decline, at any water supply work.	Not applicable as only unconfined conditions in the alluvial water source. Therefore, only the above water table consideration is relevant. **Level 1 minimal impact consideration classification.**
Water Quality 1. (a) Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity. 1. (b) No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity. 1. (c) No mining activity to be below the natural ground surface within 200m laterally from the top of high bank or 100m vertically beneath (or the three-dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source that is defined as a "reliable water supply". 1. (d) Not more than 10% cumulatively of the three-dimensional extent of the alluvial material in this water source to be excavated by mining activities beyond 200m laterally from the top of high bank and 100m vertically beneath a highly connected surface water source that is defined as a "reliable water supply".	There would be no change to beneficial use categories of the alluvial water source or any predicted increase in the salinity of Saddlers Creek as a result of the Project. Malabar has surveyed the top of the high bank of Saddlers Creek, which indicates it is located at a minimum distance of 210 m from the Maxwell Underground. Underground mining in the vicinity of Saddlers Creek would be at depths of cover greater than 125 m. Broad-scale regional mapping indicates there are some unconsolidated sediments associated with Saddlers Creek within the disturbance footprint of the mine entry area. However, site specific alluvial investigations, including drilling transects, indicates there is no alluvium within the footprint of the mine entry area. Updated alluvial mapping reflecting the site-specific investigations has been prepared by Dr Chris Gippel and is presented in the Geomorphology Assessment by Fluvial Systems (2019). Accordingly, no excavation of the highly productive alluvial sediments associated with the Jerrys Water Source (Jerrys Management Zone) is proposed. There are no alluvial water sources associated with the Muswellbrook Water Source mapped in the vicinity of the Project. **The Project meets the Level 1 minimal impact consideration classification.**

Table 8-4 Summary of Aquifer Interference Policy Assessment – Permian Porous Rock Groundwater Sources: Sydney Basin – North Coast Groundwater Source

Aquifer	Permian Porous Rock Groundwater Sources: Sydney Basin – North Coast Groundwater Source
Category	Less Productive Groundwater Source

Level 1 Minimal Impact Consideration	Assessment
Water Table 1. Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 m water table decline cumulatively at any water supply work. 2. If more than 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan then appropriate studies(5) will need to demonstrate to the Minister's satisfaction that the variation will not prevent the long-term viability of the dependent ecosystem or significant site. If more than 2m decline cumulatively at any water supply work then make good provisions should apply.	There are no high priority groundwater dependent ecosystems listed in the *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016* within 20 km of the Project. The nearest high priority groundwater dependent ecosystem listed in the Plan to the Project area is Parnell Spring in the Wollemi National Park, located approximately 27 km to the south-southeast. There are no listed high priority culturally significant sites in the *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016.* Depressurisation of the Permian coal measures of greater than 2 m due to the Project and approved mining at Mt Arthur Mine was predicted at one privately-owned bore and five mine-owned bores. Depressurisation is also predicted to extend beneath two private bores that are understood to be dry under existing conditions. A Groundwater Management Plan would be developed and implemented for the Project, and would define a groundwater monitoring strategy, groundwater level triggers and a trigger action response plan. **The Project meets the Level 2 minimal impact consideration classification.**
Water Pressure 1. A cumulative pressure head decline of not more than a 2m decline, at any water supply work.	Depressurisation of the Permian coal measures of greater than 2 m due to the Project and approved mining at Mt Arthur Mine was predicted at one privately-owned bore and five mine-owned bores. Depressurisation is also predicted to extend beneath two private bores that are understood to be dry under existing conditions. A Groundwater Management Plan would be developed and implemented for the Project, and would define a groundwater monitoring strategy, groundwater level triggers and a trigger action response plan. **The Project meets the Level 2 minimal impact consideration classification.**

Aquifer	Permian Porous Rock Groundwater Sources: Sydney Basin – North Coast Groundwater Source
Category	Less Productive Groundwater Source
Level 1 Minimal Impact Consideration	**Assessment**
Water Quality 1. Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity.	There would be no change to beneficial use categories of the Permian hard rock groundwater sources as a result of the Project. **The Project meets the Level 1 minimal impact consideration classification.**

8.2 EPBC ACT SIGNIFICANT IMPACT ON WATER RESOURCES GUIDELINES

In June 2013, the Federal Government enacted changes to the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act), to provide that 'water resources' are a matter of national environmental significance in relation to coal seam gas and large coal mining development. This change is referred to as the 'water trigger'. In December 2013, the Federal Department of the Environment released guidelines for proponents of coal seam gas and large coal mining projects to assess the potential for significant impacts on water resources.

The Project was deemed a 'controlled action' on 9 November 2018 (including water resources). The elements of the Project which require EPBC Act approval exclude activities at the Maxwell Infrastructure that are authorized by existing approvals (including the Maxwell Infrastructure Voids).

Therefore, consideration of potential impacts on matters of national environmental significance is focused on the incremental impacts of the Maxwell Underground.

8.2.1 POTENTIAL IMPACTS ON HYDROLOGICAL CHARACTERISTICS

The Significant Impact Guidelines for Water Resources provide the following guidance on potential impacts of an action on hydrological characteristics:

A significant impact on the hydrological characteristics of a water resource may occur where there are, as a result of the action:

a) changes in the water quantity, including the timing of variations in water quantity

b) changes in the integrity of hydrological or hydrogeological connections, including substantial structural damage (e.g. large scale subsidence)

c) changes in the area or extent of a water resource where these changes are of sufficient scale or intensity as to significantly reduce the current or future utility of the water resource for third party users, including environmental and other public benefit outcomes.

Groundwater modelling completed for the Project indicates:

- minimal drawdown (less than 2 m) in the "highly productive" aquifer of the shallow alluvial groundwater system along Hunter River;
- localized drawdown of up to 8 m in the "less productive" shallow alluvial groundwater system along Saddlers Creek and Saltwater Creek;
- negligible impact on access to water in known registered production bores in highly productive aquifers; and
- negligible changes to baseflow in the Hunter River and Saddlers Creek.

As outlined in **Section 4.6.2**, there are no 'high priority' GDEs listed in water sharing plans in and surrounding the Project area. Therefore there is no known risk of the Project to 'high priority' GDEs.

It is unlikely that the Project would result directly or indirectly in a substantial change in the hydrology of groundwater resources.

8.2.2 POTENTIAL IMPACTS ON WATER QUALITY

The Significant Impact Guidelines for Water Resources provide the following guidance on potential impacts of an action on water quality:

> *A significant impact on a water resource may occur where, as a result of the action:*
>
> *a) there is a risk that the ability to achieve relevant local or regional water quality objectives would be materially compromised, and as a result the action:*
>
> > *i. creates risks to human or animal health or to the condition of the natural environment as a result of the change in water quality*
> >
> > *ii. substantially reduces the amount of water available for human consumptive uses or for other uses, including environmental uses, which are dependent on water of the appropriate quality*
> >
> > *iii. causes persistent organic chemicals, heavy metals, salt or other potentially harmful substances to accumulate in the environment*
> >
> > *iv. seriously affects the habitat or lifecycle of a native species dependent on a water resource, or*
> >
> > *v. causes the establishment of an invasive species (or the spread of an existing invasive species) that is harmful*
> >
> > *vi. to the ecosystem function of the water resource, or*

b) there is a significant worsening of local water quality (where current local water quality is superior to local or regional water quality objectives), or

c) high quality water is released into an ecosystem which is adapted to a lower quality of water.

It is considered unlikely that the Project would have a significant impact on water quality within the surrounding stratigraphy (**Section 6.9**).

8.2.3 CUMULATIVE IMPACTS

The Significant Impact Guidelines for Water Resources require the action to be:

considered with other developments, whether past, present or reasonably foreseeable developments.

Cumulative groundwater depressurisation contours showing the magnitude and water table pattern caused by coincident mining at the Mt Arthur Mine and the Project are presented in **Section 6.1.2.**

The results show that there is no predicted cumulative drawdown over 2 m in the Hunter River alluvium. Drawdown of up to 8 m is predicted along Saddlers Creek, which is largely due to the Project, with no additional predicted impact from future approved operations at Mt Arthur Mine. The results show that there is also no connection in groundwater depressurisation within the shallow Permian coal measures (Layer 3 to Layer 5) between the Project and mining at Mt Arthur Mine. There is some interaction in groundwater depressurisation for the deeper coal seams that are mined at the two mine areas (i.e. from Layer 11 to Layer 15). However, the extent of depressurisation in the coal seams is limited to the north and east by the outcrop of the coal seams.

8.2.4 CONSIDERATION OF POTENTIAL FOR SIGNIFICANT IMPACT

Based on the assessment presented above, there are no predicted significant impacts on matters of national environmental significance in relation to water.

9 PROPOSED GROUNDWATER MONITORING PROGRAM

9.1 GROUNDWATER MONITORING PROGRAM

Groundwater monitoring will be conducted in accordance with a Groundwater Monitoring Plan (GWMP) that will be prepared in consultation with DoI Water. The GWMP will include full details on how and when groundwater will be monitored across the Project Area and surrounds.

9.1.1 GROUNDWATER MONITORING NETWORK AND FREQUENCY

Table 9-1 summarises the proposed monitoring network and program, and **Figure 100** shows the bore locations.

Table 9-1 Proposed Groundwater Monitoring Network

Site	Bore Name	Type	Ground Level (mAHD)	Screen Interval (mBGL)	Geology	Water Level	Field Water Quality	Full Water Quality
MU	GW03	P	-	~ 12 - 15	Saltwater Creek alluvium	Daily (logger)	Quarterly	Annual
MU	GW04	P	-	~ 12 - 15	Unnamed Creek regolith	Daily (logger)	Quarterly	Annual
MU	GW05	P	-	~ 12 - 15	Saddlers Creek alluvium	Daily (logger)	Quarterly	Annual
MU	GW06S	P	-	~35	JPS – shallow overburden	Daily (logger)	Quarterly	Annual
MU	GW06D	P	-	~100	JPS	Daily (logger)	Quarterly	Annual
MU	MB1 -Alluvial	MB	81.01	8 – 11	Hunter River alluvium	Daily (logger)	Quarterly	Annual
MU	MB4-Alluvial	MB	81.43	10 - 18	Hunter River alluvium	Daily (logger)	Quarterly	Annual
MU	MW3	MB	81.641	2.9 – 6.9	Hunter River alluvium	Daily (logger)	Quarterly	Annual
MU	MB2-Alluvial	MB	115.34	5 - 7	Saddlers Creek alluvium	Daily (logger)	Quarterly	Annual
MU	MW2	MB	119.36	4 – 9.5	Saddlers Creek alluvium	Daily (logger)	Quarterly	Annual
MU	MB3-Alluvial	MB	132.72	8.5-14.5	Saddlers Creek alluvium (upslope)	Daily (logger)	Quarterly	Annual
MU	MW1	MB	136.53	6 – 9	Saddlers Creek alluvium (upslope)	Daily (logger)	Quarterly	Annual
MU	MB2-Regolith	MB	115.43	20 - 29	Regolith	Daily (logger)	Quarterly	Annual
MU	MB3-Regolith	MB	137.34	27 - 30	Regolith	Daily (logger)	Quarterly	Annual
MU	DD1041 - Deep	MB	187.32	387.3	JPS	Quarterly	Quarterly	Annual
MU	DD1041 - Shallow	MB	187.32	-	JPS	Quarterly	Quarterly	Annual
MU	DD1057	MB	146.93	164-188	JPS – Arrowfield overburden	Quarterly	Quarterly	Annual
MU	DD1004	MB	217.38	105.7	JPS – Blakefield overburden	Quarterly	Quarterly	Annual
MU	DD1005	MB	225.02	138.6	JPS – Blakefield overburden	Quarterly	Quarterly	Annual
MU	DD1014	MB	183.4	90.5	JPS – Blakefield overburden	Quarterly	Quarterly	Annual
MU	DD1015	MB	212.65	162.5	JPS – Blakefield overburden	Quarterly	Quarterly	Annual

Site	Bore Name	Type	Ground Level (mAHD)	Screen Interval (mBGL)	Geology	Water Level	Field Water Quality	Full Water Quality
MU	DD1016	MB	201.15	126.4	JPS – Blakefield overburden	Quarterly	Quarterly	Annual
MU	DD1025	MB	169.81	44.62	JPS – Blakefield overburden	Quarterly	Quarterly	Annual
MU	MB4-Coal	MB	81.34	42 - 47	JPS - Coal	Quarterly	Quarterly	Annual
MU	DD1027	MB	235.82	252.8	JPS – Edderton Seam	Quarterly	Quarterly	Annual
MU	DD1030	MB	160.08	282.5	JPS – Edderton Seam	Quarterly	Quarterly	Annual
MU	DD1032	MB	140.25	276.5	JPS – Piercefield overburden	Quarterly	Quarterly	Annual
MU	MB1_ Redbank	MB	80.89	51 - 57	JPS – Redbank Creek Seam	Quarterly	Quarterly	Annual
MU	MB1 - Whybrow	MB	80.84	25-28	JPS - Whybrow Seam	Quarterly	Quarterly	Annual
MU	DD1052	MB	183.12	105-127	JPS – Whynot Seam overburden	Quarterly	Quarterly	Annual
MU	DD1043	MB	173.78	182-203	JPS – Woodlands Hill overburden	Quarterly	Quarterly	Annual
MU	RD1189 (SD1_DD001)	VWP	208.63	78.9	Woodlands Hill Seam	Daily (logger)	N/A	N/A
				145.5	ZZBF Seam			
				186.2	Warkworth Seam			
				230	Mt Arthur Seam			
				255.5	Piercefield Seam			
				315	Bayswater Seam			
				322	Wynn Seam			
MU	RD1192 (RBR2)	VWP	177.06	61.2	Wambo Seam	Daily (logger)	N/A	N/A
				80	Redbank Seam			
				148.5	Blakefield Seam			
MU	BLK6R12 (RD1220)	VWP	186.25	25	Whybrow Seam	Daily (logger)	N/A	N/A
				40.5	Redbank Seam			
				86.5	Whynot Seam			
				113.7	Blakefield Seam			
MU	VWP1 (RD1221) (RDW006A)	VWP	80.96	21	Interburden	Daily (logger)	N/A	N/A
				40	Interburden			
				73	Interburden			
				87	Whybrow Seam			
				109.2	Whynot Seam			
				138	Blakefield Seam			
MU	RBD1 (VWP) (DD1170)	VWP	169.55	24.65	Whybrow Seam	Daily (logger)	N/A	N/A
				33.55	Redbank Seam			
				79.5	Whynot Seam			
				103.3	Blakefield Seam			
MU	WND16 (VWP) (DD1188)	VWP	130.58	33.75	Wambo Seam	Daily (logger)	N/A	N/A
				59.25	Whynot Seam			
				90.15	Blakefield Seam			
				110.5	Blakefield Seam			
MU	WND26 (VWP) (DD1187)	VWP	163.71	77.3	Whybrow Seam	Daily (logger)	N/A	N/A
				84.6	Redbank Seam			
				123.45	Wambo Seam			
				144.25	Whynot Seam			
MI	W1102	MB	186.70	23	Maitland Group			
MI	GW01D	MB	213.22	12-15	Base regolith	Daily (logger)	Quarterly	Annual
MI	GW01S	MB	213.17	29 - 32	Greta Coal Measures - Coal	Daily (logger)	Quarterly	Annual

Site	Bore Name	Type	Ground Level (mAHD)	Screen Interval (mBGL)	Geology	Water Level	Field Water Quality	Full Water Quality
MI	GW02D	MB	202.98	8-14	Base regolith	Daily (logger)	Quarterly	Annual
MI	GW02S	MB	202.98	69 - 72	Greta Coal Measures - Coal	Daily (logger)	Quarterly	Annual

Note: *Coordinates in GDA94 Zone 56*
MI – Maxwell Infrastructure
MB – Monitoring Bore
OH – Open Hole (exploration drill hole)
JPS – Jerrys Plains Subgroup
mbgl = metres below ground level
MU – Maxwell Underground
VWP – Vibrating Wire Piezometer
P – Proposed bore

9.1.2 GROUNDWATER LEVEL MONITORING AND REPORTING

Groundwater monitoring will be undertaken in accordance with the GWMP. Manual groundwater level monitoring will be conducted for all monitoring bores, with dataloggers installed within selected bores to gather temporal variations in water levels. Data will also be downloaded from the existing VWPs, pressure readings recorded and converted to groundwater elevations within a central database.

Ongoing monitoring will enable natural groundwater level fluctuations (such as responses to rainfall) to be distinguished from potential groundwater level impacts due to depressurisation resulting from Project. Ongoing monitoring of groundwater levels will also be used to assess the extent and rate of depressurisation against model predictions.

Yearly reporting of the water level results from the monitoring network will be included in the Annual Review. The reporting will include comparison to climate trends and surface water monitoring results to identify changes in the surface water and groundwater interactions. The Annual Review will also identify if any additional monitoring sites are required, or if optimisation of the existing monitoring sites should be undertaken.

9.1.3 GROUNDWATER QUALITY MONITORING AND REPORTING

Groundwater quality sampling will be conducted in order to detect any changes in groundwater quality during and post mining. Baseline data has been collected from the existing bores, as presented in **Section 4.4.4**. Additional data will be collected prior to commencement of mining, particularly for bores recently installed as part of the Project (i.e. GW01S/D, GW02S/D, MW1, MW2 and MW3). Sampling will include collection of field analytes of pH and EC on a quarterly basis, as well as annual sampling for laboratory analysis of a full suite of analytes to determine any changes in beneficial groundwater use (i.e. livestock drinking water). The full suite will include:

- physico-chemical indicators – pH, electrical conductivity, total dissolved solids;
- major ions – calcium, fluoride, magnesium, potassium, sodium, chloride, sulphate;
- total alkalinity as $CaCO_3$, HCO_3, CO_3; and
- dissolved and total metals and metalloids – aluminium, arsenic, barium, boron, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, strontium, silver, vanadium and zinc.

Similar to the water level monitoring, yearly reporting of the water quality results from the monitoring network will be included in the Annual Review. The Annual Review will consider if any additional monitoring sites are required, or if optimisation of the existing monitoring sites, frequency of sampling and analytical suite should be undertaken.

9.1.4 GROUNDWATER BALANCE

Monitoring of mine water seepage into the Maxwell Underground area is to be undertaken, including recording of seepage volumes on a monthly basis, as well as measuring field water quality on a quarterly basis. The objective of the monitoring is to provide an early indication of any mixing of shallow alluvial groundwaters within the Permian strata. Water quality analysis should be similar as for the groundwater monitoring bores. The seepage monitoring program should include:

- measurement of water pumped from the mining areas using flow meters or other suitable gauging apparatus;
- monitoring quality of water pumped from the mining areas (full water quality suite);
- correlation of rainfall records (and catchments) with mining area seepage records so groundwater and surface water can be separated; and
- monitoring of coal moisture content.

In addition, the mine water balance will be reported annually, documenting volumes of water and tailings material discharged to the Maxwell Infrastructure area. Pit lake (North Void and South Void) and tailings fill (East Void) elevations will also be recorded on a quarterly basis.

9.1.5 TRIGGER LEVELS

Within the Water Management Plan, proposed triggers for water level and water quality for site compliance monitoring network will be documented. This will include establishment of triggers for EC, pH and sulphate.

The observed groundwater levels will also be reviewed against the model predictions on an annual basis. Judgement of an experienced hydrogeologist will determine when water levels deviate significantly from that predicted by the groundwater model, and determine the reason for this deviation. The review would consider the impact of mining, and other factors that could result in declining water levels including climatic conditions, rainfall recharge and pumping from private (and mine owned) bores.

9.2 PROPOSED GEOLOGICAL INVESTIGATION PROGRAM

The groundwater assessment utilizes geological information to understand and characterize the groundwater regime. Over the life of the project, additional geological data will be collected, including details on lithology, groundwater intersection and intersection of structures (i.e. faults and dykes). This information will be used to routinely update the site geological model. This information will be stored and made available as required for future groundwater investigations and/or updates to the model.

9.3 MODEL UPDATES

Every five years the validity of the model predictions would be assessed and if the data indicates significant deviation from the model predictions, an updated groundwater model would be constructed for simulation of mining.

10 MANAGEMENT AND MITIGATION MEASURES

Management of groundwater beneath and adjacent to the Project will involve the establishment of a robust surface water and groundwater level and quality monitoring program, for relevant groundwater and surface water sources. Operational reporting will occur at frequencies suited to the mine development and be part of the basis of annual reporting to key stakeholders.

Should monitoring indicate the changes in groundwater levels and quality, and surface waters are more extensive or significant than predicted, mitigation measures will be considered. Mitigation measures that may be considered following discussion with relevant government authorities include:

- injection of water into the depressurised aquifers;
- grouting and cut off measures;
- sourcing of additional water from other sources;
- obtaining additional water licence allocations; and
- treatment of mine water for reuse within the water management system.

If mitigation measures are not feasible, 'make good' measures with affected land owners would be carried out, potentially including:

- ensuring the bore owner has access to a similar quantity and quality of water for the water bore's authorised purpose for example by:
  - bore enhancement by deepening the bore or improving its pumping capacity;
  - constructing a new water bore; and
  - providing a supply of an equivalent amount of water of a suitable quality by piping it from an alternative source.
- carry out a plan to monitor the water bore, for example, by undertaking periodic bore assessments.

11 CONCLUSIONS

The Project involves the extraction of coal over a period of approximately 26 years from four seams within the Wittingham Coal Measures using the following underground mining methods:

- bord and pillar with pillar extraction in the Whynot Seam; and
- longwall extraction in the Woodlands Hill Seam, Arrowfield Seam and Bowfield Seam.

CHPP reject material would be emplaced preferentially within the existing East Void at the Maxwell Infrastructure.

This Groundwater Assessment presents the significant advances in the datasets gathered (including baseline data), hydrogeological conceptualisation details, numerical modelling complexity and uncertainty analyses that were previously completed in the Preliminary Groundwater Assessment in support of the Gateway Application.

This Groundwater Assessment has been guided by the requirements of the NSW Department of Planning and Environment SEARs for the Project (revised 17 January 2019), including the Commonwealth Department of the Environment and Energy assessment requirements (issued 20 November 2018), and the advice and recommendations from Department of Industry – Water (DoI Water) (dated 20 December 2018), the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) (dated 9 November 2018) and the Gateway Panel's *Report by the Mining & Petroleum Gateway Panel to accompany a Conditional Gateway Certificate for the Maxwell Coal Project* issued on 20 December 2018. The Groundwater Assessment was also prepared cognisant of other State Government agencies' comments included in Attachment 2 to the SEARs, as well as the Muswellbrook Shire Council (dated 29 August 2018).

In particular, this Groundwater Assessment focuses on the potential impacts of the Project and minimal harm criteria as prescribed in the NSW Aquifer Interference Policy.

The Project groundwater model developed for this Groundwater Assessment was specifically designed and based on the following:

- Data analysis and conceptualisation of the groundwater system, including delineation of hydrostratigraphic units and their hydraulic properties, and groundwater movement (recharge, storage and discharge) through the flow systems.
- Development of a regional-scale 3-dimensional numerical groundwater flow model. This was based on data analysis and development of an appropriate conceptual hydrogeological model.

- Steady state and transient calibration of the numerical groundwater flow model using up to 18 years of observed groundwater level data from a variety of sources including data collected specifically for the Project, data from DoI Water, data from the former Drayton Mine and neighbouring Mt Arthur Mine (via data sharing arrangements), and the Bore Census (ENRS, 2019).
- Transient prediction for the 26-year mine plan conducted with temporal resolution of the extraction schedule (including concurrent/cumulative effects of the Mt Arthur Mine open cut operations and rejects/tailings emplacement until 2026).
- Maximum cumulative predictions including the approved underground mine activities at Mt Arthur Mine.
- A 1,000-year post-mining recovery simulation period.
- Sensitivity and IESC-compliant uncertainty analysis of model projections with reference to key underlying assumptions.
- Proposed measures to avoid, mitigate and/or offset (if necessary) potential impacts on groundwater resources and recommendations for future groundwater monitoring to measure actual impacts on groundwater resources associated with the development.

A review of the available data, literature and conceptual hydrogeology associated with other studies from the area and surrounds was carried out as a basis for the numerical model development. This was supported by a review of currently available information on geology, rock mass hydraulic properties, and strata geometry for the area. Due consideration was given to the setup and creation of model boundaries and surface water-groundwater interaction processes, in particular Saddlers Creek, Hunter River alluvium and weathered rock beneath. Justification for all the modelling approaches that were used has been given within this report. Care was taken to ensure that hydraulic parameters within the model were maintained within realistic ranges that were based on actual measured data or published information for this region, in particular consideration of Mackie Environmental Research (2009). Application of recharge rates was based largely on estimates and model calibration, but the zones and values used within the model are consistent with the conceptual hydrogeology for the Project area and surrounds, and other local studies including those of the former Drayton Mine and Mt Arthur Mine.

Steady-state and transient calibration of the 3-dimensional numerical groundwater flow model were undertaken, yielding generally good performance, with statistics that are commonly used to judge calibration quality well within the indicative ranges of the Australian Groundwater Modelling Guidelines (Barnett *et al.*, 2012). Calibration was conducted using both groundwater level/pressure and surface water data. A variety of approaches to analysing the data was applied, including vertical groundwater head differences, temporal groundwater head differences, stream flow gains and losses along the Hunter River and Saddlers Creek, and surface water levels in the Plashett Reservoir. Model calibration to the comprehensive groundwater level/pressure data was generally good.

The 3-dimensional numerical groundwater flow model achieves a Class 2 result overall in accordance with the Australian Groundwater Modelling Guidelines model confidence level classification table, as guided by IESC Information Guidelines Explanatory Note: *Uncertainty Analysis – Guidance for Groundwater Modelling within a Risk Management Framework*.

Based on the 3-dimensional numerical groundwater flow modelling, as a consequence of the Project, there is expected to be:

- negligible groundwater drawdown in the alluvial sediments of the Hunter River;
- localised drawdown of up to 8 m within the alluvium along Saddlers Creek and Saltwater Creek; no high priority GDEs are mapped within this area, but vegetation like the Swamp Oak that may access groundwater has been identified in this area;
- no impacts on landholder bores intersecting alluvium;
- predicted reduction in groundwater levels at one privately owned bore that intersects the Permian coal measures and is predicted to have groundwater present;
- substantial depressurisation in the fractured and porous rock groundwater sources in the near vicinity of the Project;
- negligible reductions in surface water flows/balance resulting from changes in groundwater baseflows to surface stream systems (i.e. Hunter River and Saddlers Creek);
- total groundwater inflows to the underground workings of approximately 750 ML/year on average (during the 26 years of the Project), and ranging up to a peak in the order of 1,387 ML/year in Year 12 of the Project;
- total inflow to the remaining voids at the Maxwell Infrastructure is very low, on average 3 ML/year, but can be up to 11 ML/year during the Project. Post mining the groundwater levels in the final voids equilibrate and all three voids act as a sink;
- negligible change in groundwater quality at the Maxwell Underground area as a result of the Project in the short-term and in the long-term; and
- potential mixing of water quality between the backfilled pit at the Maxwell Infrastructure area and Greta Coal Measures underlying the Liddell Ash Dam to the east. Geochemical analysis indicates water quality within the spoil and leachate from rejects is similar to the water quality within the Greta Coal Measures. Groundwater within the Greta Coal Measures are also not utilised by landholders, therefore unlikely to be an impact on the beneficial use of groundwater.

The potential impacts of mining on surface water resources and other water dependent assets, other than those assessed within this Groundwater Assessment, are assessed elsewhere in the EIS.

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FIGURES

LEGEND
- Mining Operation
- Proposed Mining Operation
- Railway
- Local Government Boundary
- State Forest
- National Parks and Wildlife Service Estate
- Maxwell Project Exploration Licence Boundary
- Maxwell Project Mining and Coal Lease Boundary
- Indicative Extent of Underground Development

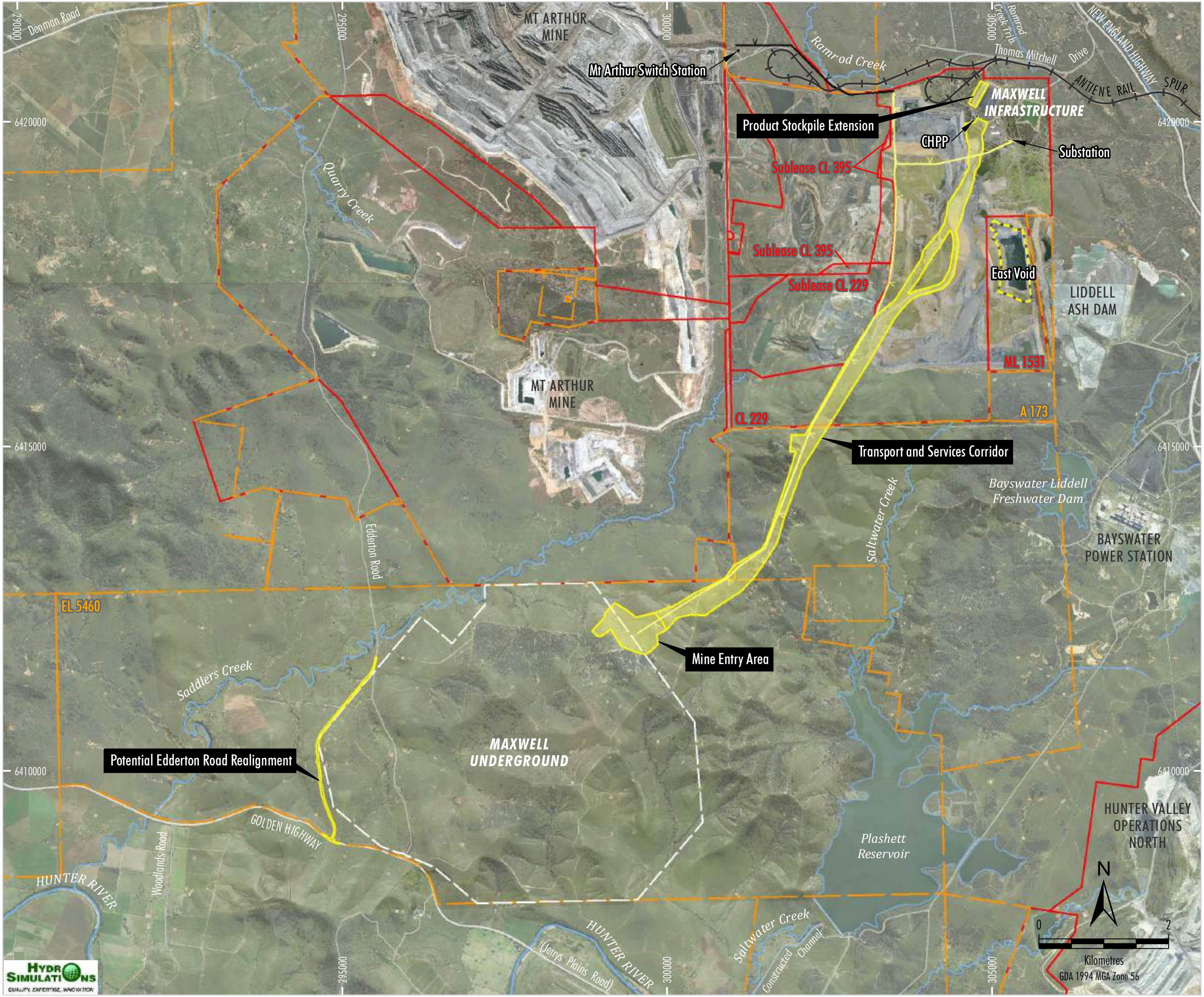
Source: © NSW Department of Planning and Environment (2019); NSW Department of Finance, Services and Innovation (2019); Office of Environment and Heritage NSW (2019)

MALABAR COAL

MAXWELL PROJECT

Regional Location

Figure 1



LEGEND
- Railway
- Exploration Licence Boundary
- Mining and Coal Lease Boundary
- Indicative Extent of Underground Development
- Indicative Surface Development Area
- CHPP Reject Emplacement Area
- Proposed 66 kV Power Supply
- Proposed Ausgrid 66 kV Power Supply Extension #

Subject to separate assessment and approval.

Source: © NSW Department of Planning and Environment (2019); NSW Department of Finance, Services & Innovation (2019) Orthophoto Mosaic: 2018, 2016, 2011

MALABAR COAL

MAXWELL PROJECT

General Arrangement of the Project

Figure 2

SHM-18-03 Maxwell_EIS_App GW_202B

LEGEND
- Railway
- Exploration Licence Boundary
- Mining and Coal Lease Boundary
- CHPP Reject Emplacement Area

Source: © NSW Department of Planning and Environment (2019); NSW Department of Finance, Services & Innovation (2019) Orthophoto Mosaic: 2018, 2016, 2011

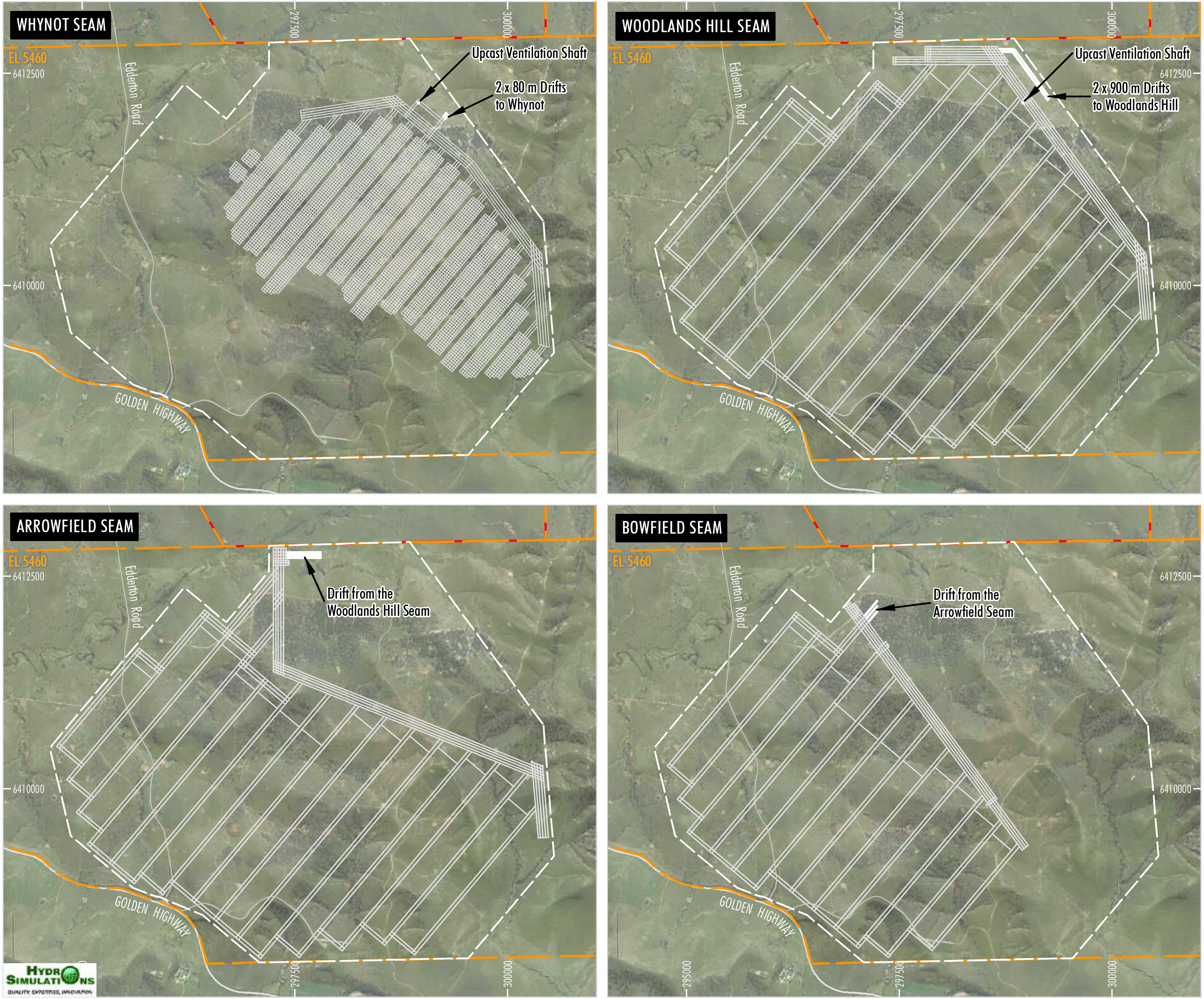
MALABAR COAL

MAXWELL PROJECT

CHPP Reject Emplacement Area

Figure 3

TOC



LEGEND
Exploration Licence Boundary
Mining and Coal Lease Boundary
Indicative Extent of Underground Development
Indicative Underground Mining Layout

Source: © NSW Department of Planning and Environment (2019); Department of Finance, Services & Innovation (2019) Orthophoto Mosaic: 2016, 2011

N
0 2
Kilometres
GDA 1994 MGA Zone 56

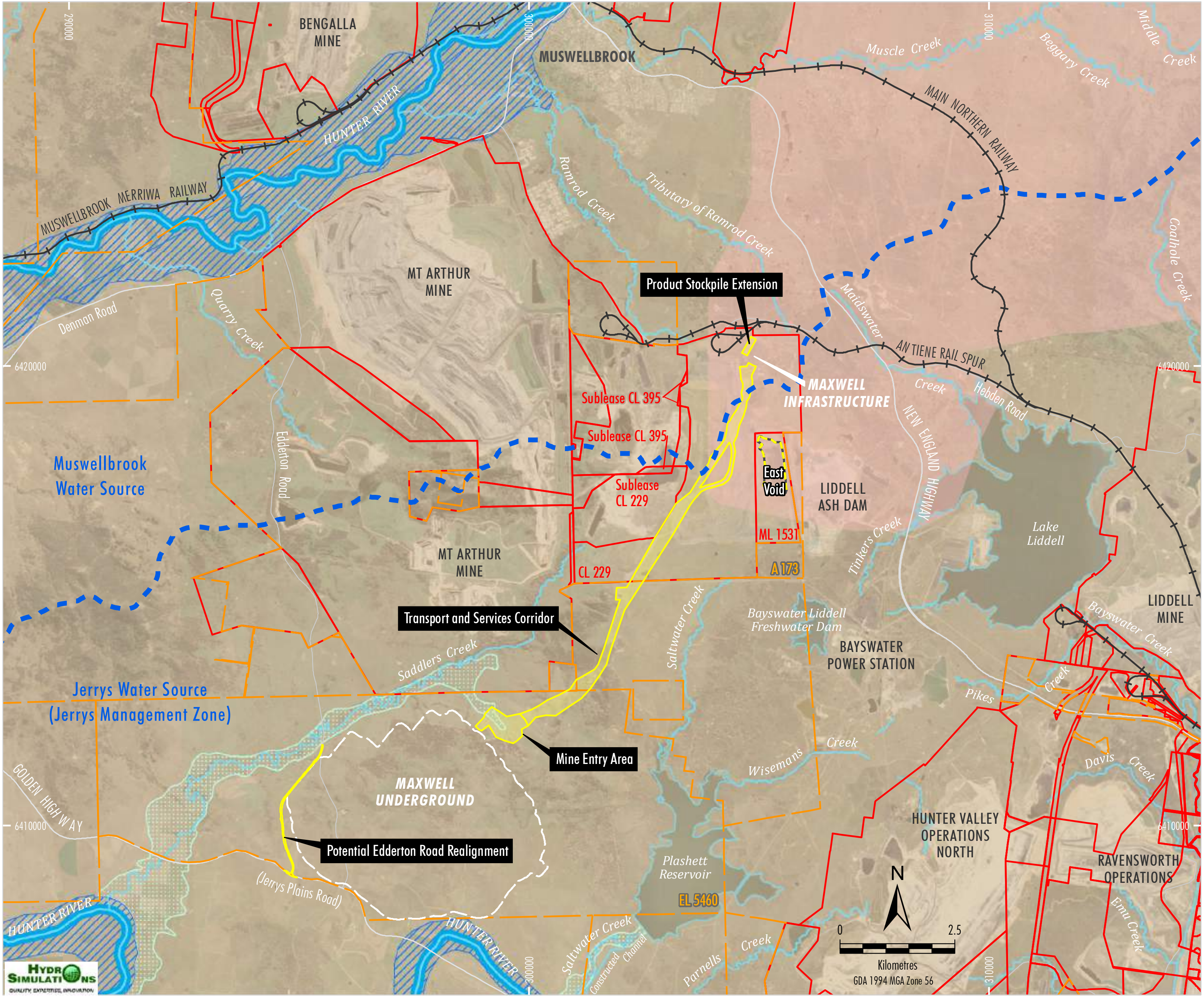
MALABAR COAL

M A X W E L L P R O J E C T

Indicative Underground Mining Layout

Figure 4

SHM-18-03 Maxwell_EIS_App GW_204A



LEGEND
- Railway
- Exploration Licence Boundary
- Mining and Coal Lease Boundary
- Indicative Surface Development Area
- CHPP Reject Emplacement Area
- Extent of Conventional Subsidence (20 mm subsidence contour)

North Coast Fractured and Porous Rock Groundwater Sources
- Sydney Basin - North Coast Groundwater Source
- New England Fold Belt Coast Groundwater Source

Hunter Unregulated and Alluvial Water Sources
- Management Zone Boundary
- Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone)
- Groundwater Sources in Jerrys Water Source#

Hunter Regulated River Water Source
- Hunter Regulated River Water Source

 # As per Department of Primary Industries (2018) database of groundwater sources (Water Sharing Plan Groundwater Sources) based on mapping of unconsolidated alluvial sediments sourced from geological data created by the Resources and Geoscience Division and Soil Landscape Units from the Department of Planning and Environment. Only water within actual alluvial sediments is covered within this source. Alluvial sediments are absent from the mine entry area.

Source: © NSW Department of Planning and Environment (2019); NSW Department of Finance, Services & Innovation (2019); NSW Department of Primary Industries - Water (2019); MSEC (2019) Orthophoto Mosaic: 2018, 2016, 2011

MALABAR COAL

MAXWELL PROJECT

Water Sharing Plan Boundaries in the Vicinity of the Project

Figure 5

SHM-18-03 Maxwell_EIS_App GW_205A

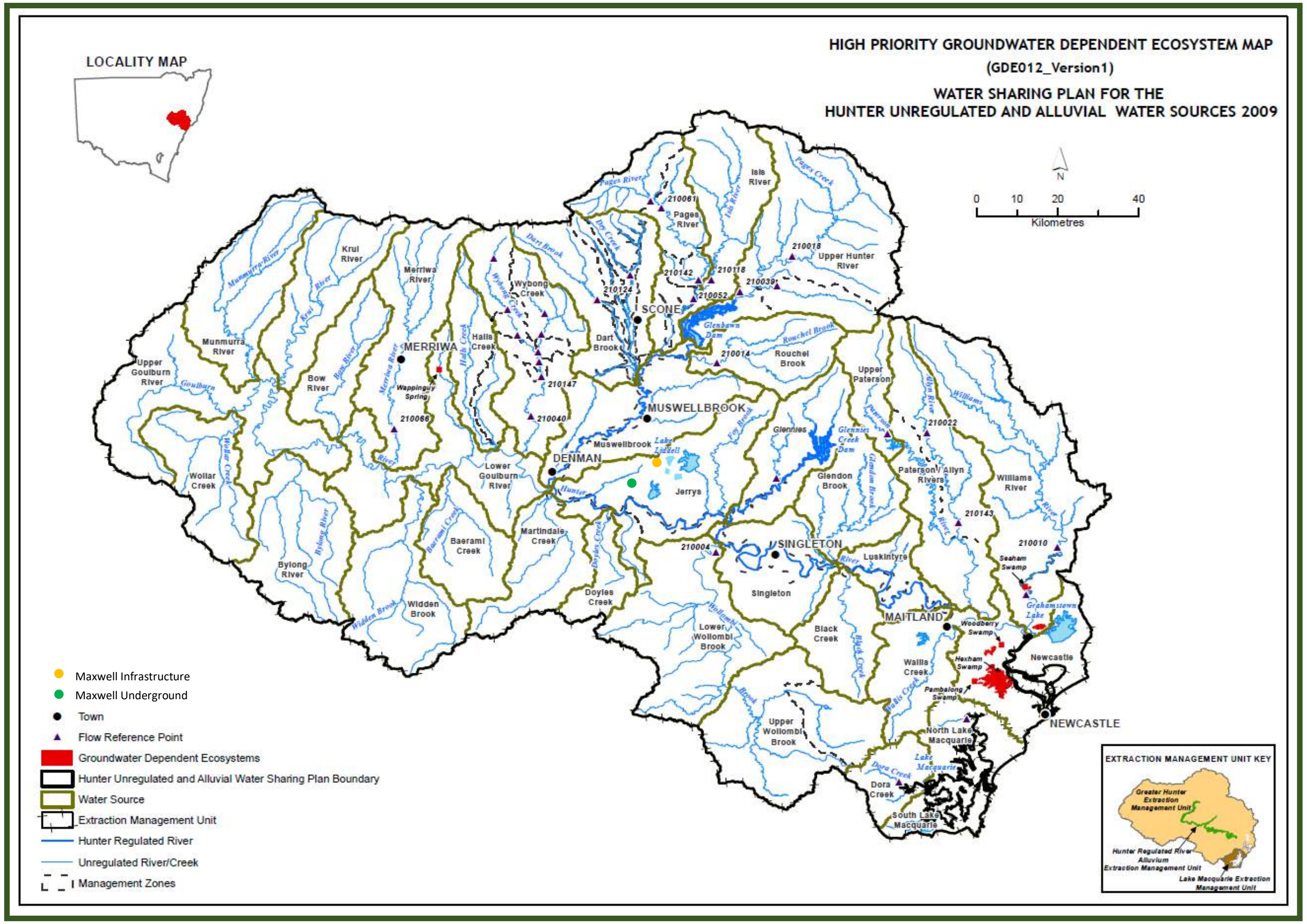


Figure 6 **Map of 'High Priority' GDEs under Hunter Unregulated and Alluvial WSP**

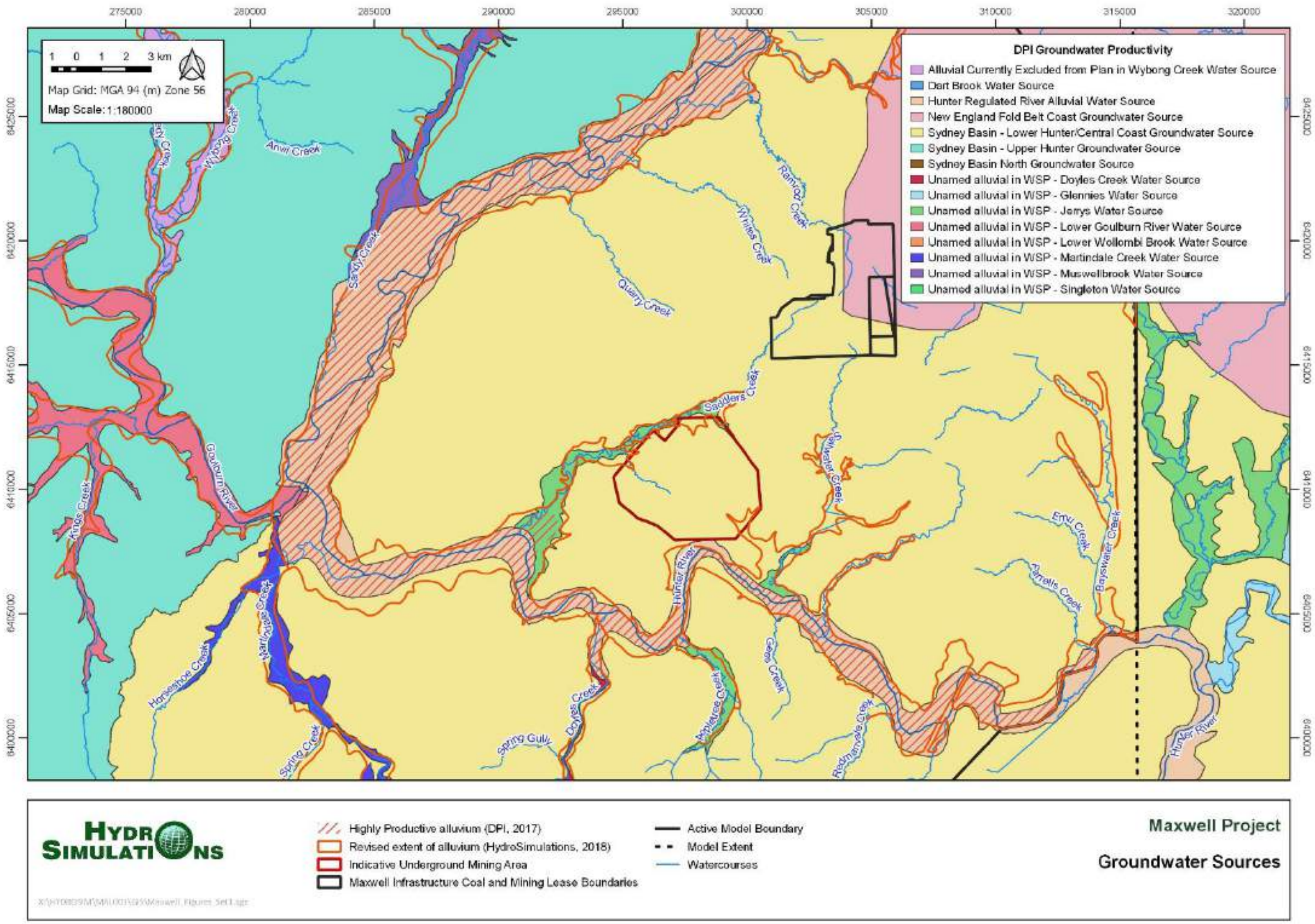
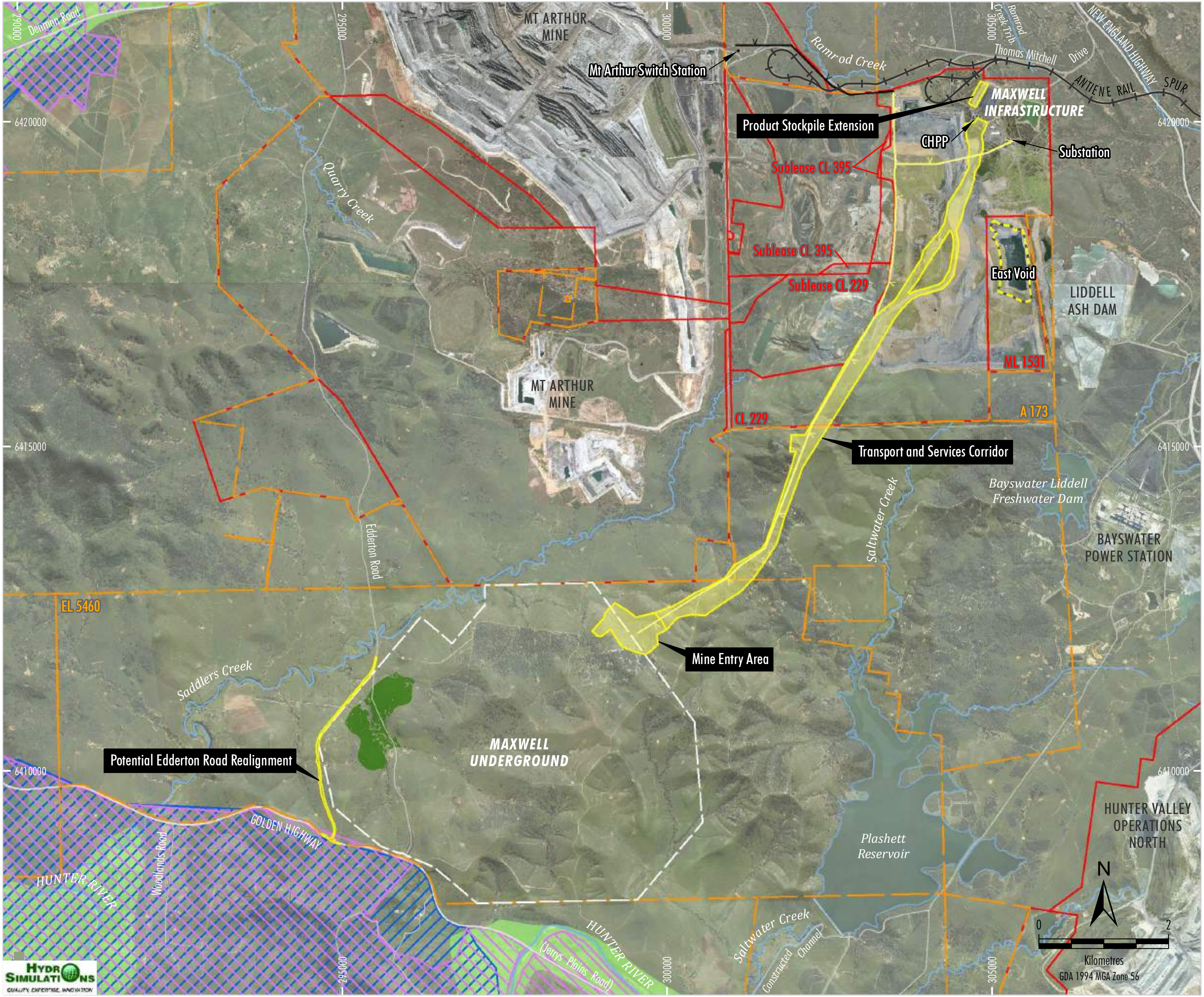


Figure 7 Groundwater Sources

TOC



SHM-18-03 Maxwell_EIS_App GW_206A

LEGEND
- Railway
- Exploration Licence Boundary
- Mining and Coal Lease Boundary
- Indicative Extent of Underground Development
- Indicative Surface Development Area
- CHPP Reject Emplacement Area
- Proposed 66 kV Power Supply
- Proposed Ausgrid 66 kV Power Supply Extension #

Strategic Agricultural Land
- Equine Critical Industry Cluster Land
- Viticulture Critical Industry Cluster Land
- Regionally Mapped Biophysical Strategic Agricultural Land
- Verified Biophysical Strategic Agricultural Land

Subject to separate assessment and approval.

Source: © NSW Department of Planning and Environment (2019); NSW Department of Finance, Services & Innovation (2019); SLR (2019) Orthophoto Mosaic: 2018, 2016, 2011

MALABAR COAL

MAXWELL PROJECT

Strategic Agricultural Land in the Vicinity of the Project

Figure 8

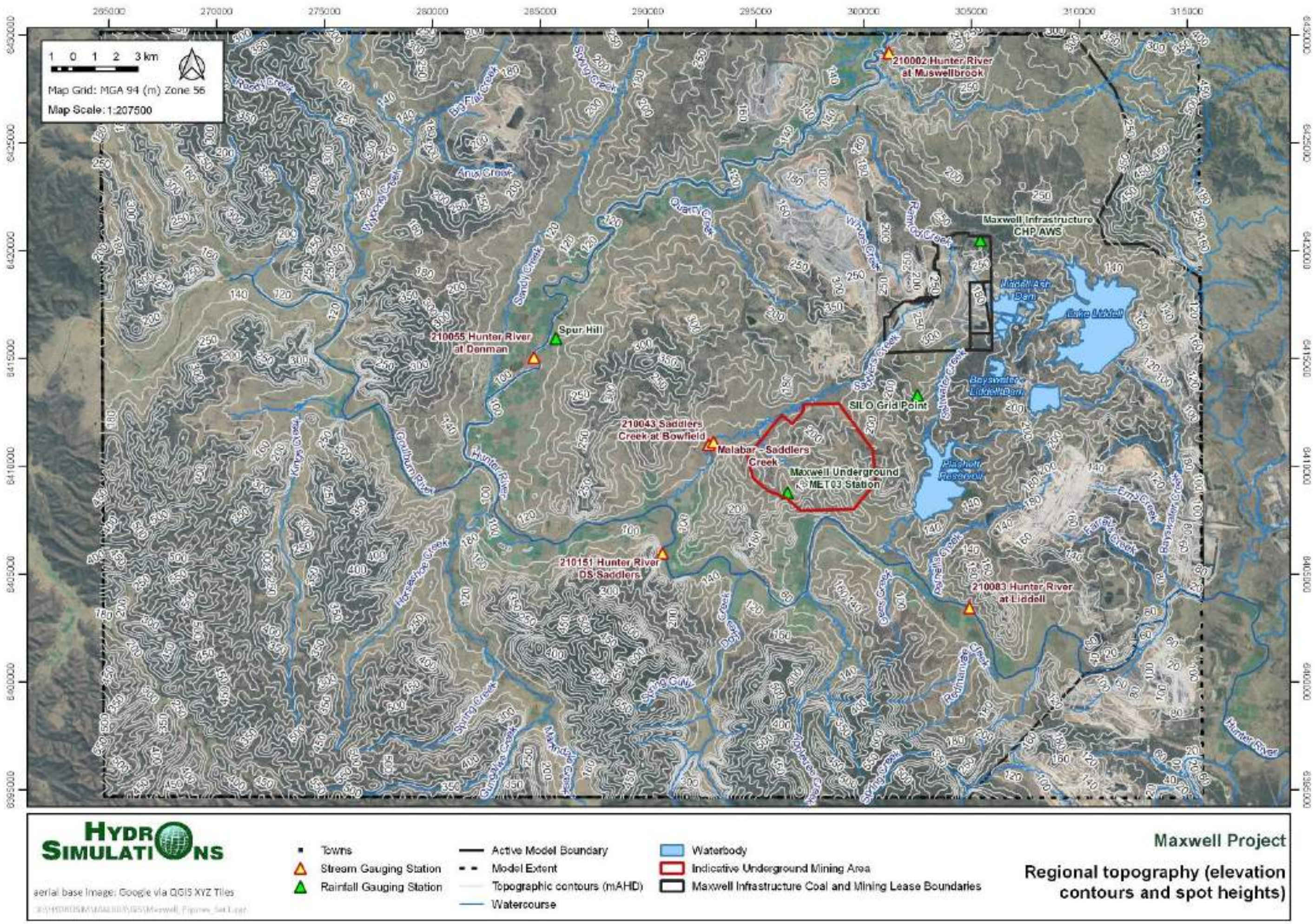


Figure 9 Regional topography (elevation contours and spot heights)

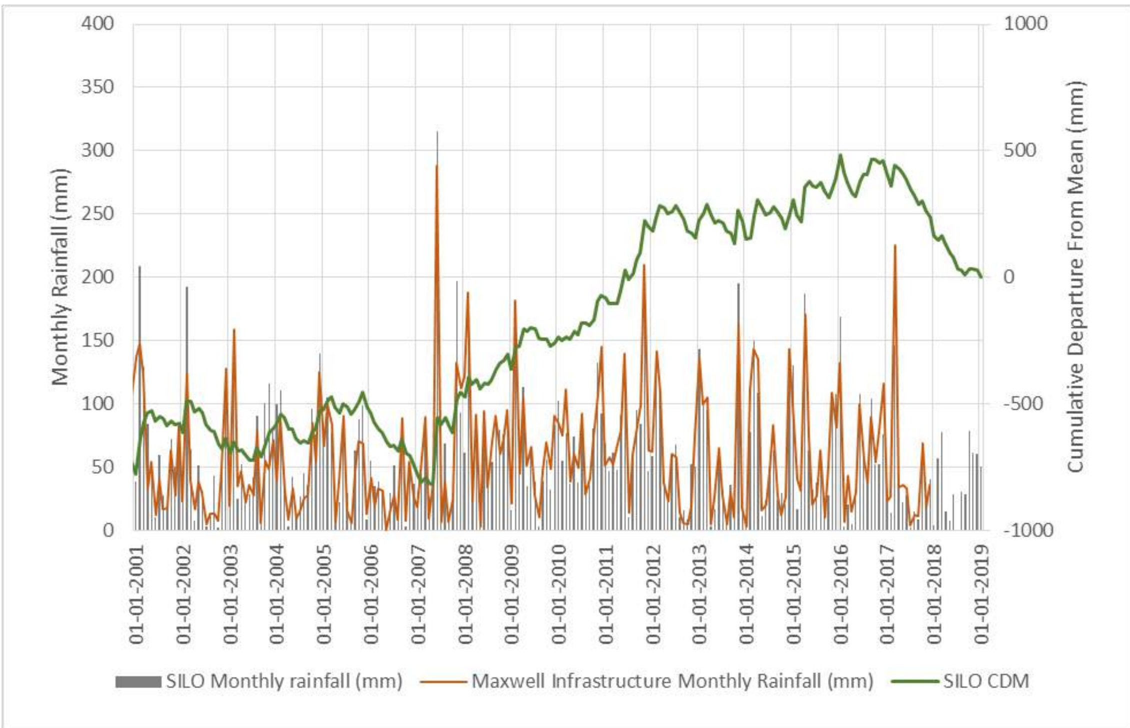


Figure 10 Rainfall and Cumulative Departure from Mean

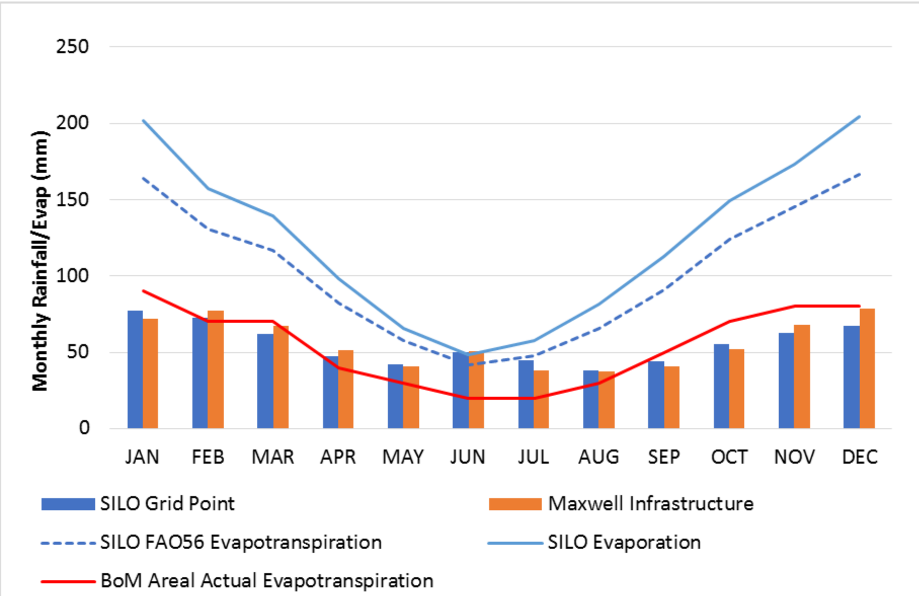


Figure 11 Average Monthly Rainfall, Evaporation and Evapotranspiration

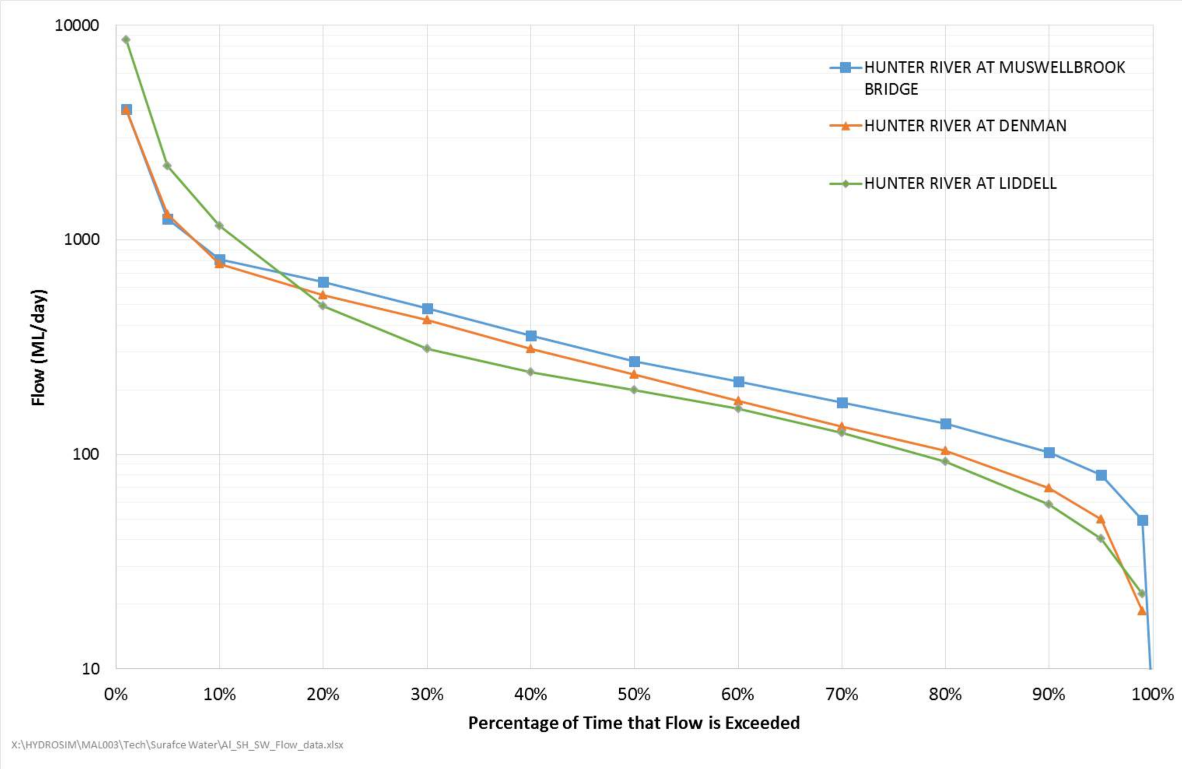


Figure 12 Flow exceedance, Hunter River

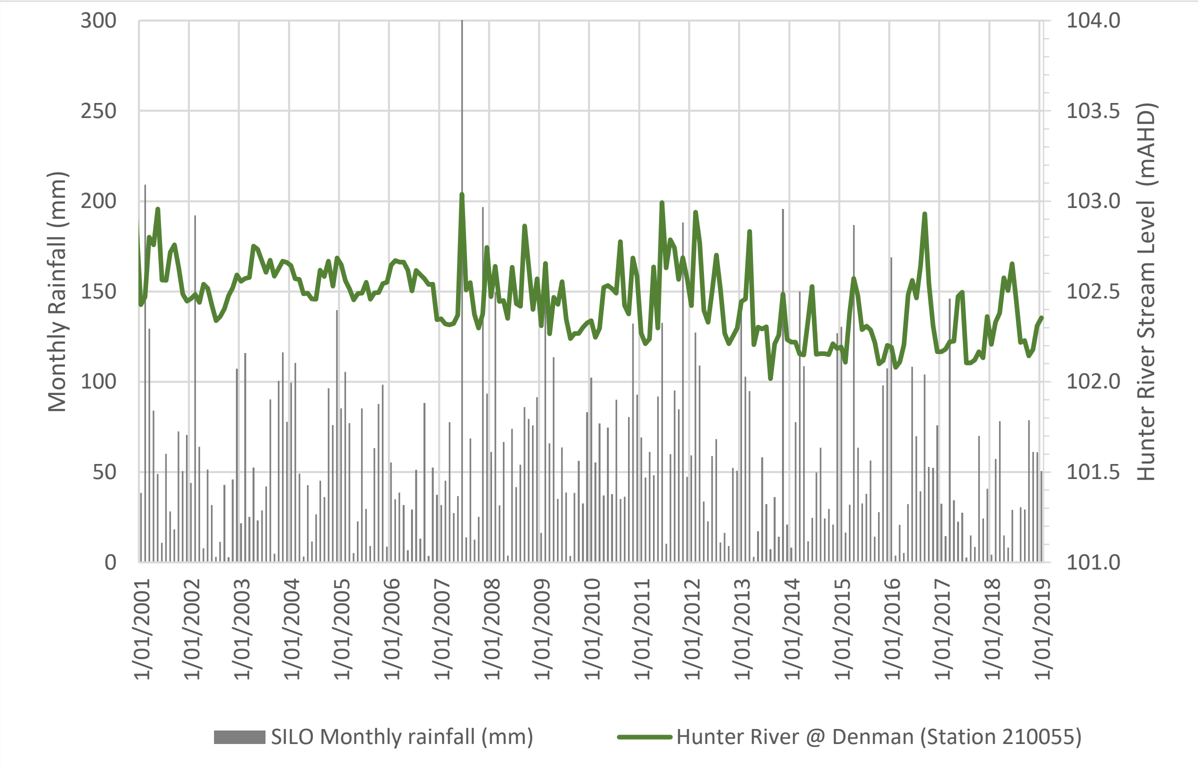


Figure 13 Rainfall versus Hunter River Levels @ Denman (Station 210055)

Figure 14 Photographs of Saddlers Creek – Autumn 2018 (Source: EcoLogical 2019)

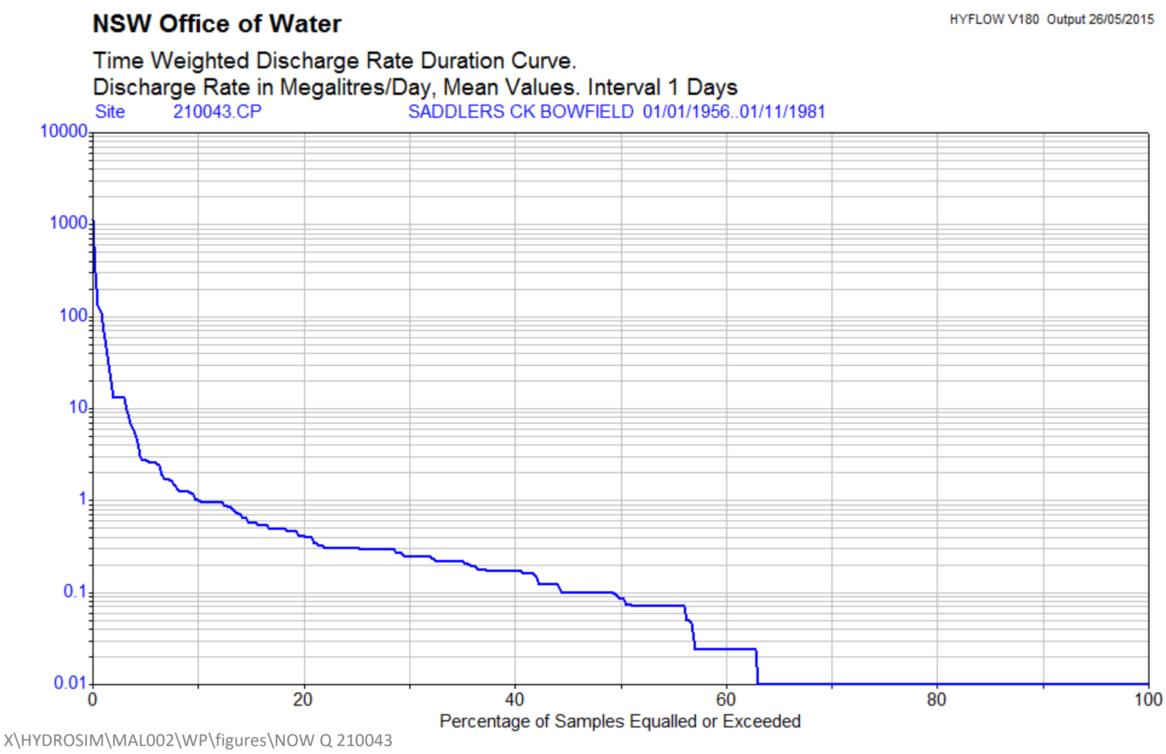


Figure 15 **Discharge rate duration curve, Saddlers Creek**

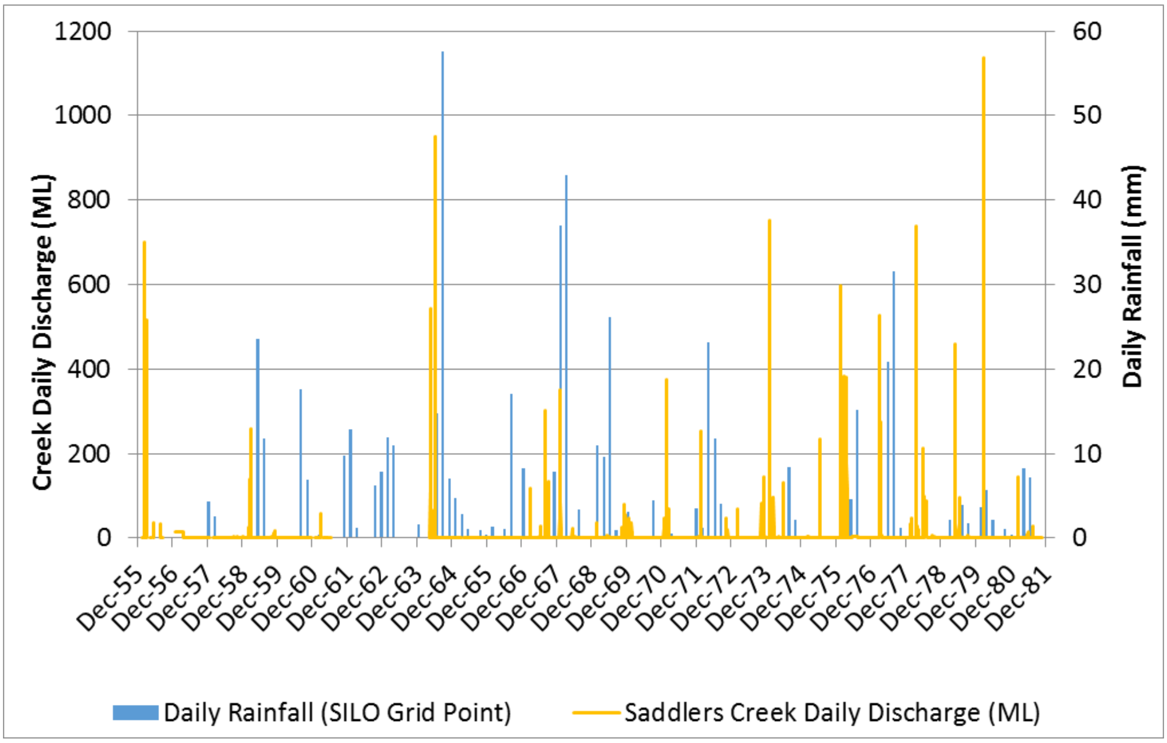


Figure 16 **Saddlers Creek (Station 210043) Daily Discharge versus Daily Rainfall**

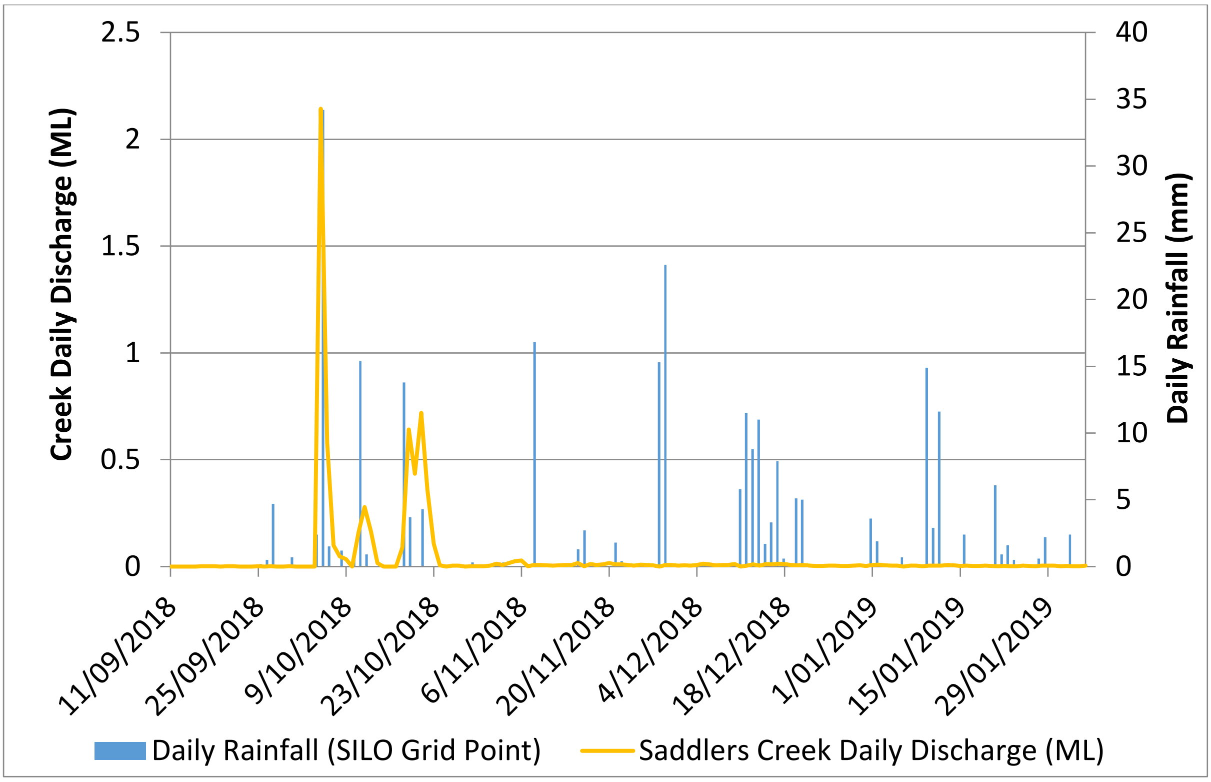


Figure 17 Saddlers Creek (Malabar) Daily Discharge versus Daily Rainfall

Figure 18 Photographs of Saltwater Creek Tributary – Autumn 2018 (Source: EcoLogical 2019)

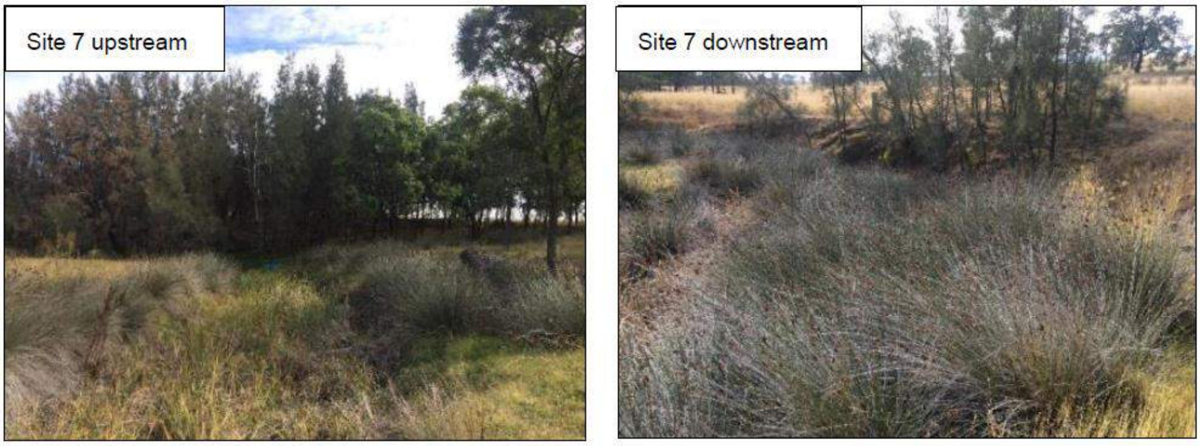


Figure 19 Photographs of Ramrod Creek – Autumn 2018 (Source: EcoLogical 2019)

Figure 20 Photographs of Unnamed Creek (Source: Fluvial Systems, taken July 2018)

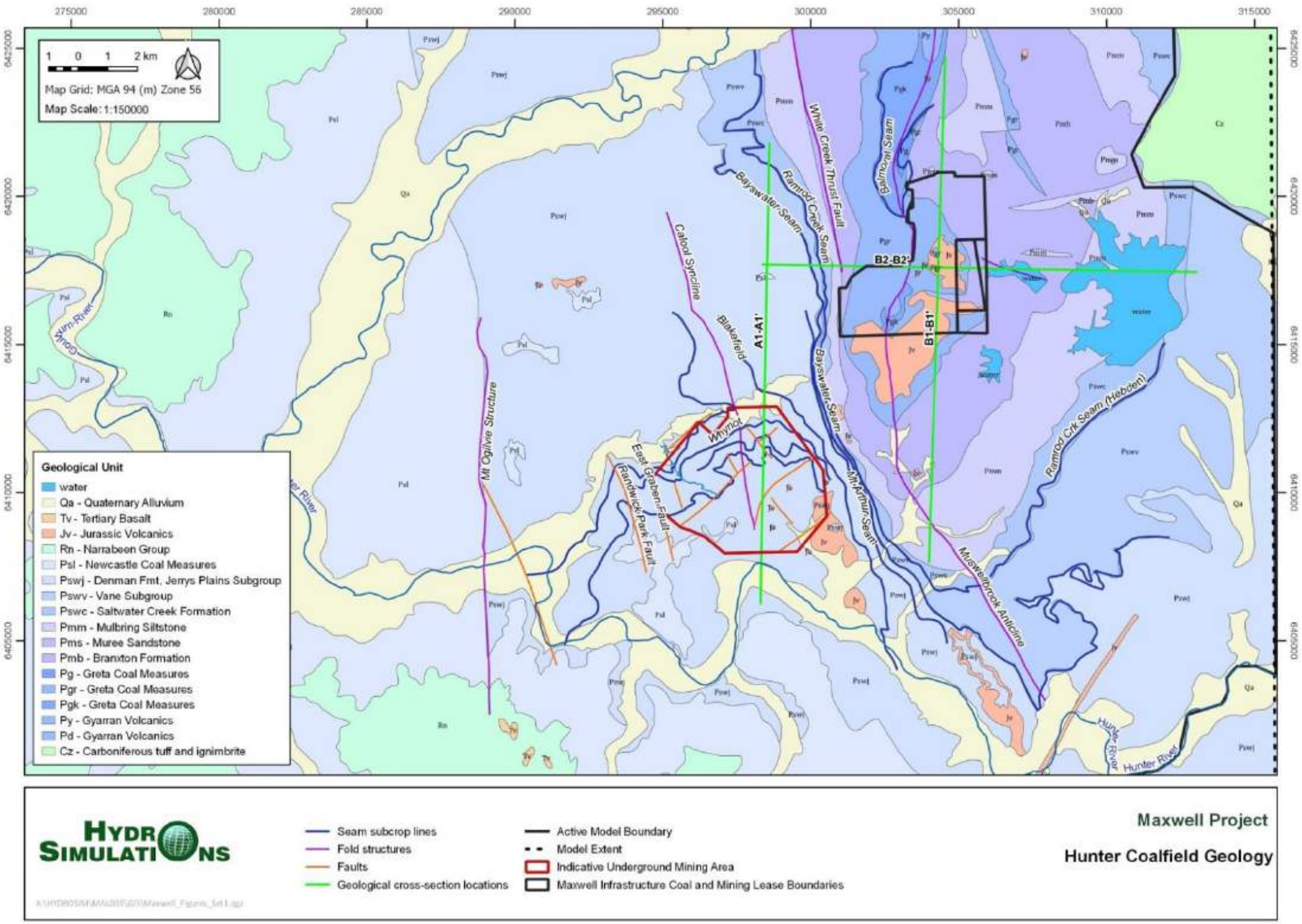


Figure 21 Geology (Hunter Coalfields 100k)

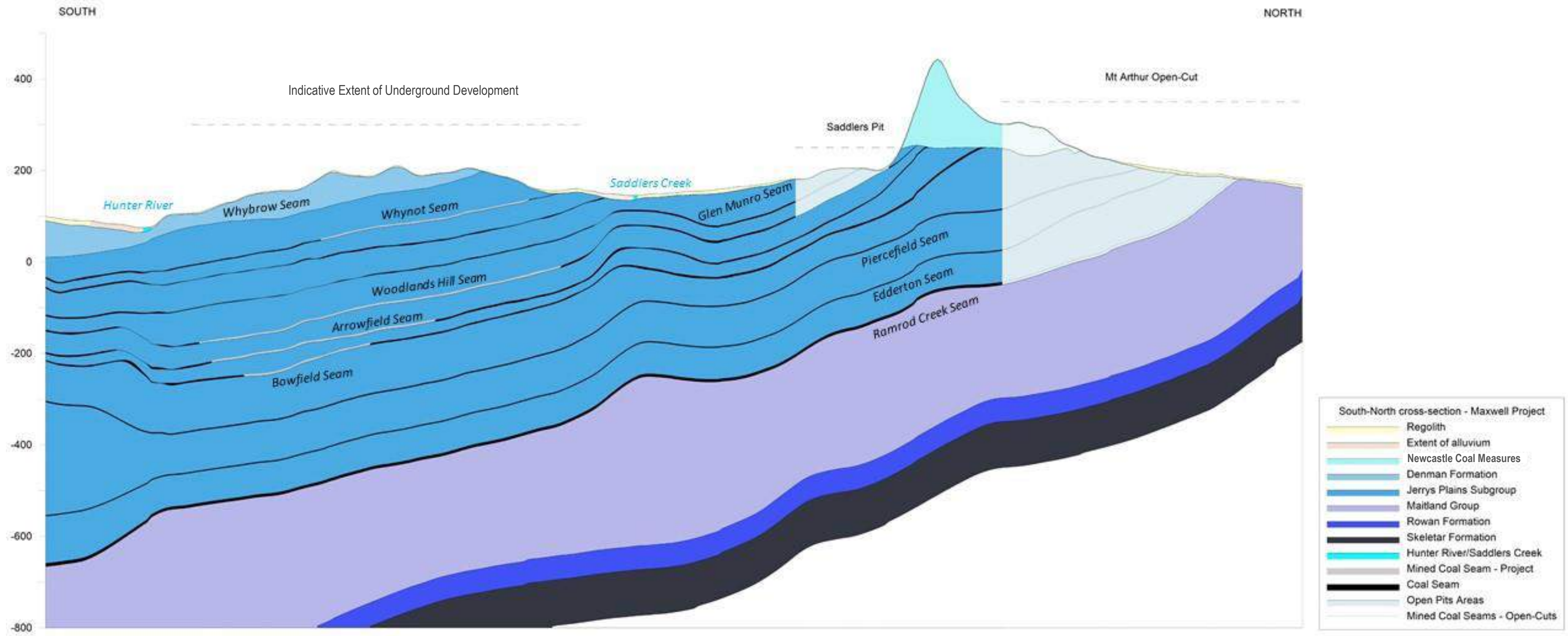


Figure 22 A1-A1'- Proposed Underground N to S Geological Section

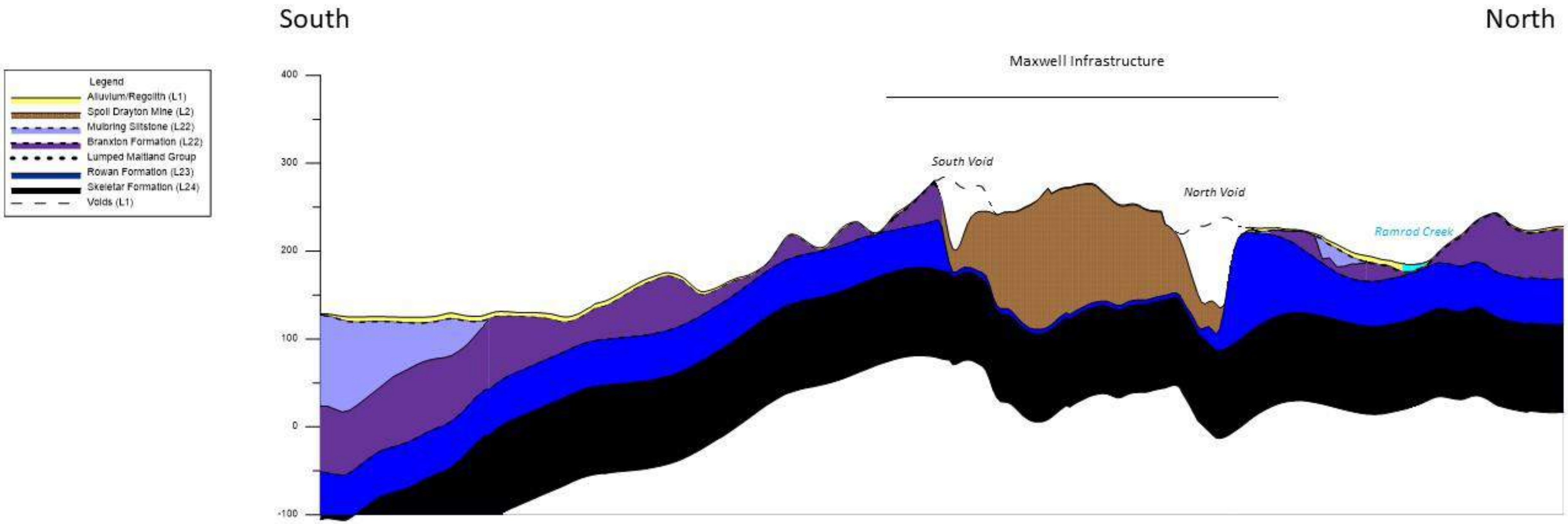


Figure 23 B1-B1'- Maxwell Infrastructure N to S Geological Section

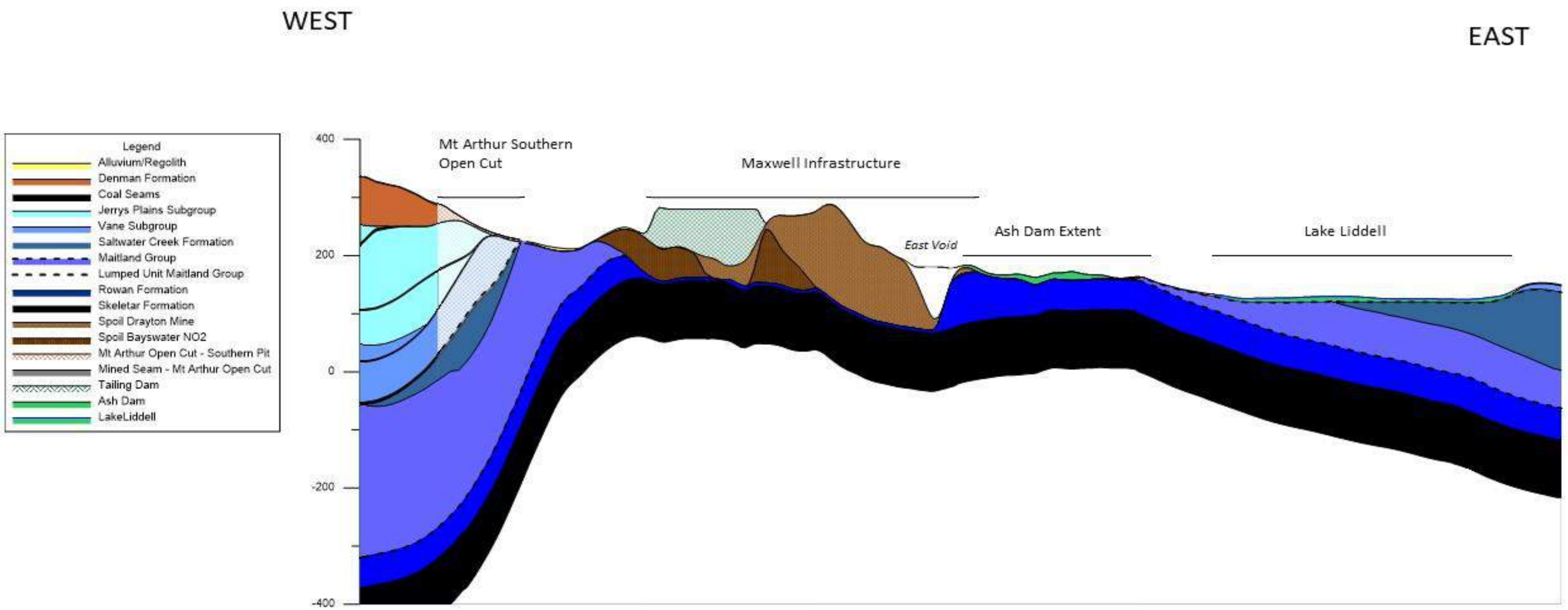


Figure 24 B2-B2'- Maxwell Infrastructure W to E Geological Section

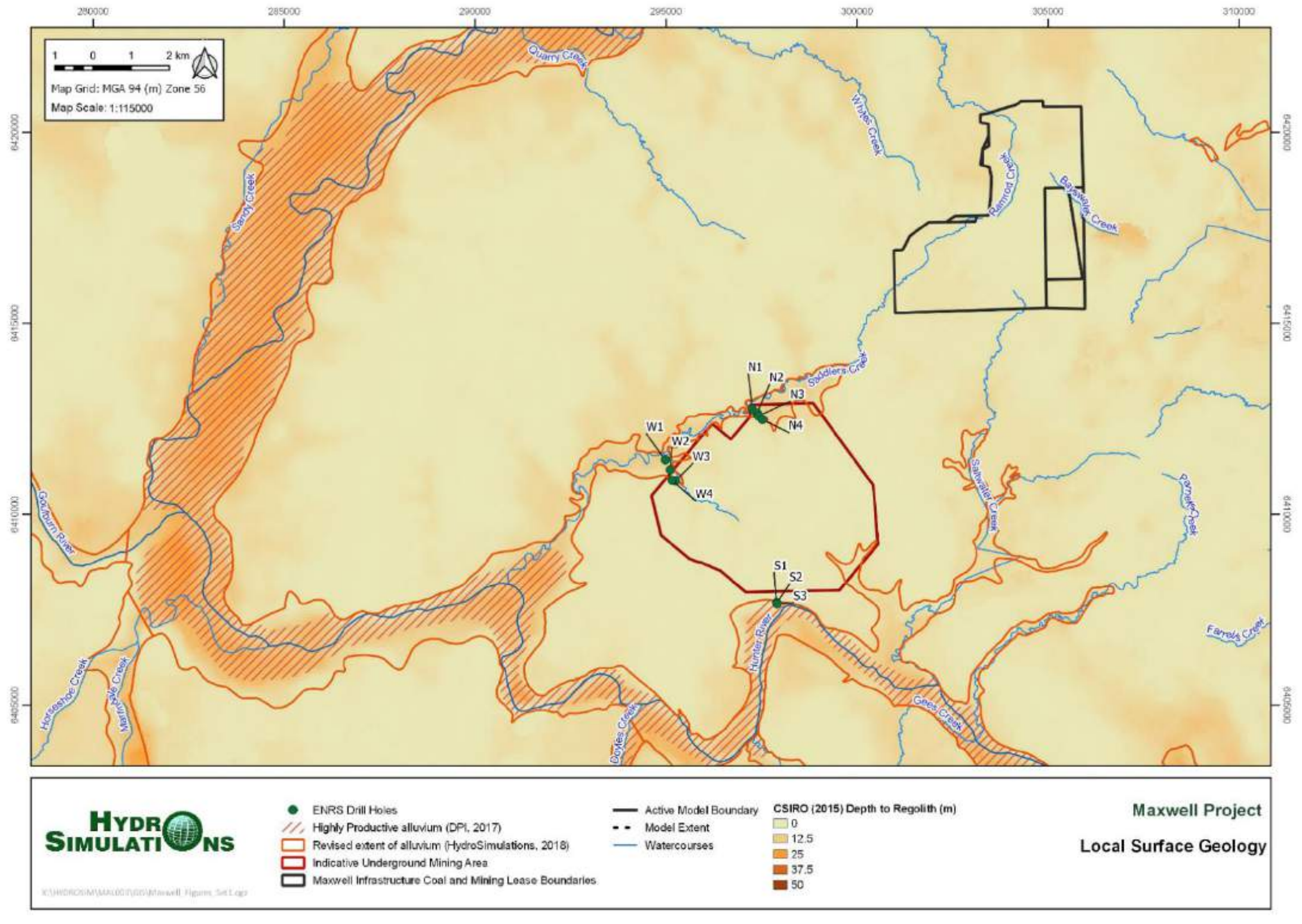


Figure 25 **Local Surface Geology**

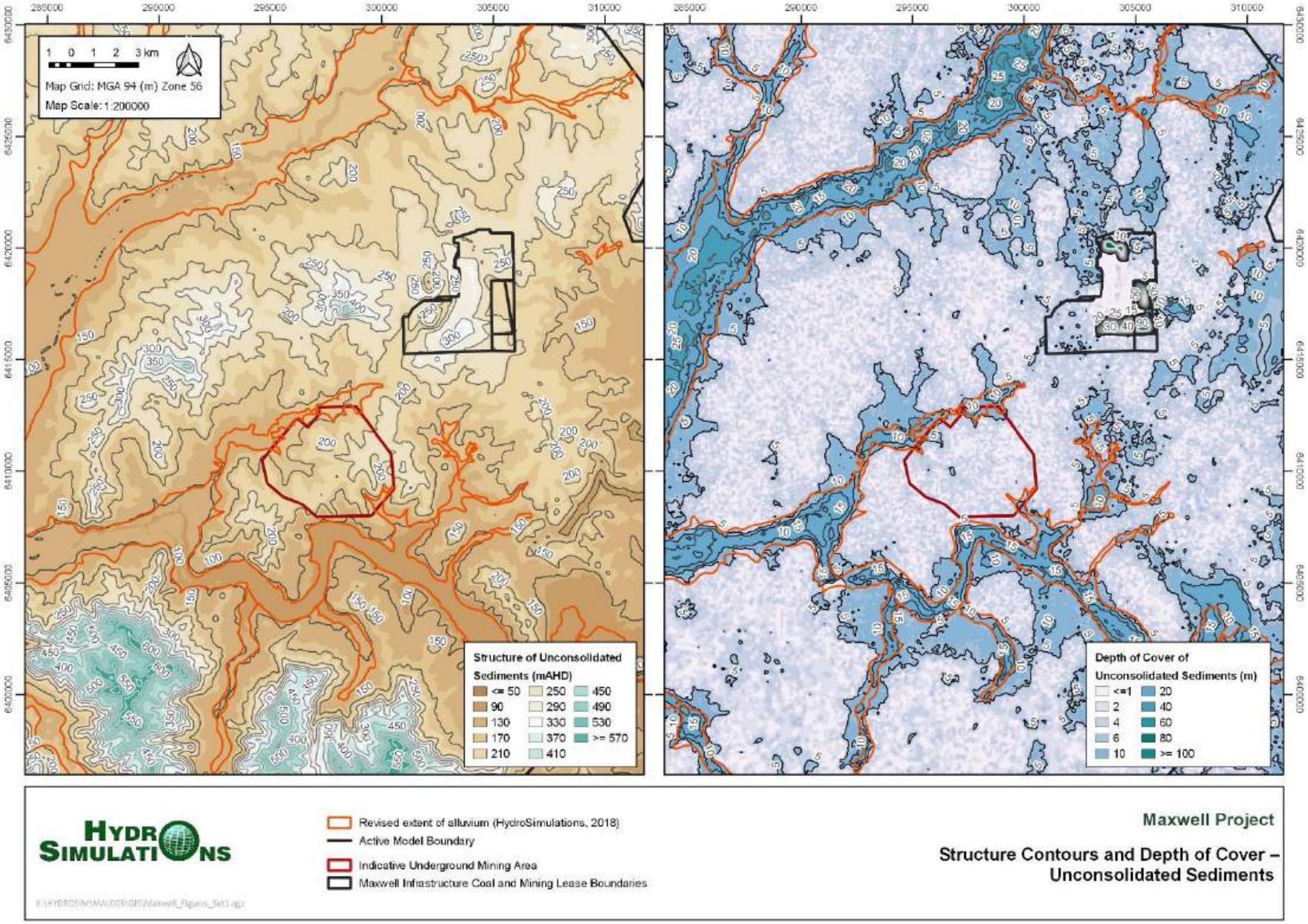


Figure 26 Structure Contours and Thickness – Unconsolidated Sediments

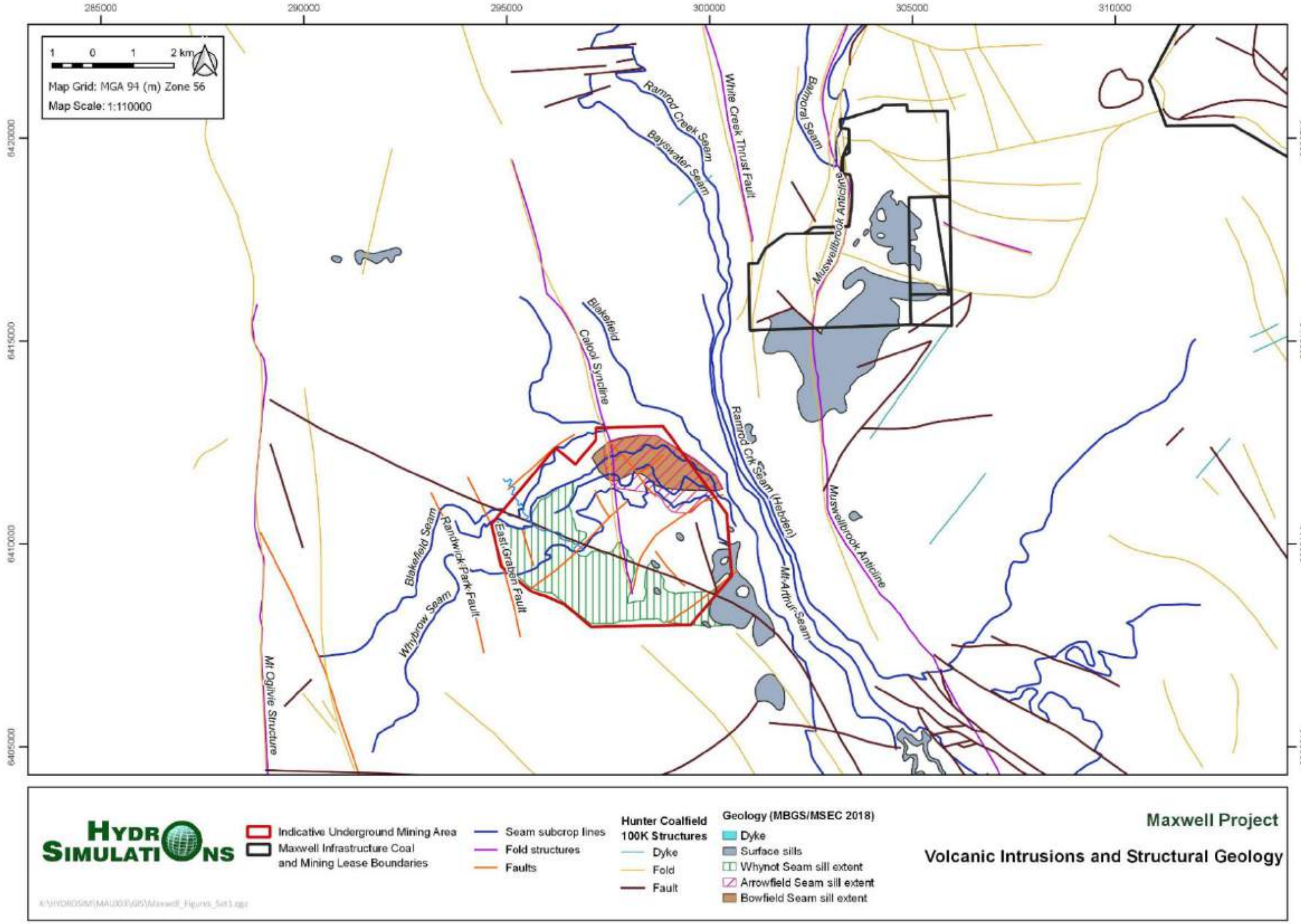


Figure 27 Map of Volcanic Intrusions and Structural Geology

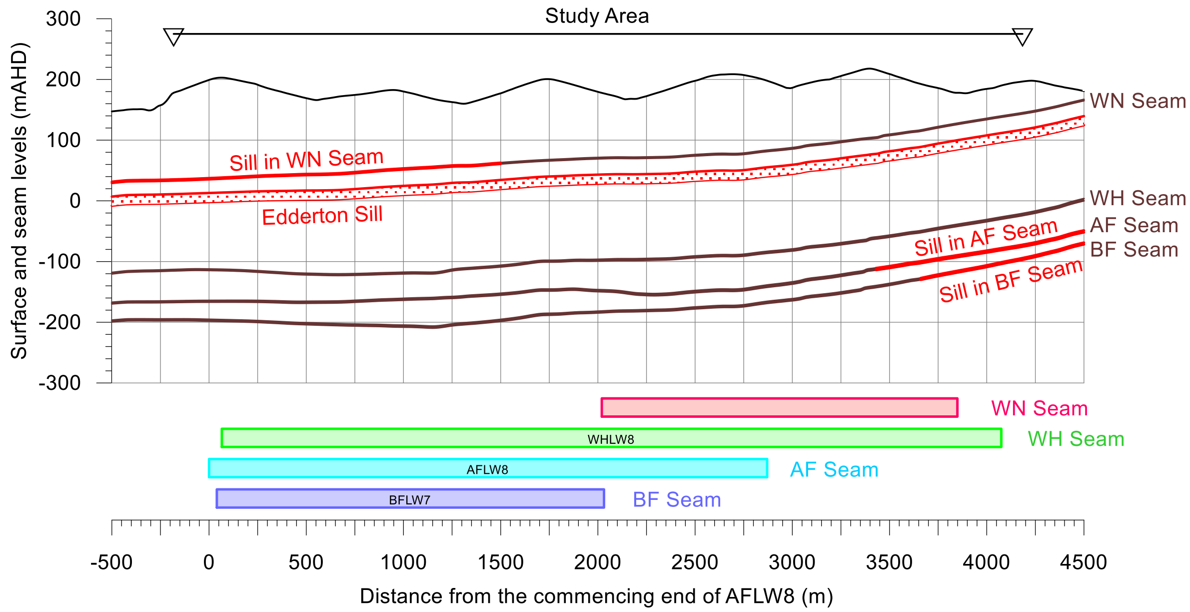


Figure 28 Volcanic Intrusions – Cross Section (Source: MSEC 2019)

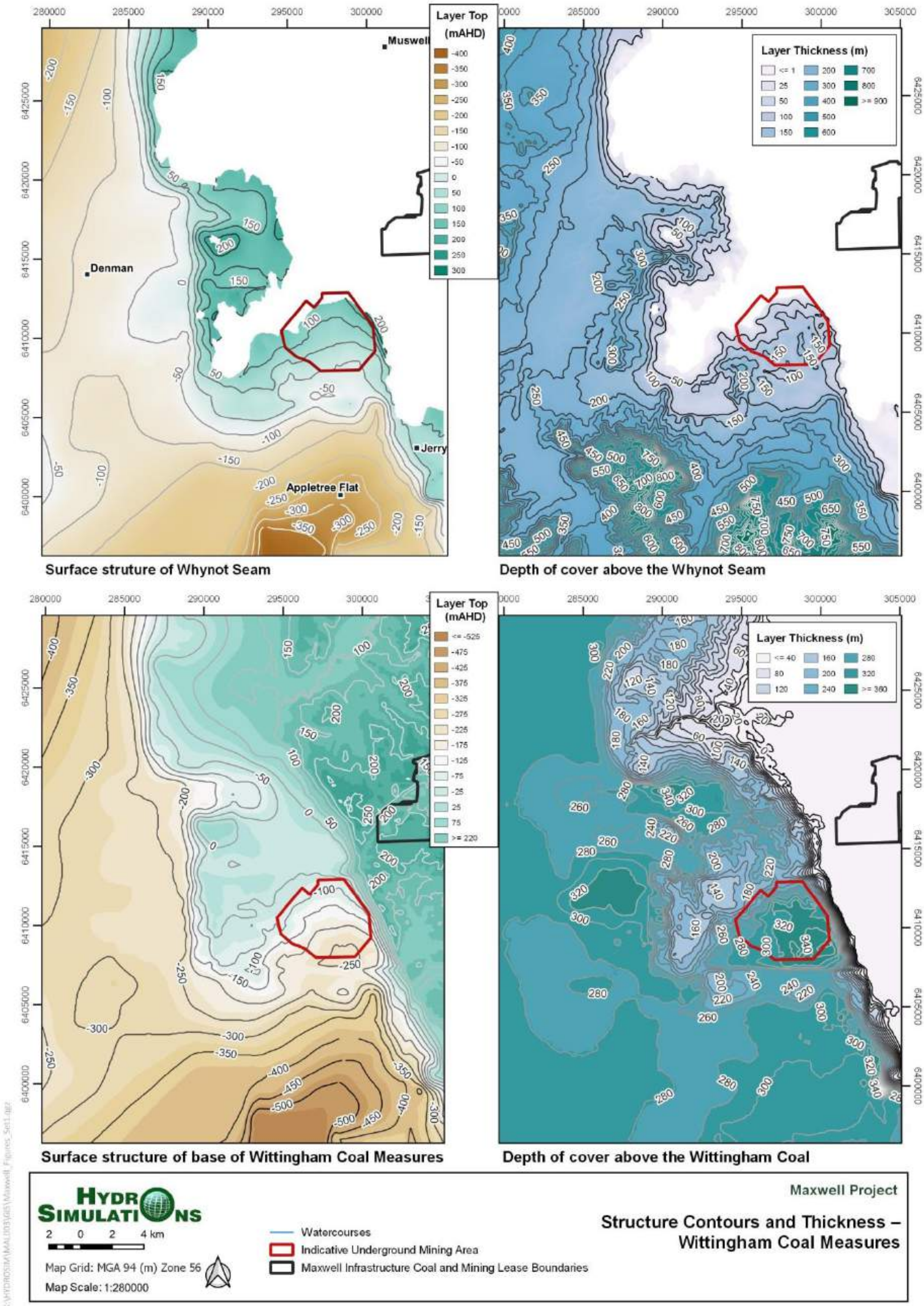


Figure 29 Structure Contours and Thickness – Wittingham Coal Measures

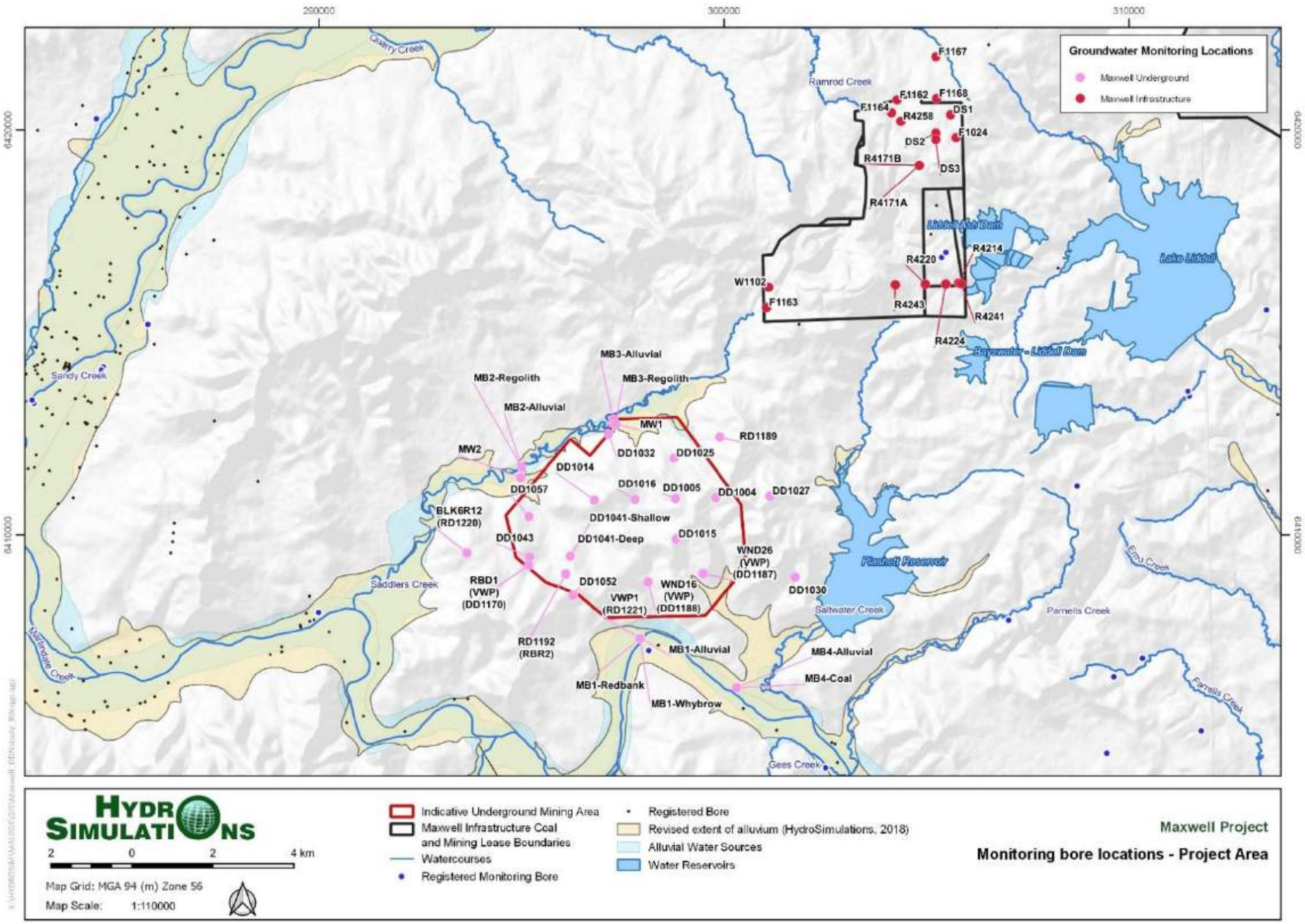


Figure 30 Monitoring Bore Locations – Project Area

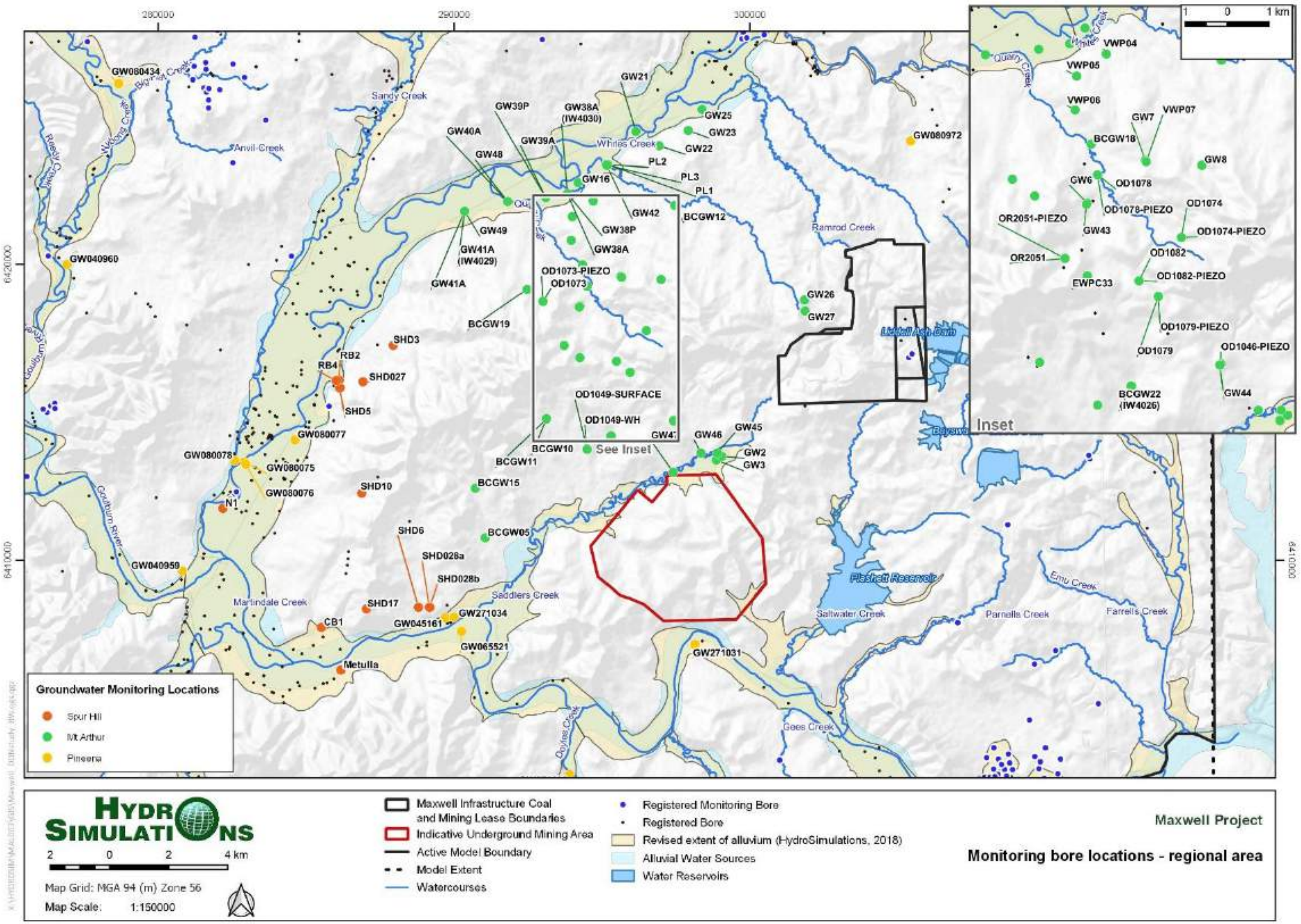


Figure 31 Monitoring Bore Locations – Surrounding Bores

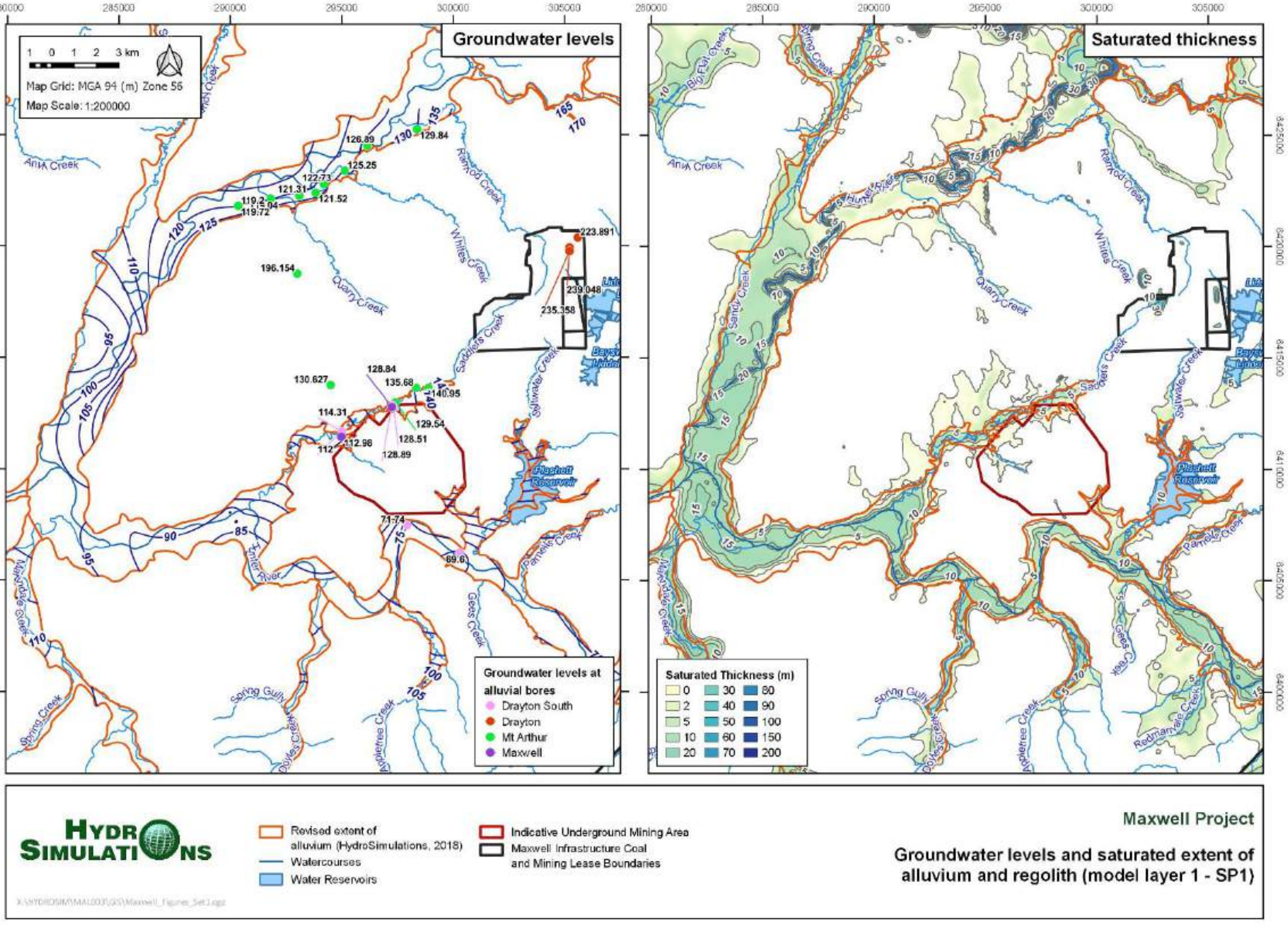


Figure 32 Unconsolidated Sediments - Interpolated Saturated Thickness

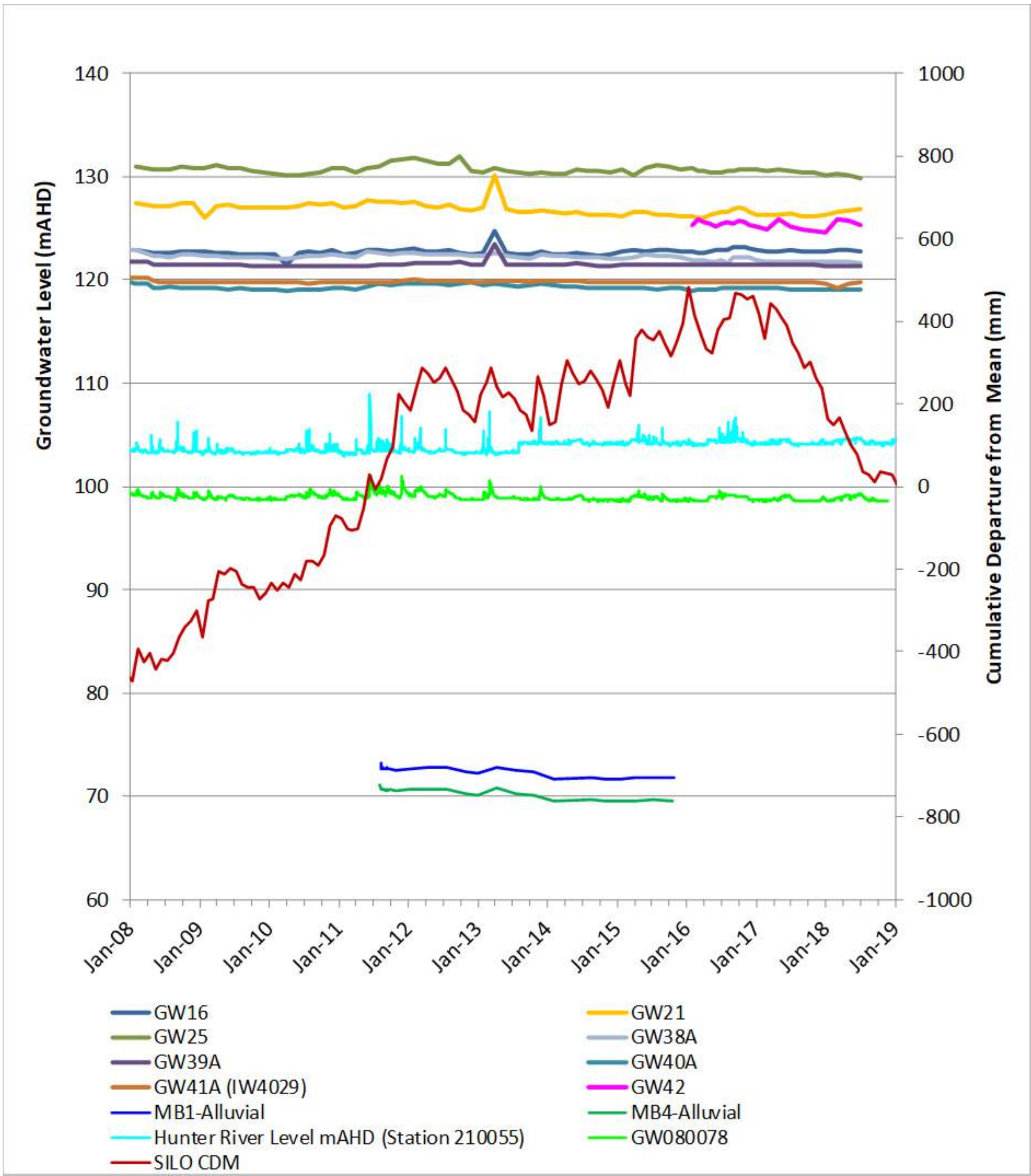


Figure 33 Hydrographs – Hunter River Alluvium

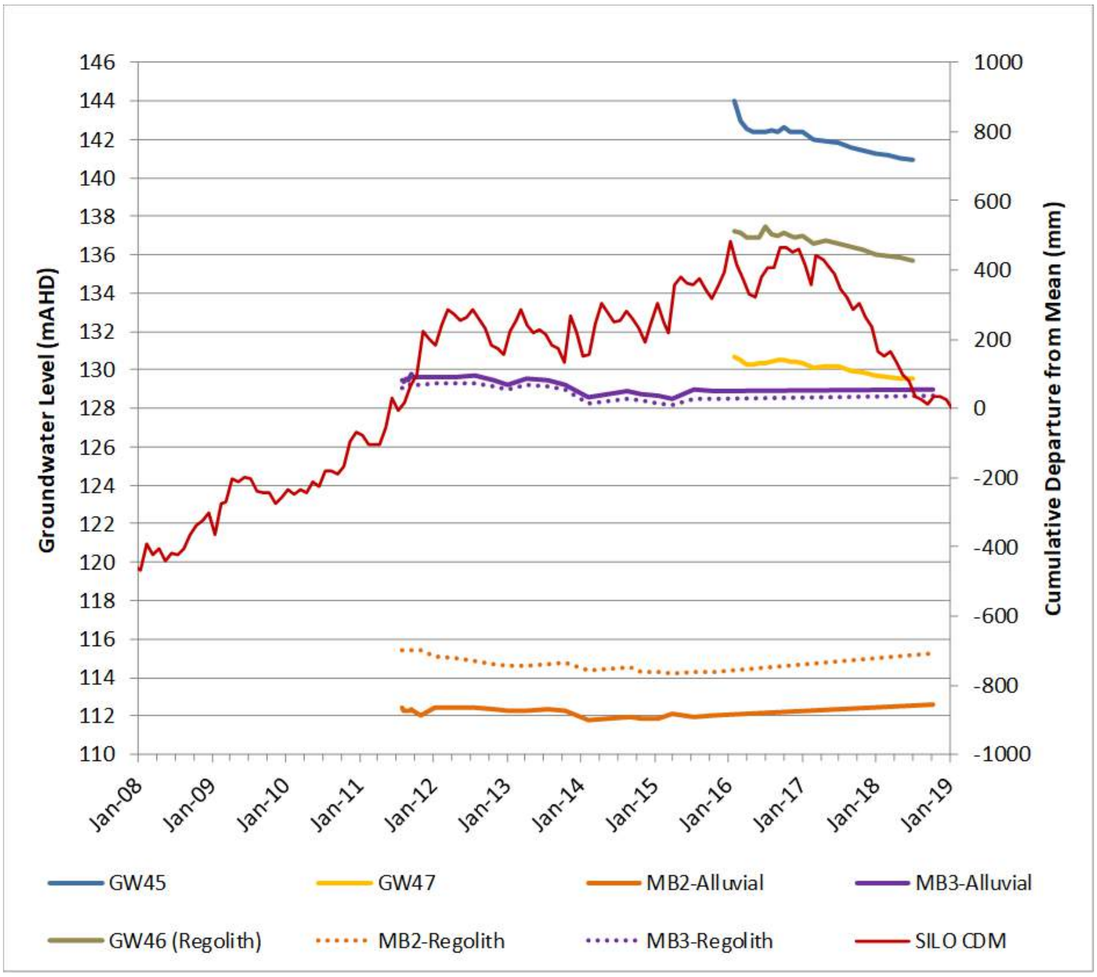


Figure 34 **Hydrographs – Saddlers Creek Alluvium and Regolith**

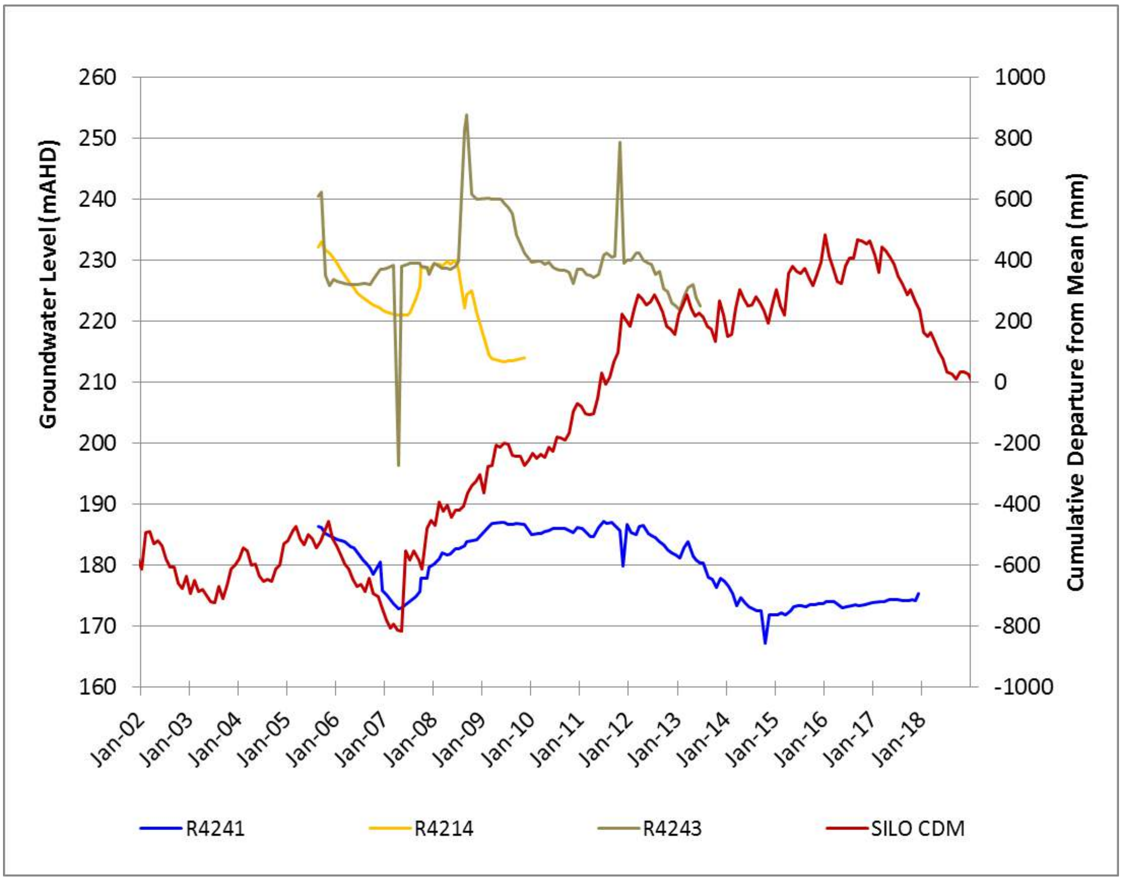


Figure 35 **Hydrographs – Jurassic Volcanics**

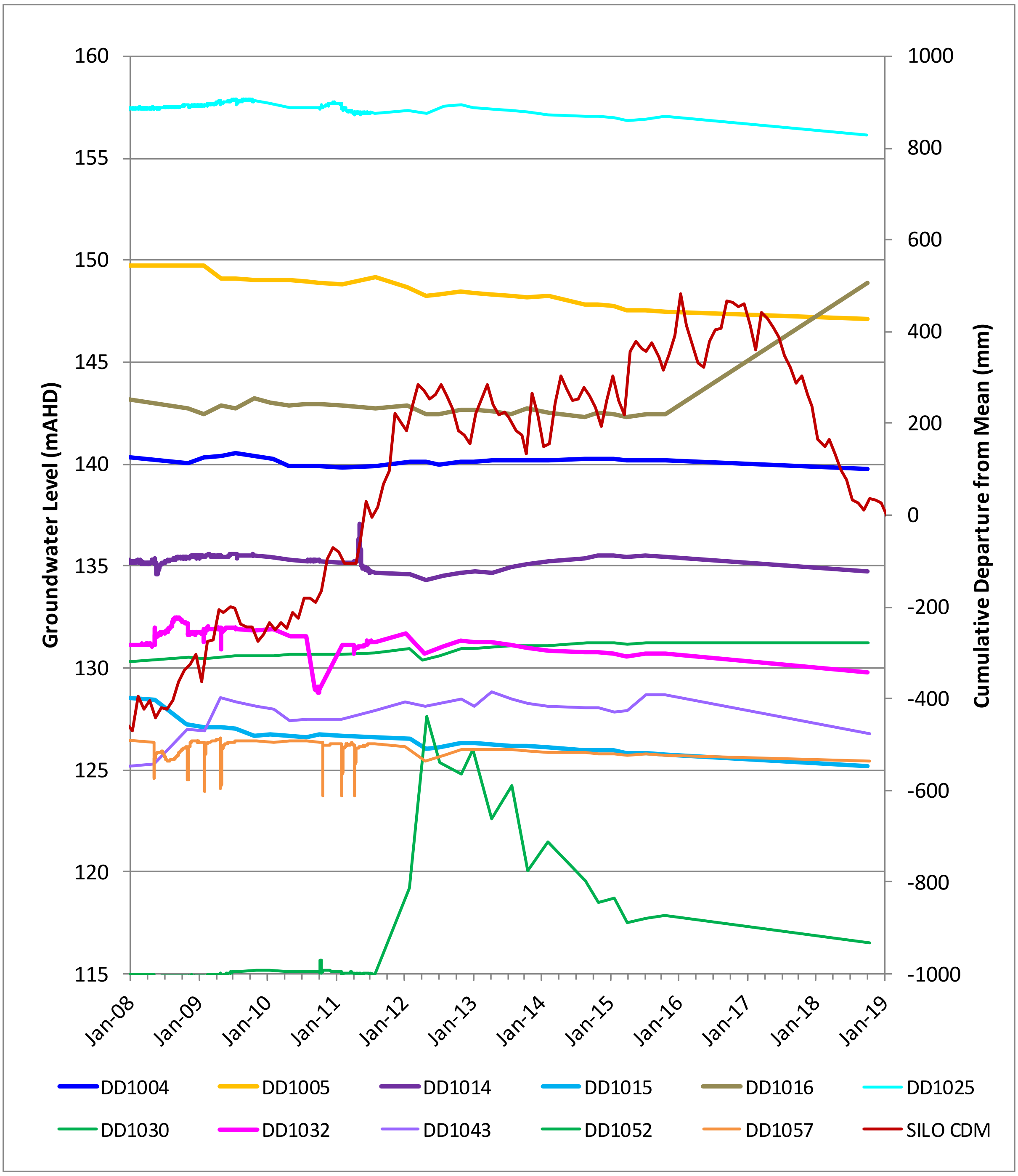


Figure 36 **Hydrographs – Wittingham Coal Measures at Maxwell Underground**

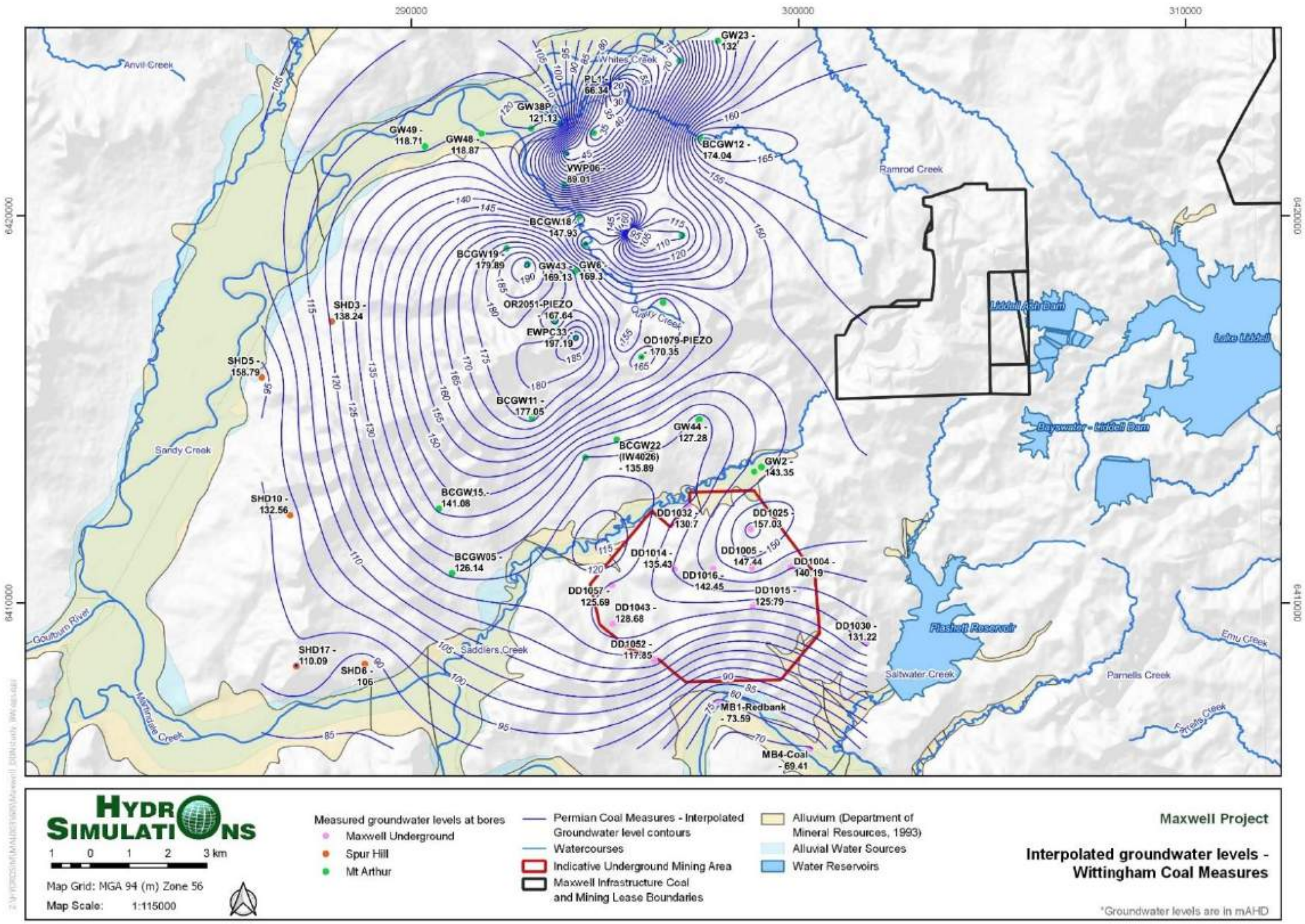


Figure 37 **Permian Coal Measures – Interpolated Potentiometric Surface and Recent Groundwater Levels**

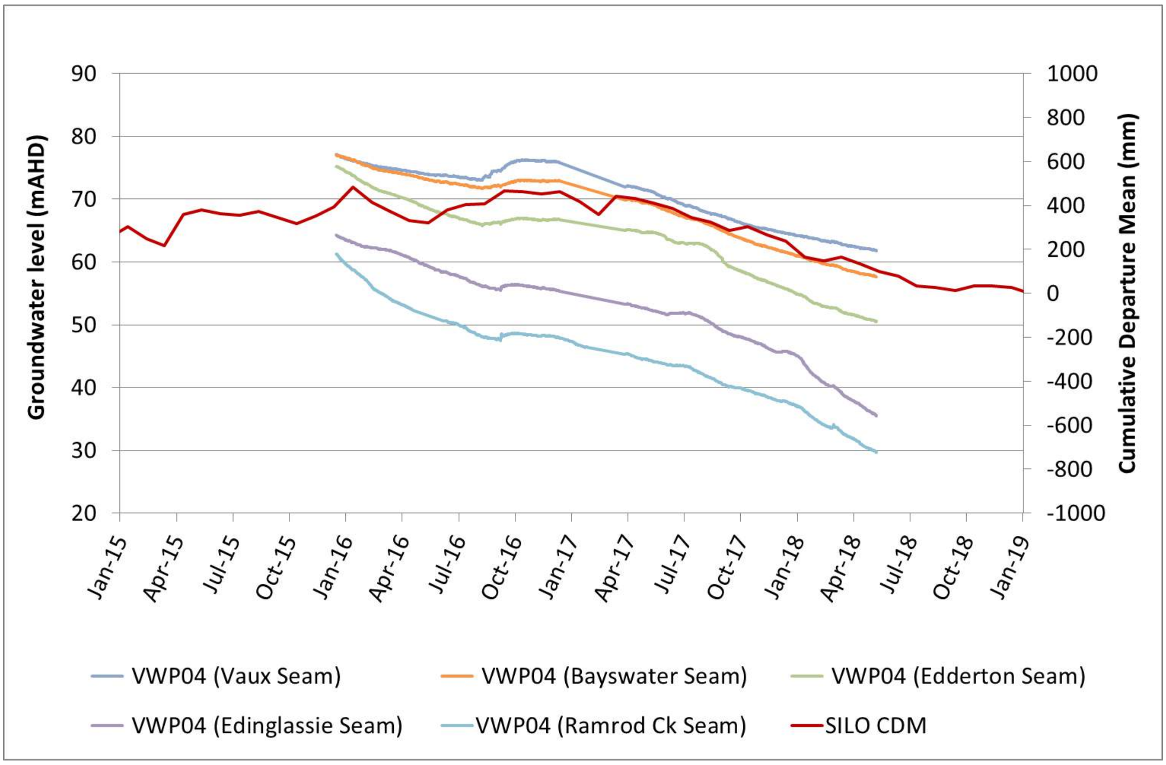


Figure 38 Hydrographs – Wittingham Coal Measures at Mt Arthur Mine – VWP04

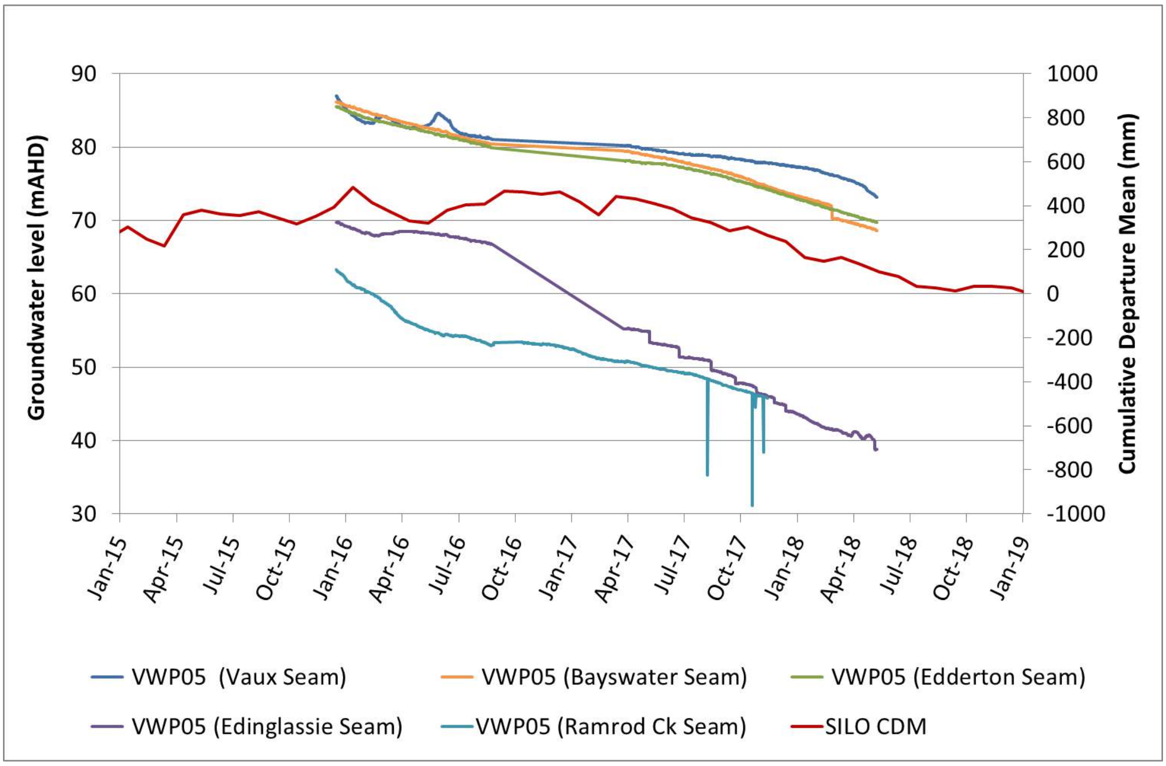


Figure 39 Hydrographs – Wittingham Coal Measures at Mt Arthur Mine – VWP05

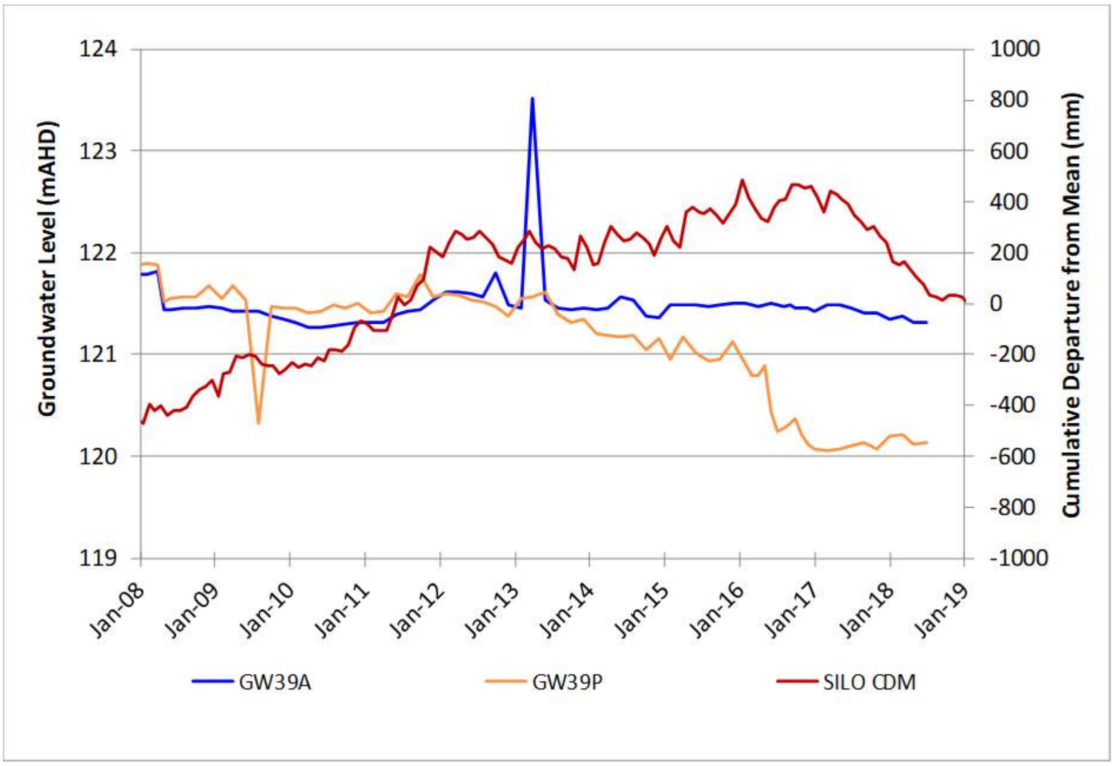


Figure 40 **Hydrographs – GW39A and GW39P**

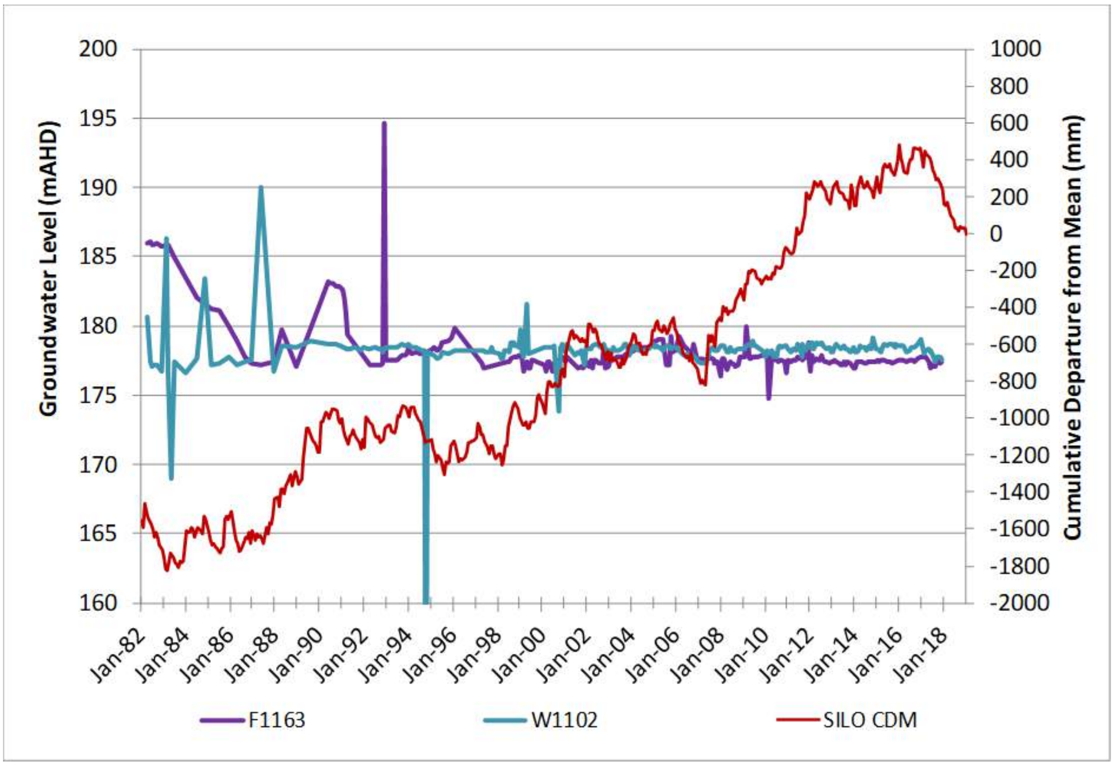


Figure 41 **Hydrographs – Maitland Group**

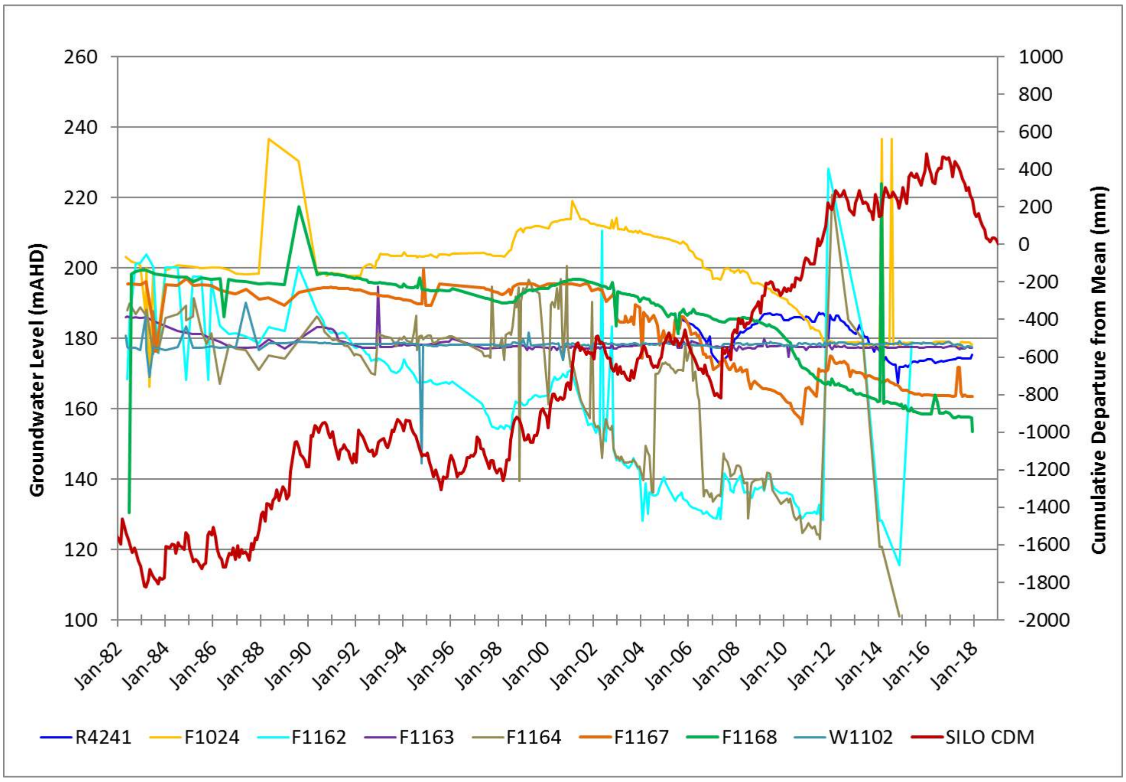


Figure 42 Hydrographs – Greta Coal Measures

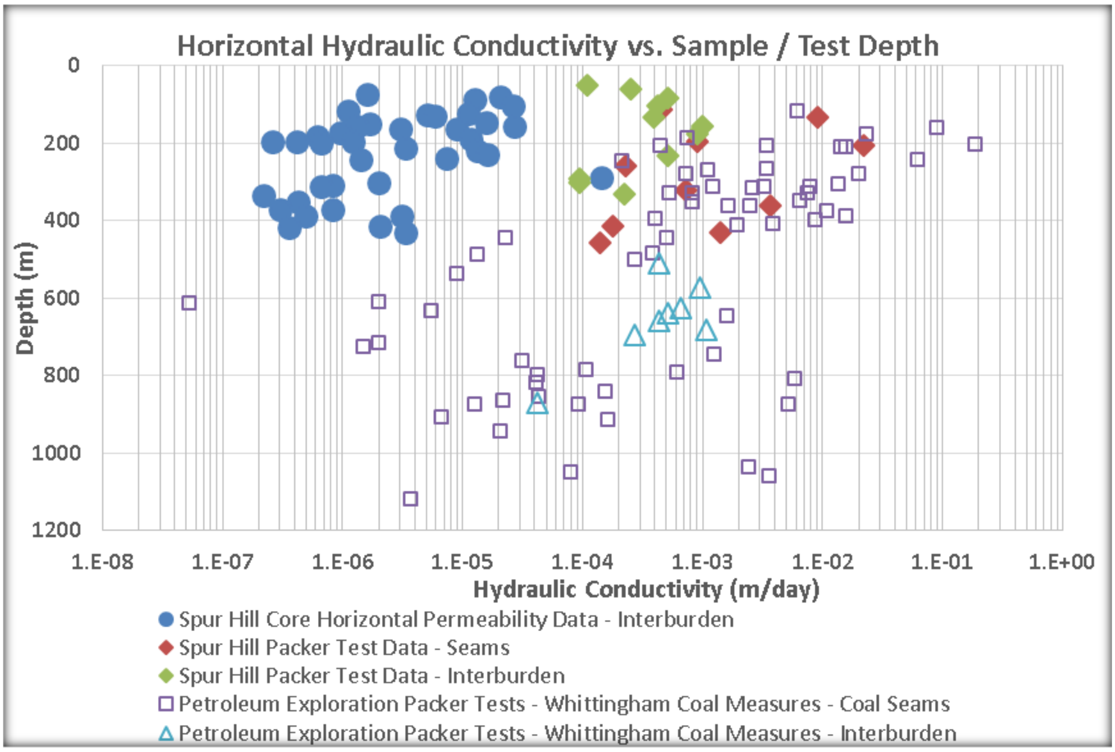


Figure 43 **Horizontal Hydraulic Conductivity vs Depth**

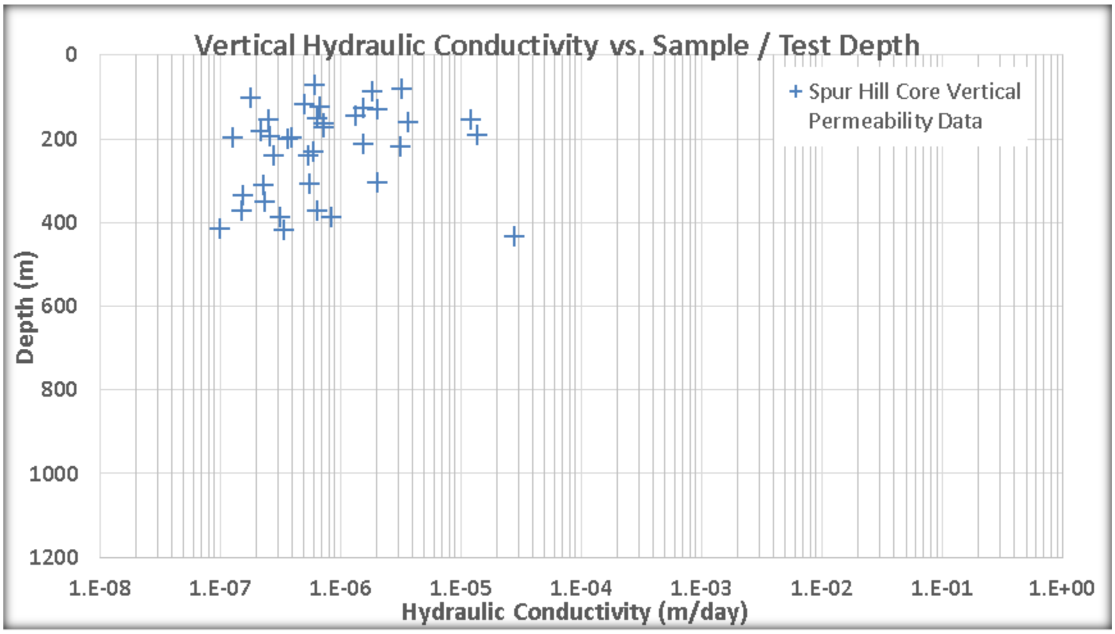


Figure 44 **Vertical Hydraulic Conductivity vs Depth**

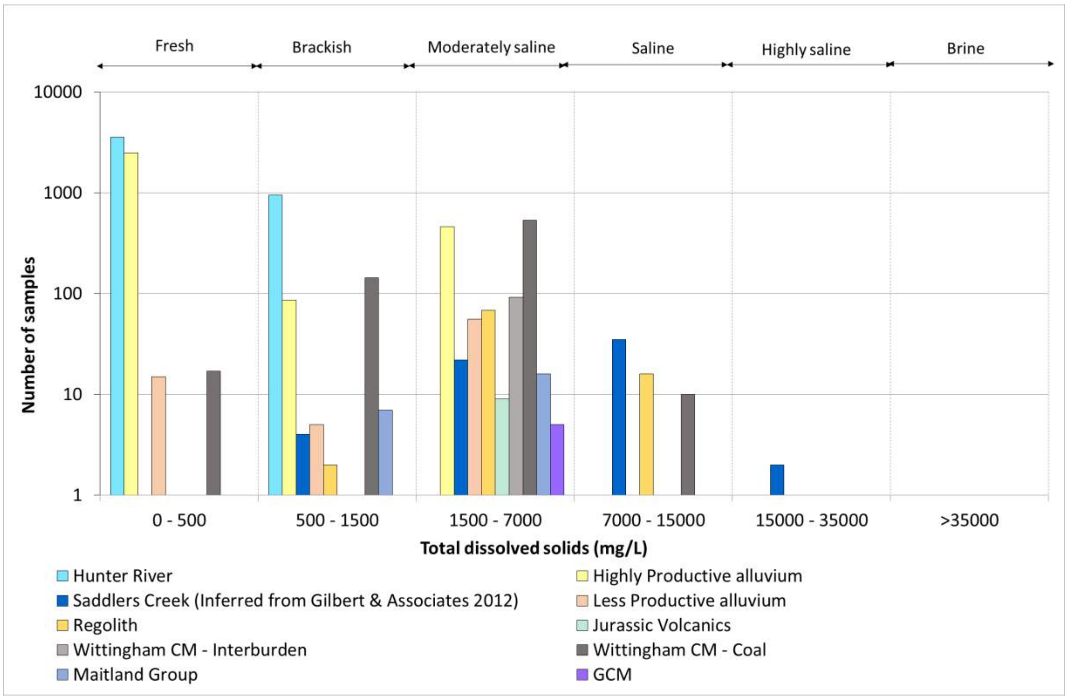


Figure 45 Water Quality – TDS Histogram

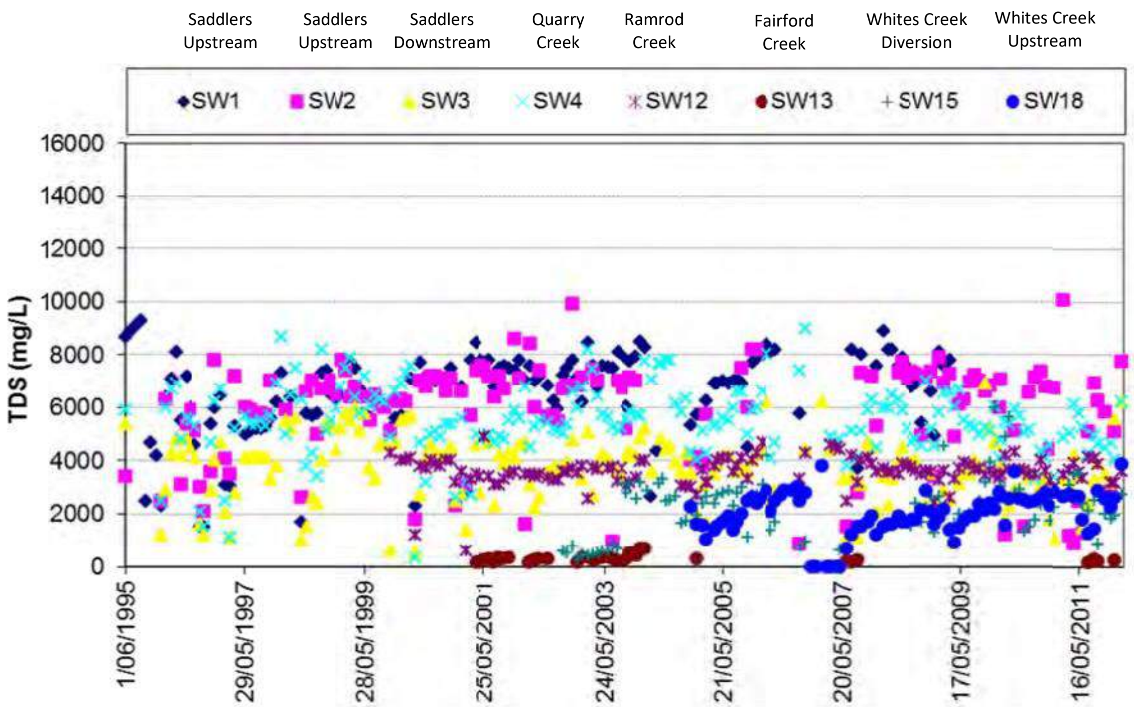


Figure 46 Saddlers Creek Surface Water Quality (Source: Gilbert & Associates 2012)

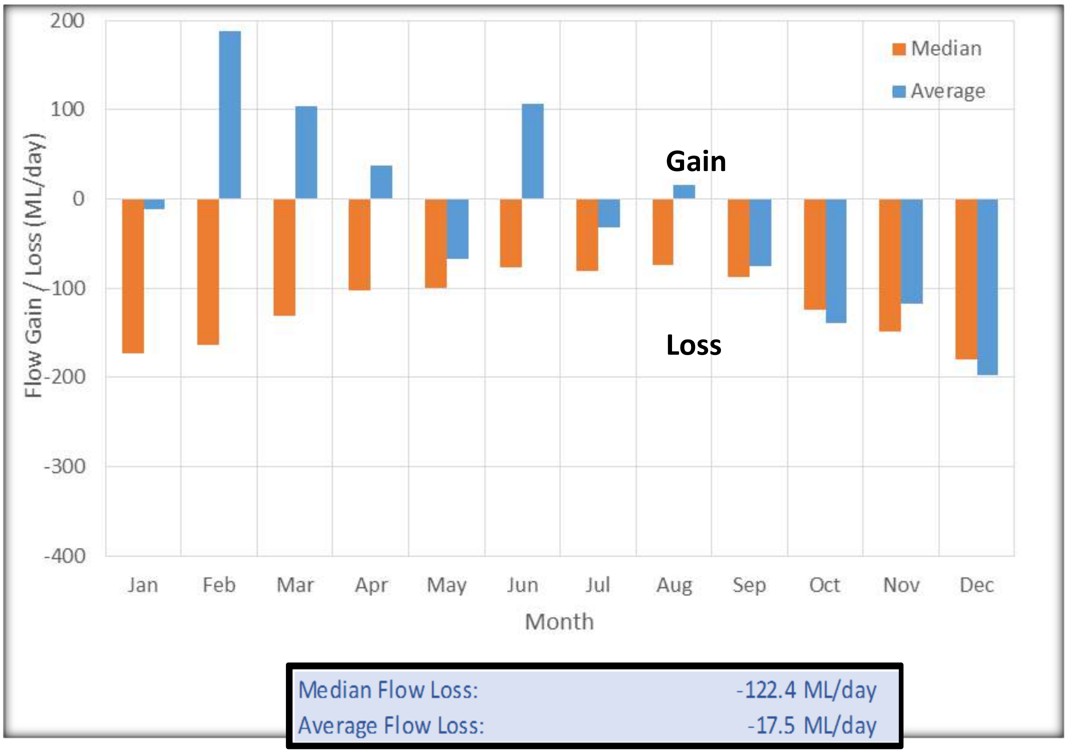


Figure 47 **Monthly Flow Gain/Loss on the Hunter River between Muswellbrook and Liddell (1913-2013)**

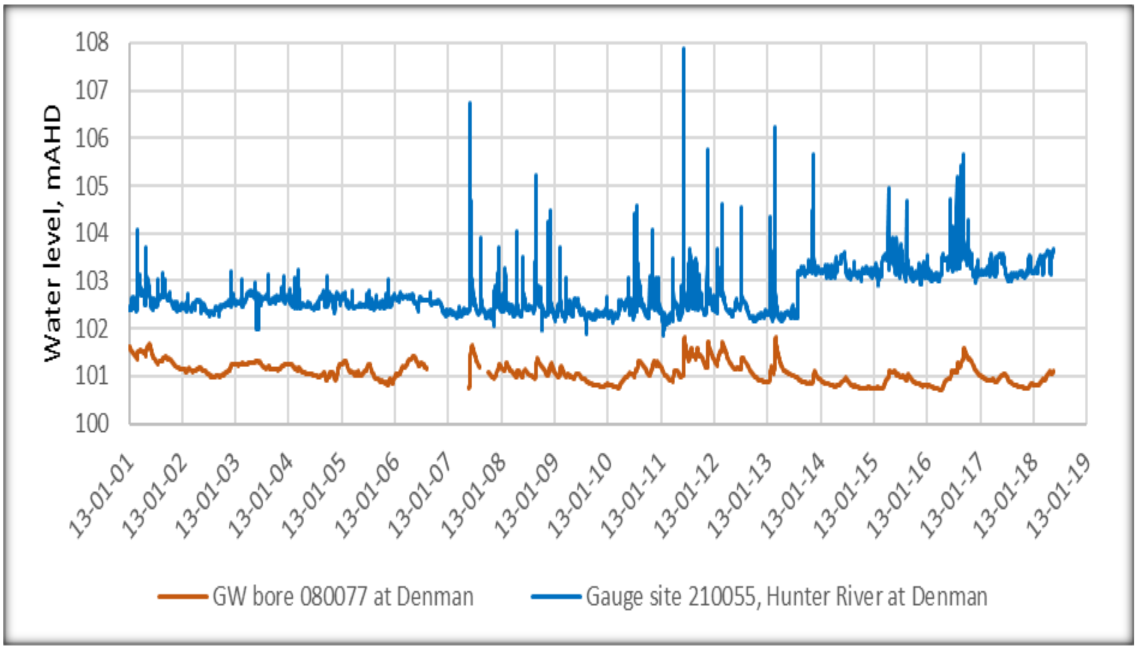


Figure 48 **Hunter River Surface Water and Alluvium Water Levels**

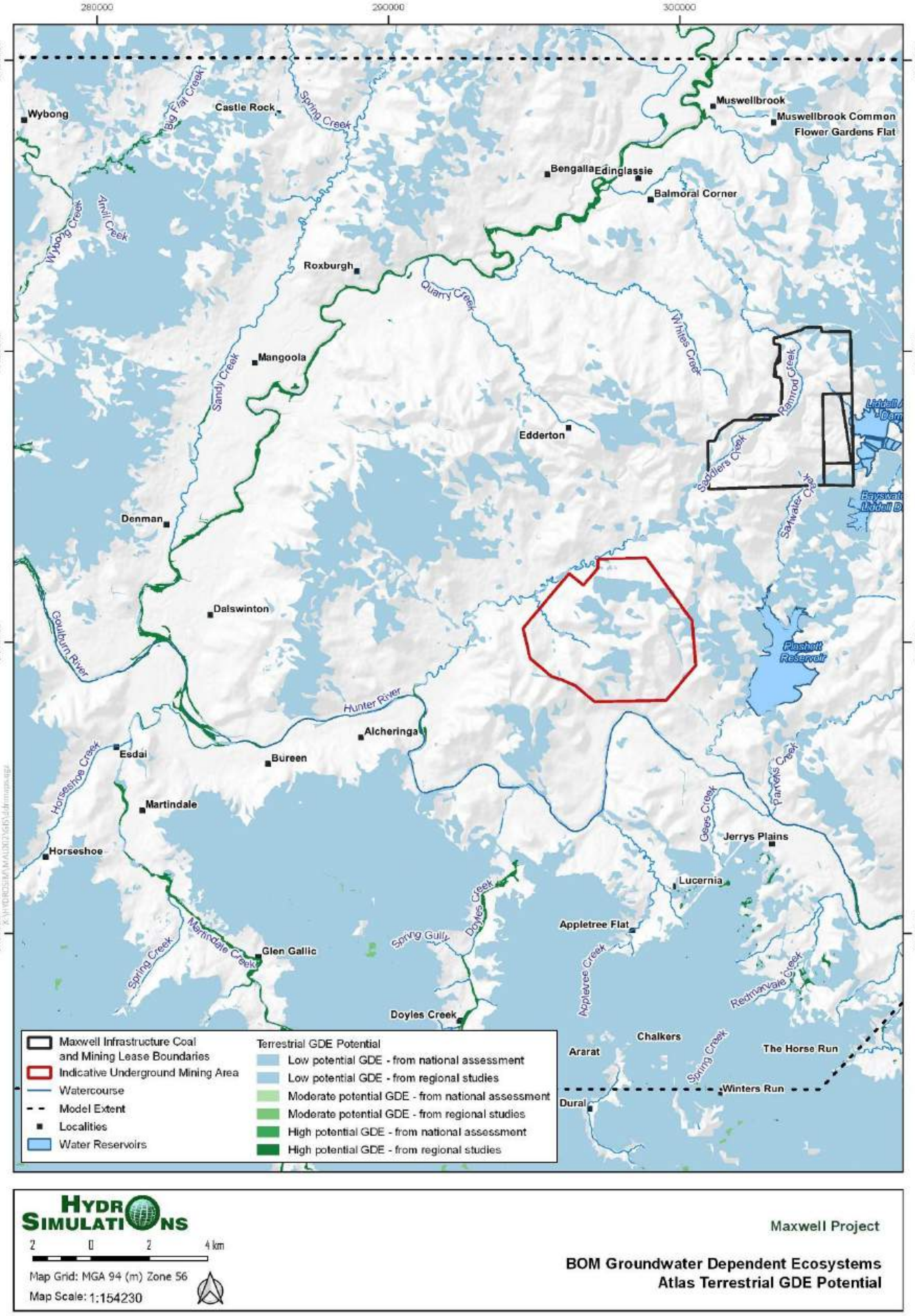


Figure 49 **Potential GDEs from the GDE Atlas for the Project area**

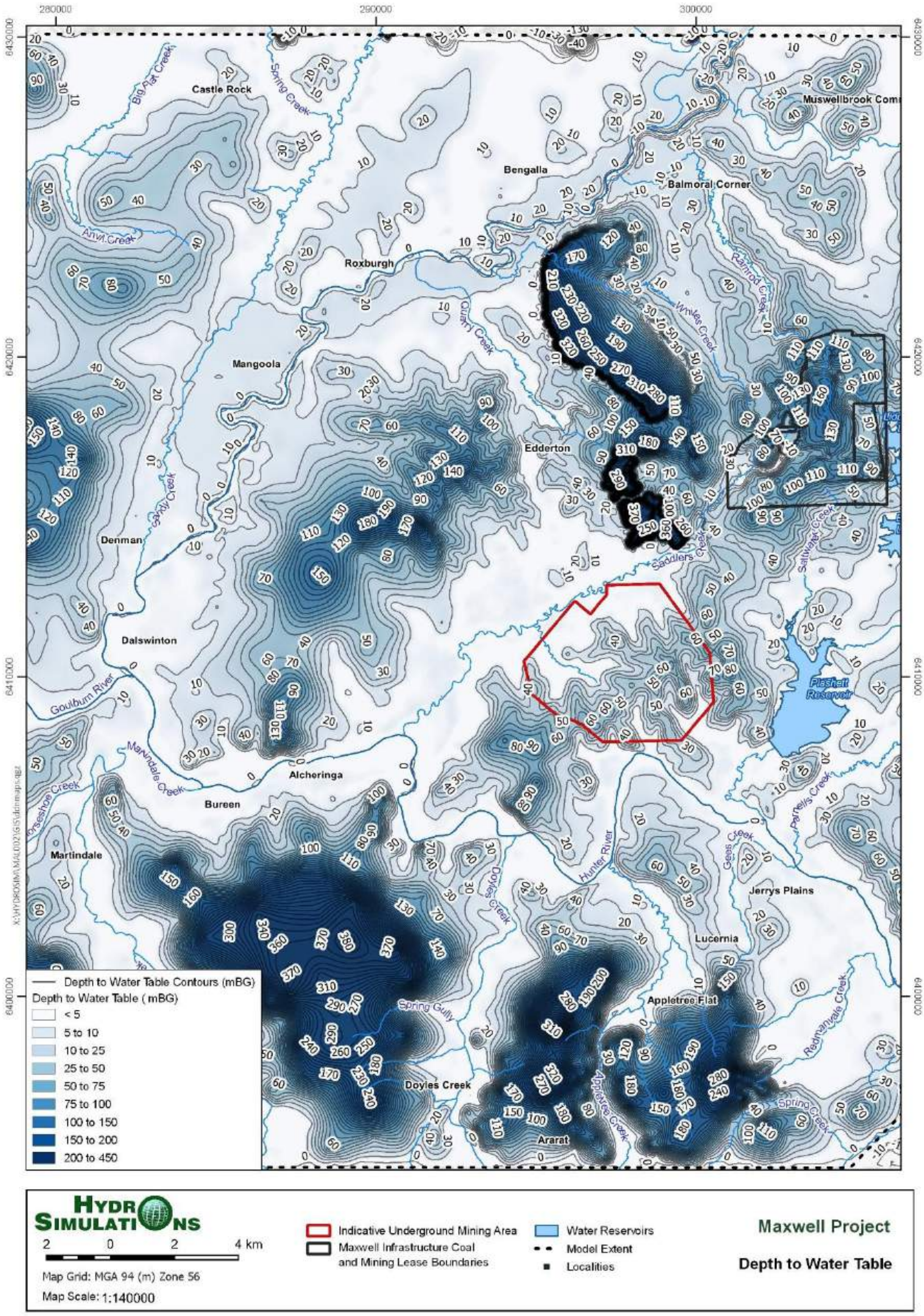


Figure 50 **Inferred Depth to Water Table**

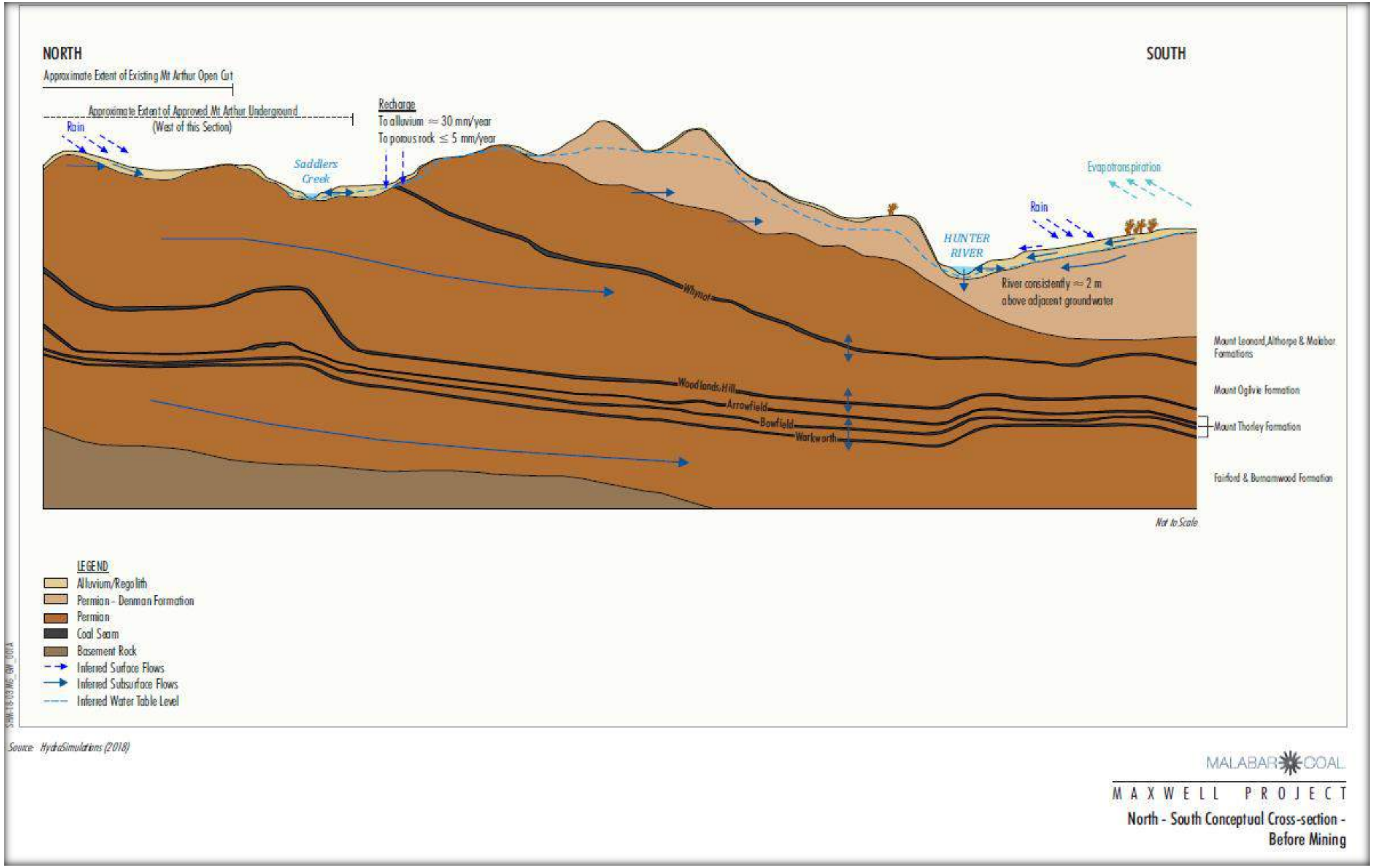


Figure 51 North – South Conceptual Cross Section, EL 5460, before Mining (not to scale)

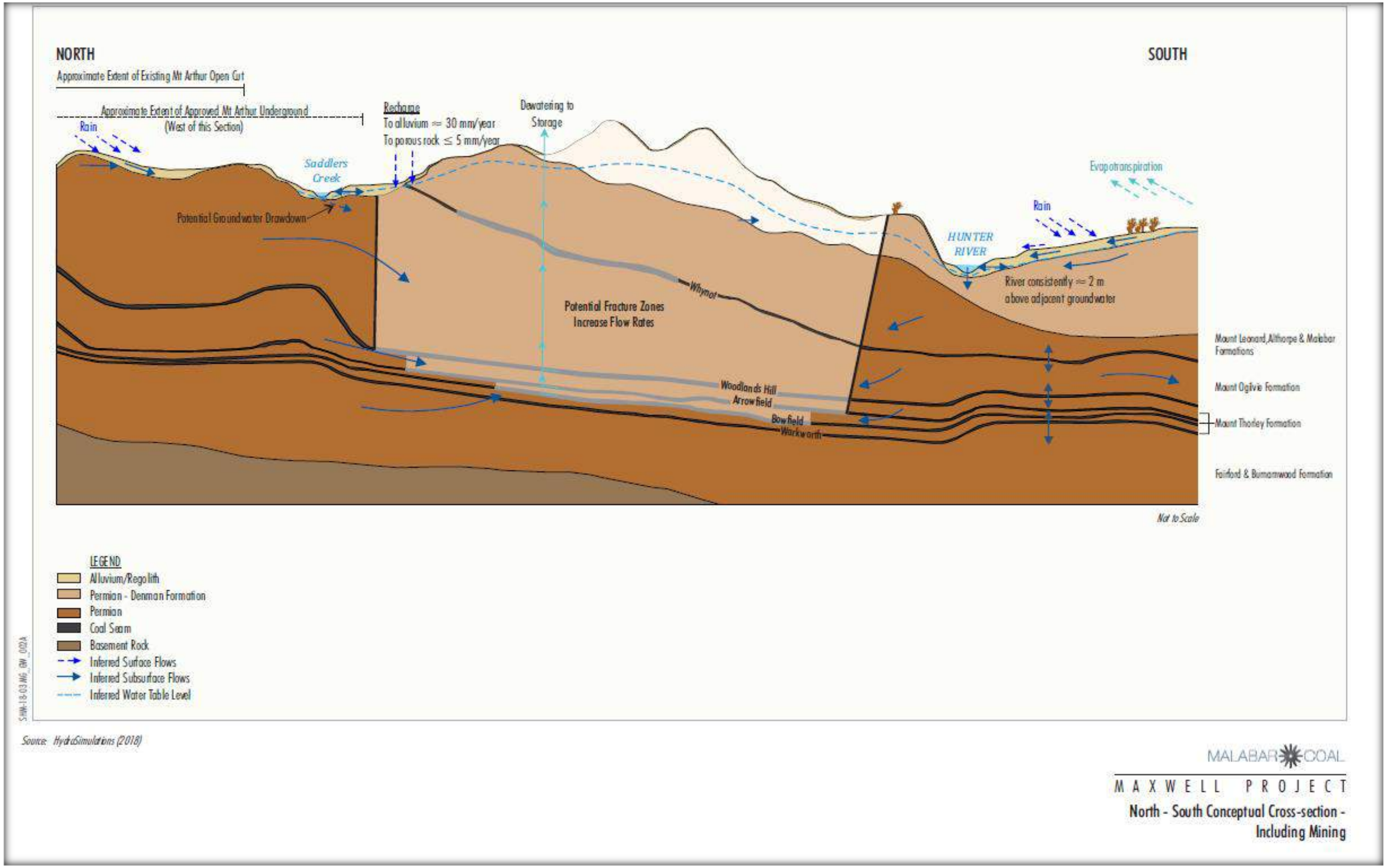


Figure 52 North – South Conceptual Cross Section, EL 5460, including Mining (not to scale)

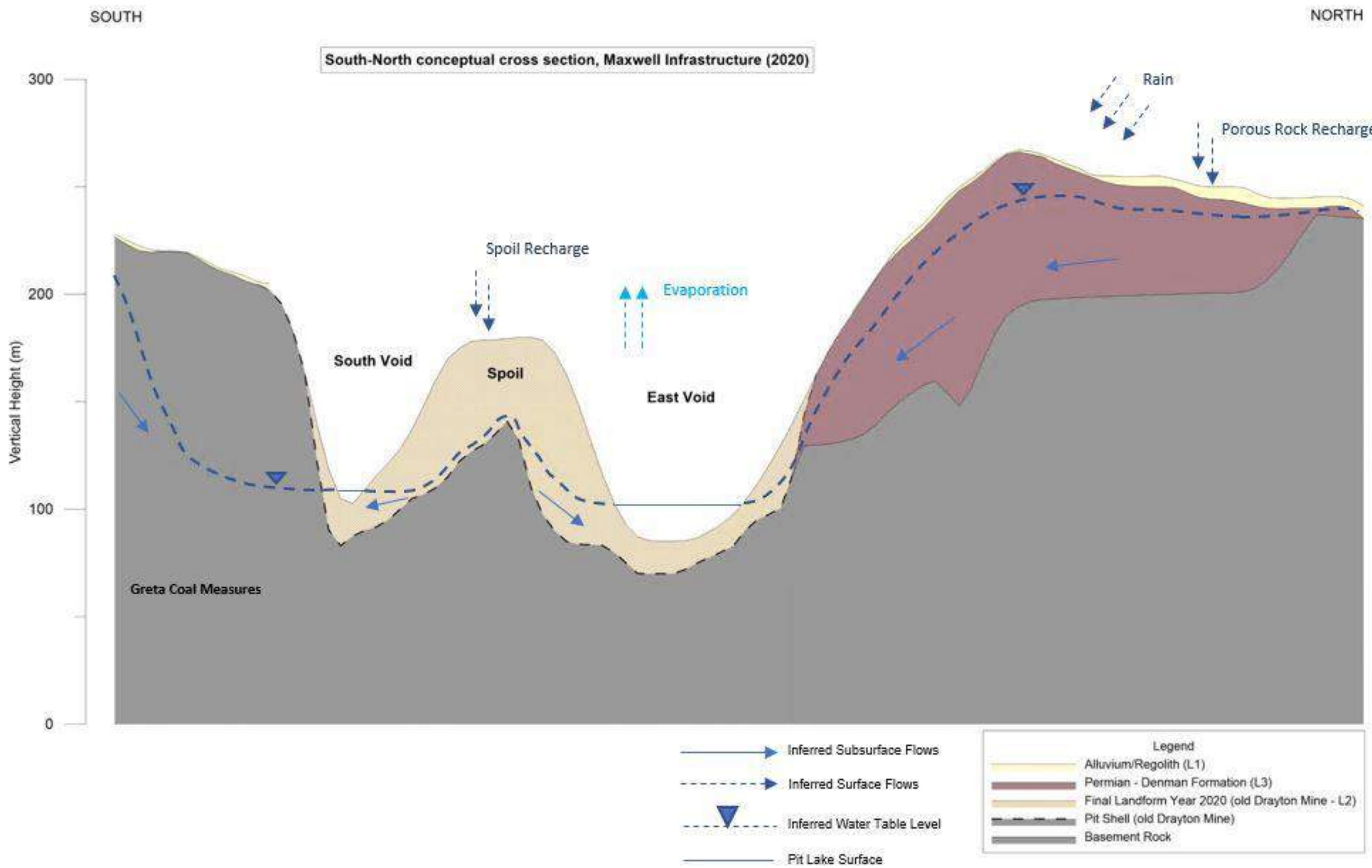


Figure 53 North South Conceptual Cross Section, Maxwell Infrastructure, 2020

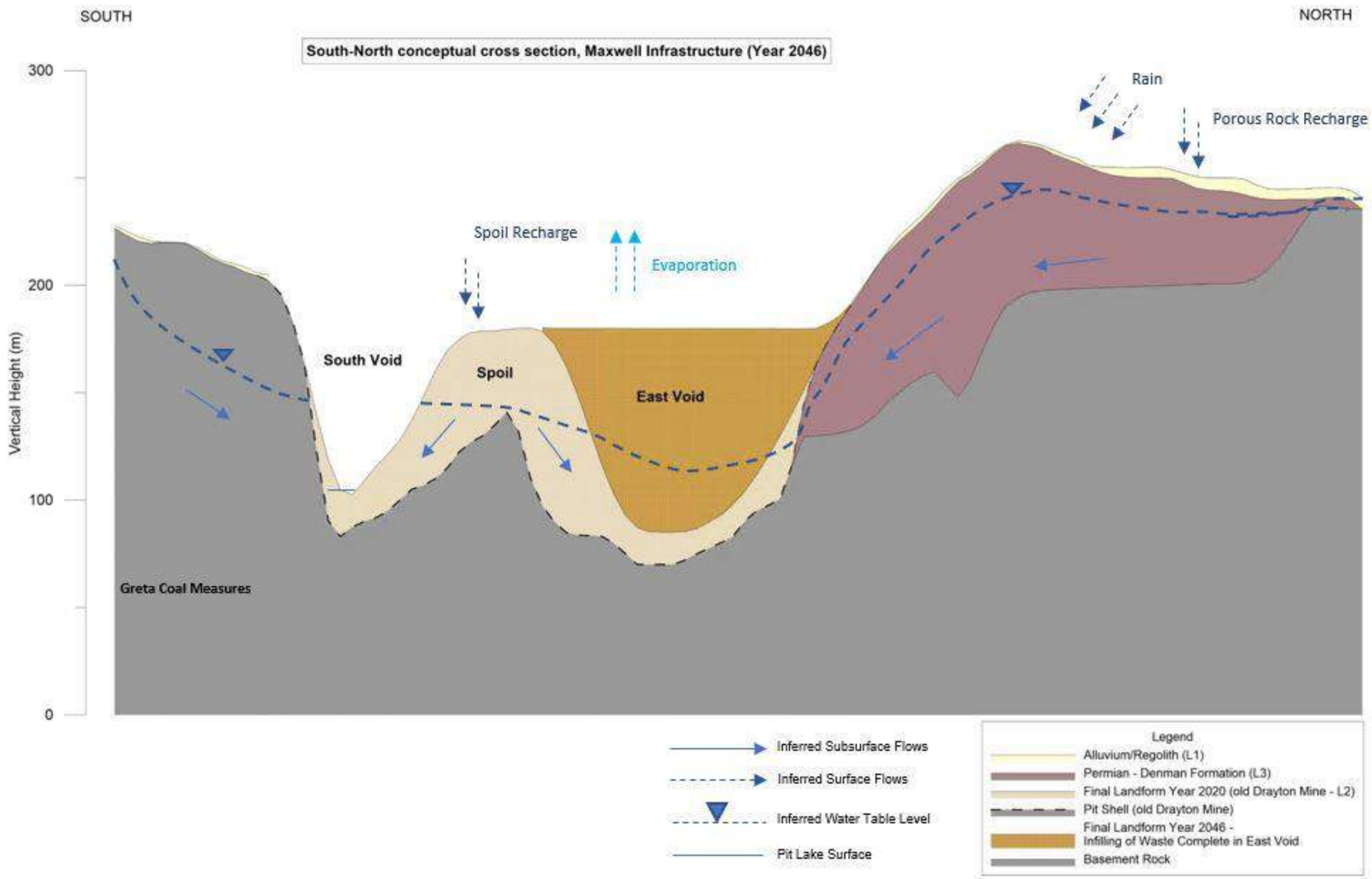


Figure 54 North South Conceptual Cross Section, Maxwell Infrastructure, 2046

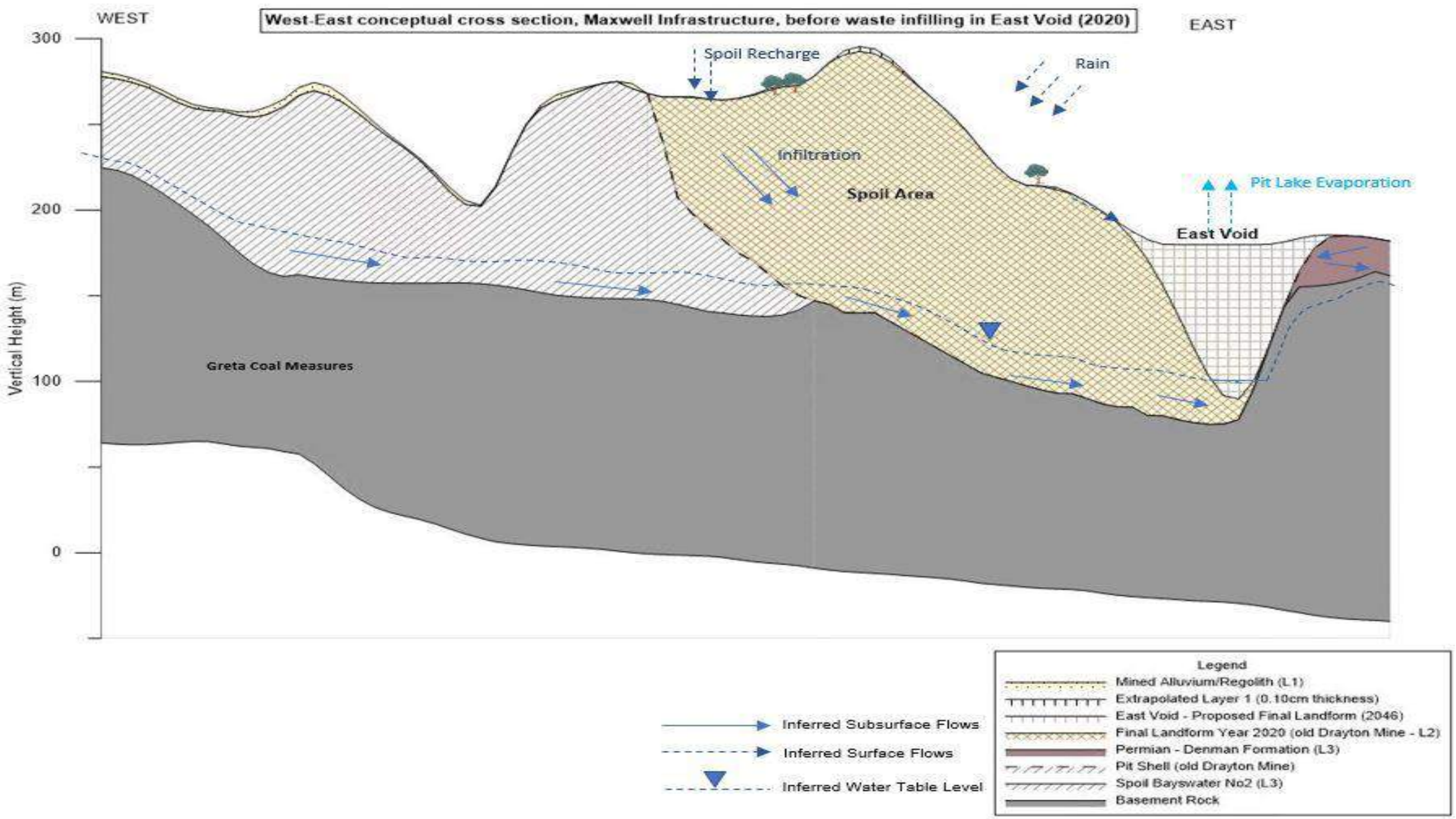


Figure 55 East-West Conceptual Cross Section, Maxwell Infrastructure, before CHPP reject emplacement in East Void, 2020

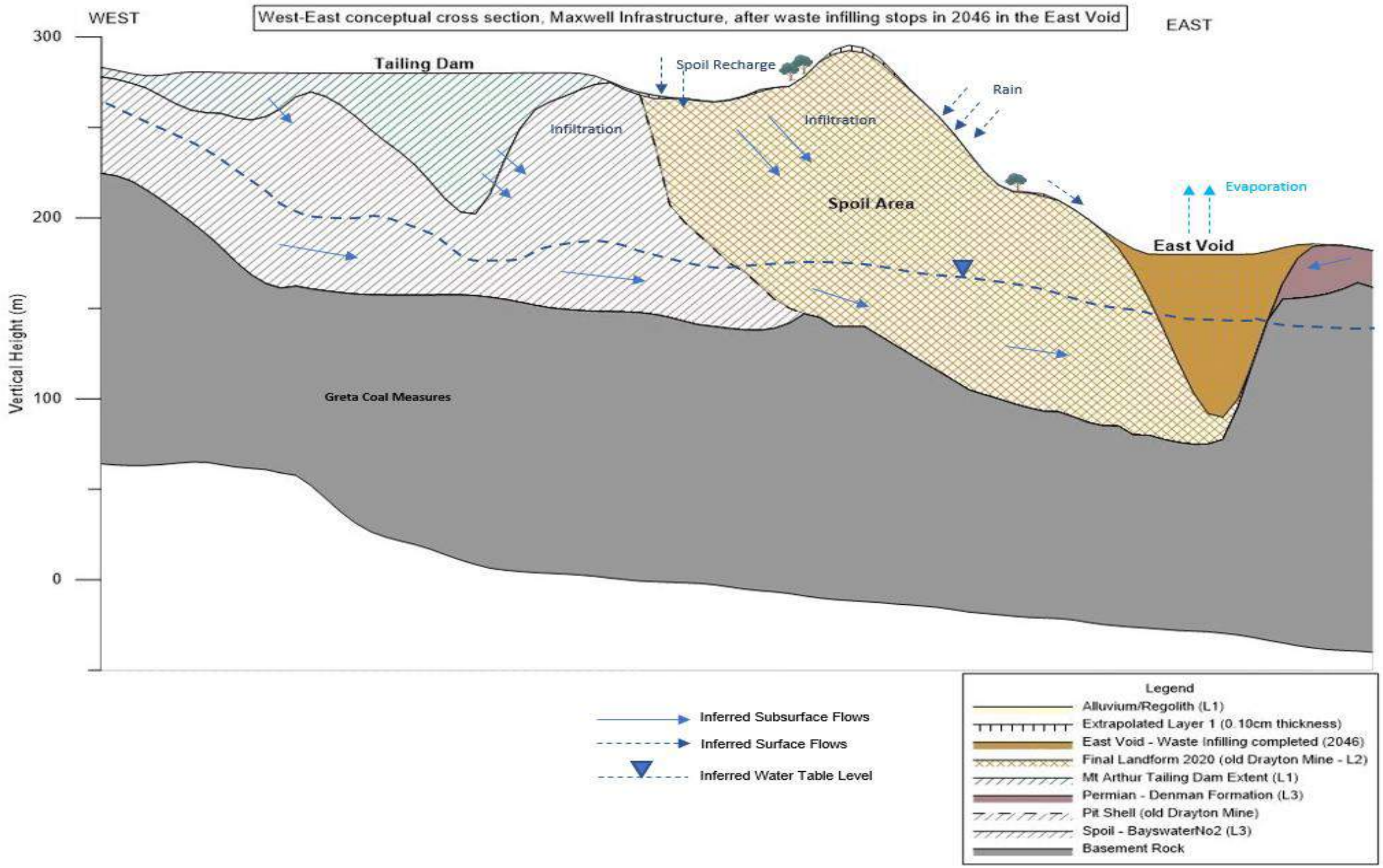


Figure 56 East-West Conceptual Cross Section, Maxwell Infrastructure, after Completion of CHPP reject emplacement in East Void, 2046

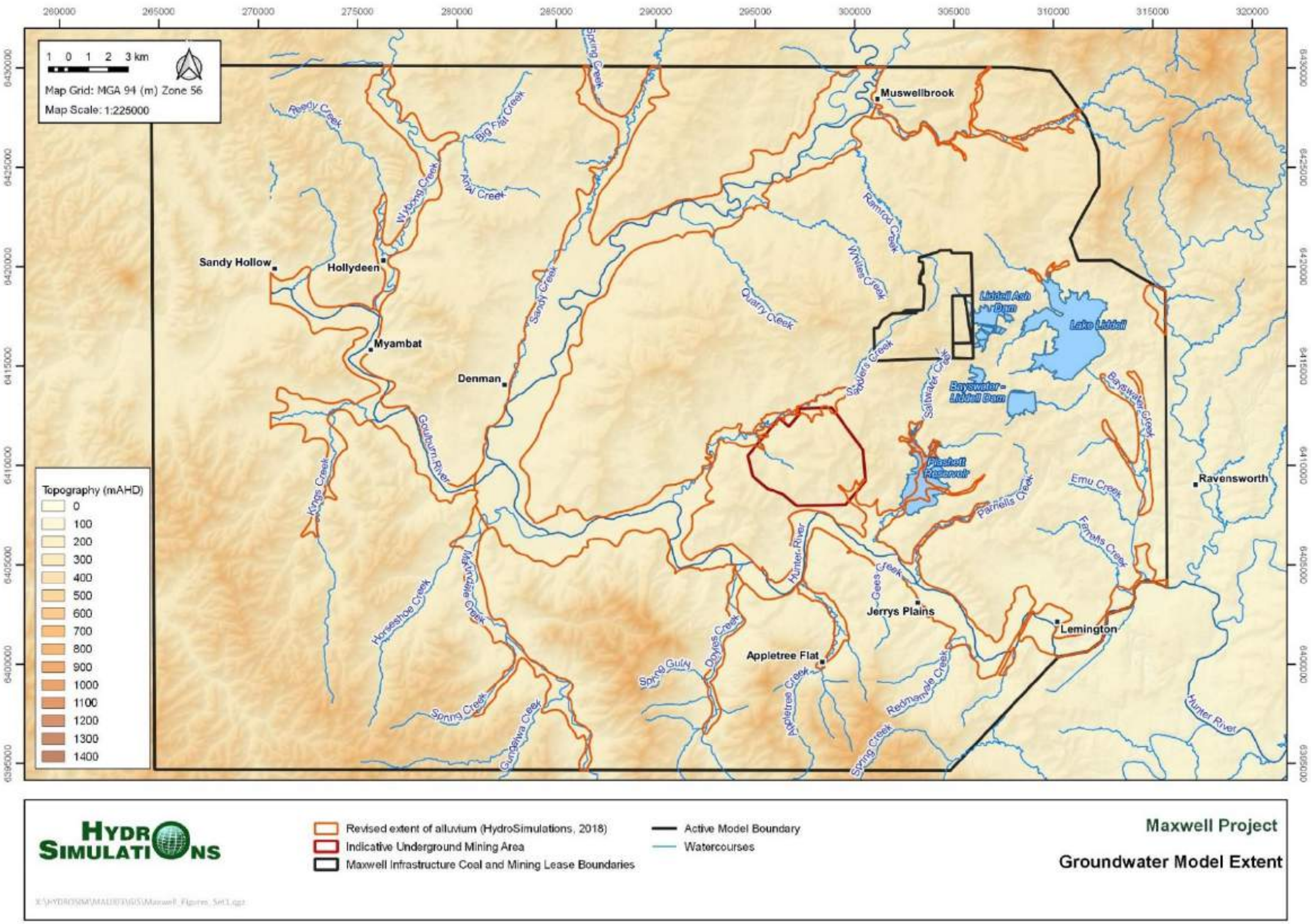


Figure 57 Groundwater Model Extent

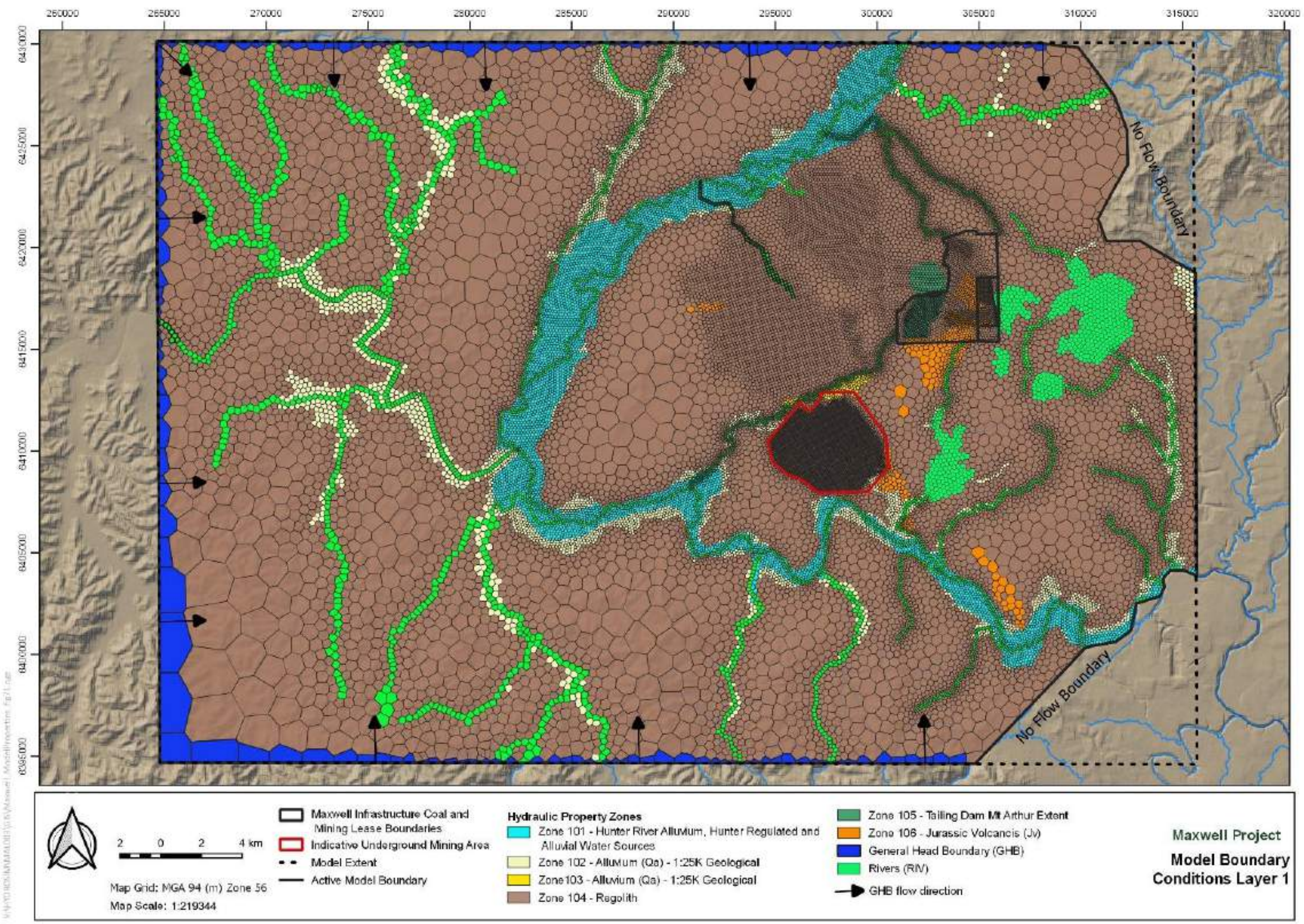


Figure 58 Model Boundary Conditions in Layer 1

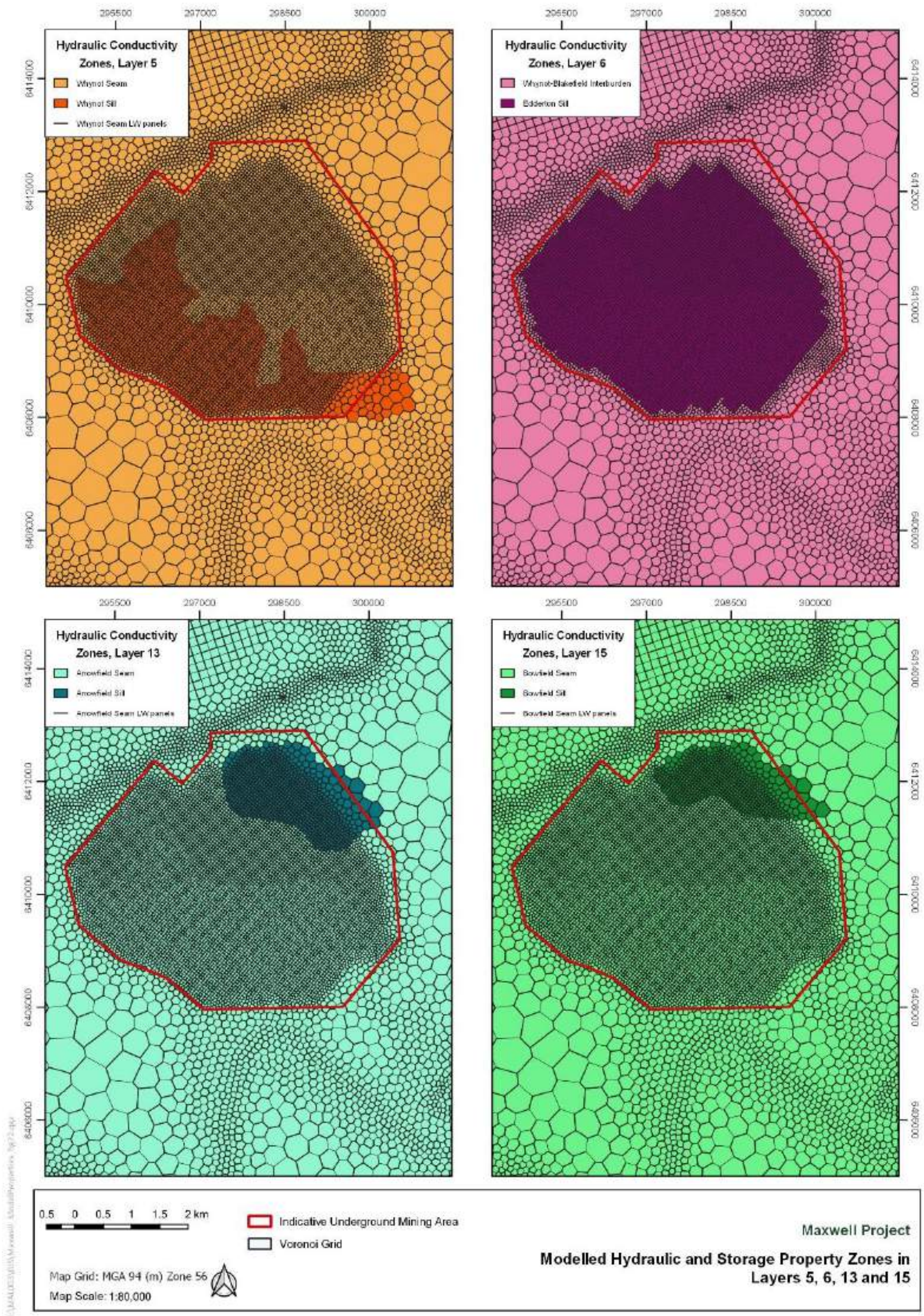


Figure 59 Modelled Hydraulic and Storage Property Zones in Layers 5, 6, 13 and 15

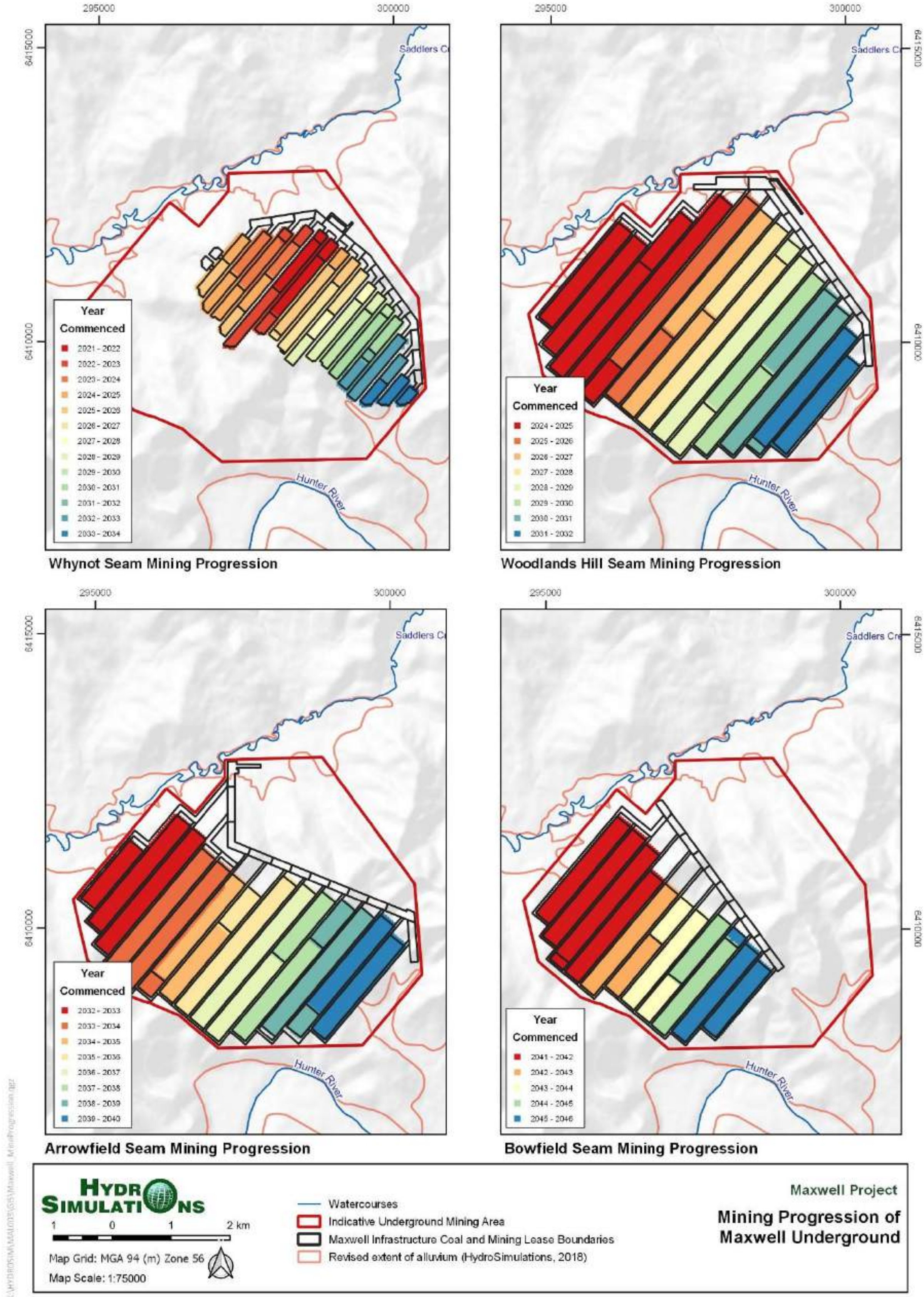


Figure 60 **Mining Progression of Maxwell Underground**

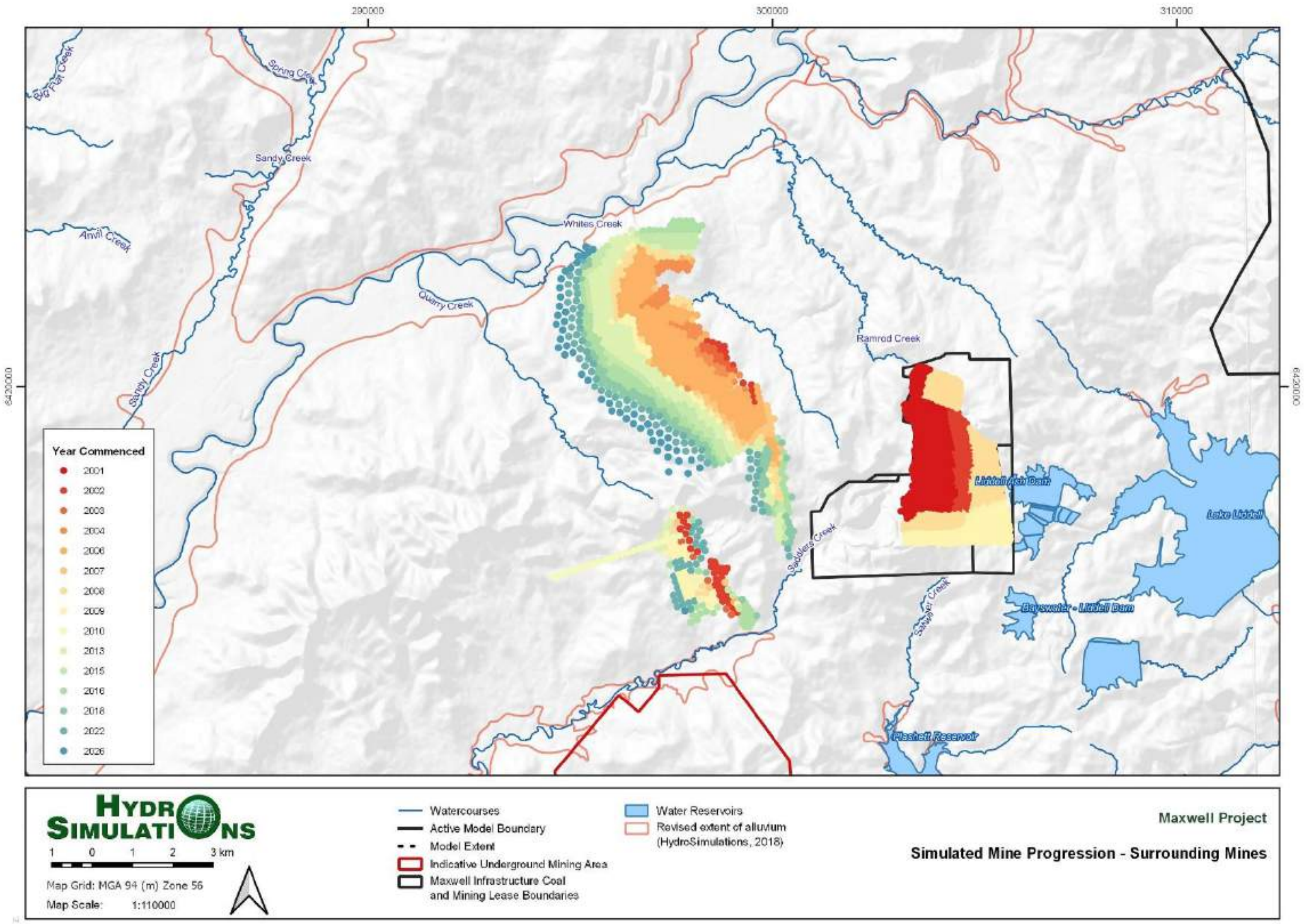


Figure 61 Simulated Mine Progression – Surrounding Mines

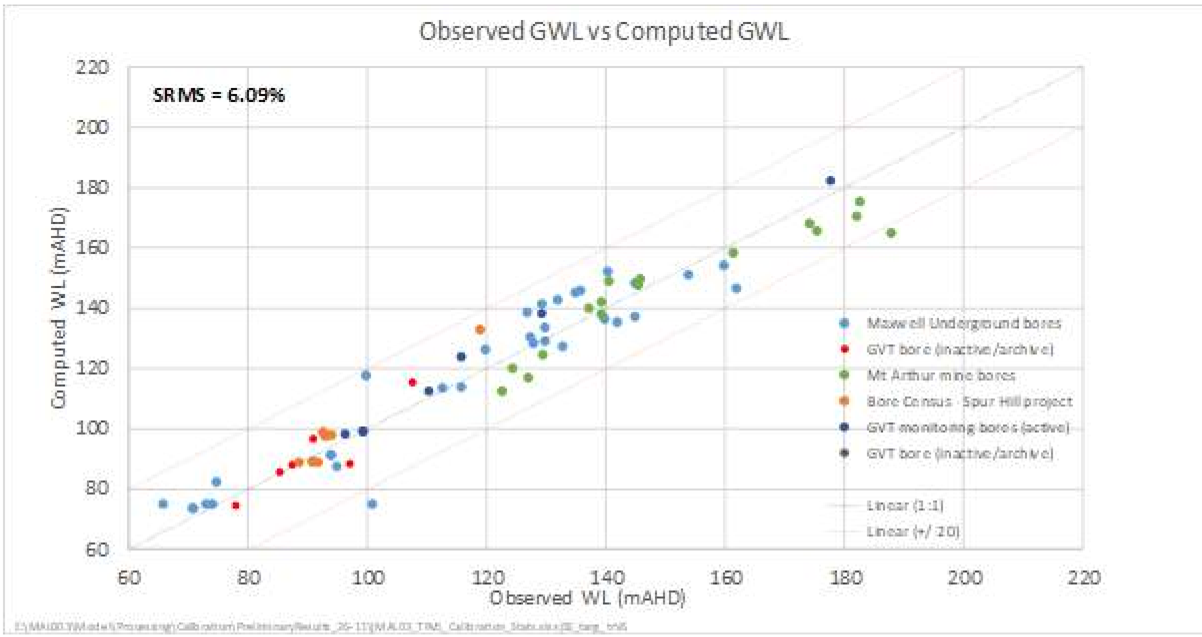


Figure 62 Steady-State Calibration – Modelled to Observed Groundwater Levels

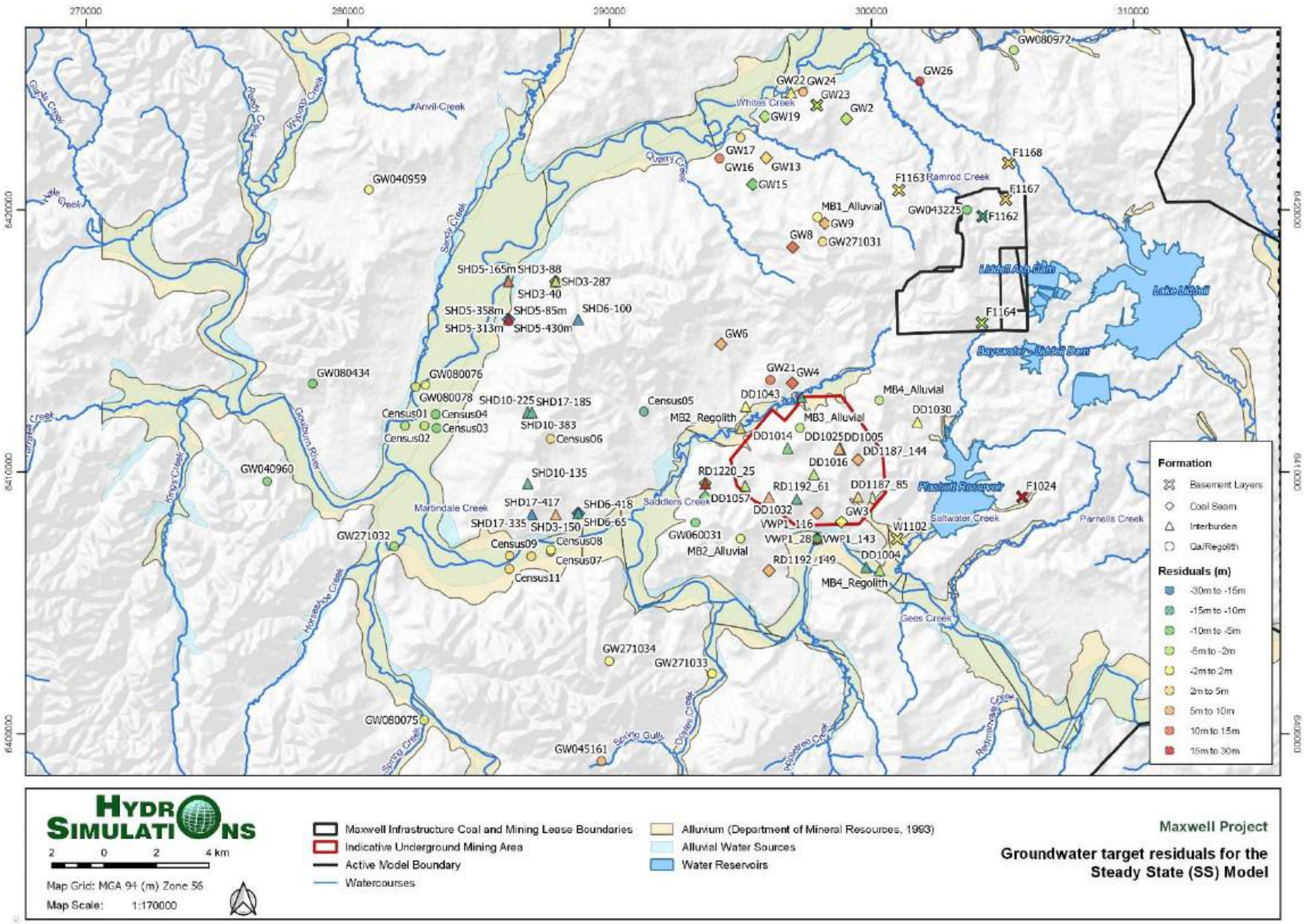


Figure 63 Steady-State Calibration Residual Map ***[defined as observed minus modelled]***

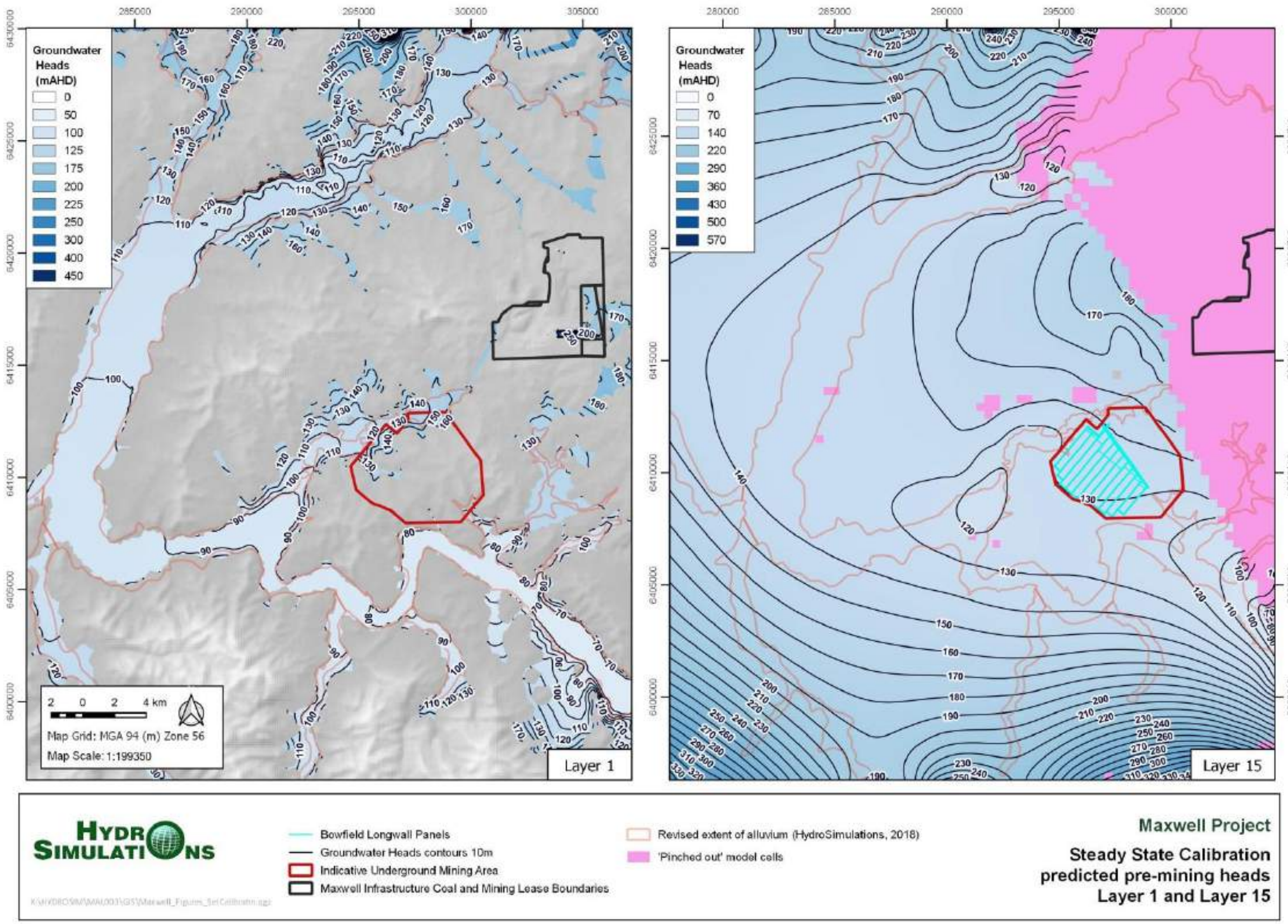


Figure 64 Steady-State Calibration Predicted Pre-Mining Heads – Layer 1 and Layer 15

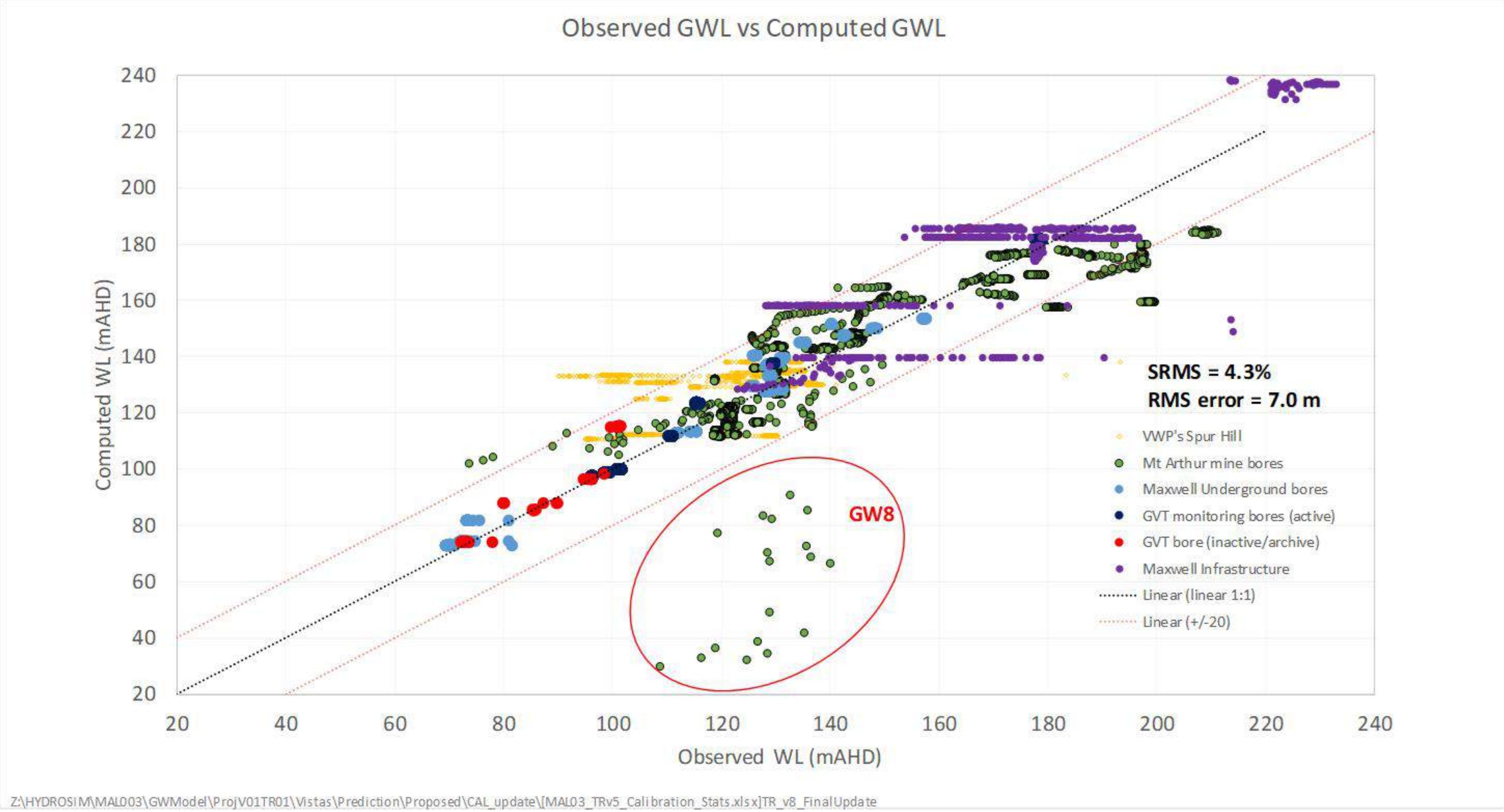


Figure 65 Transient Calibration – Modelled to Observed Groundwater Levels

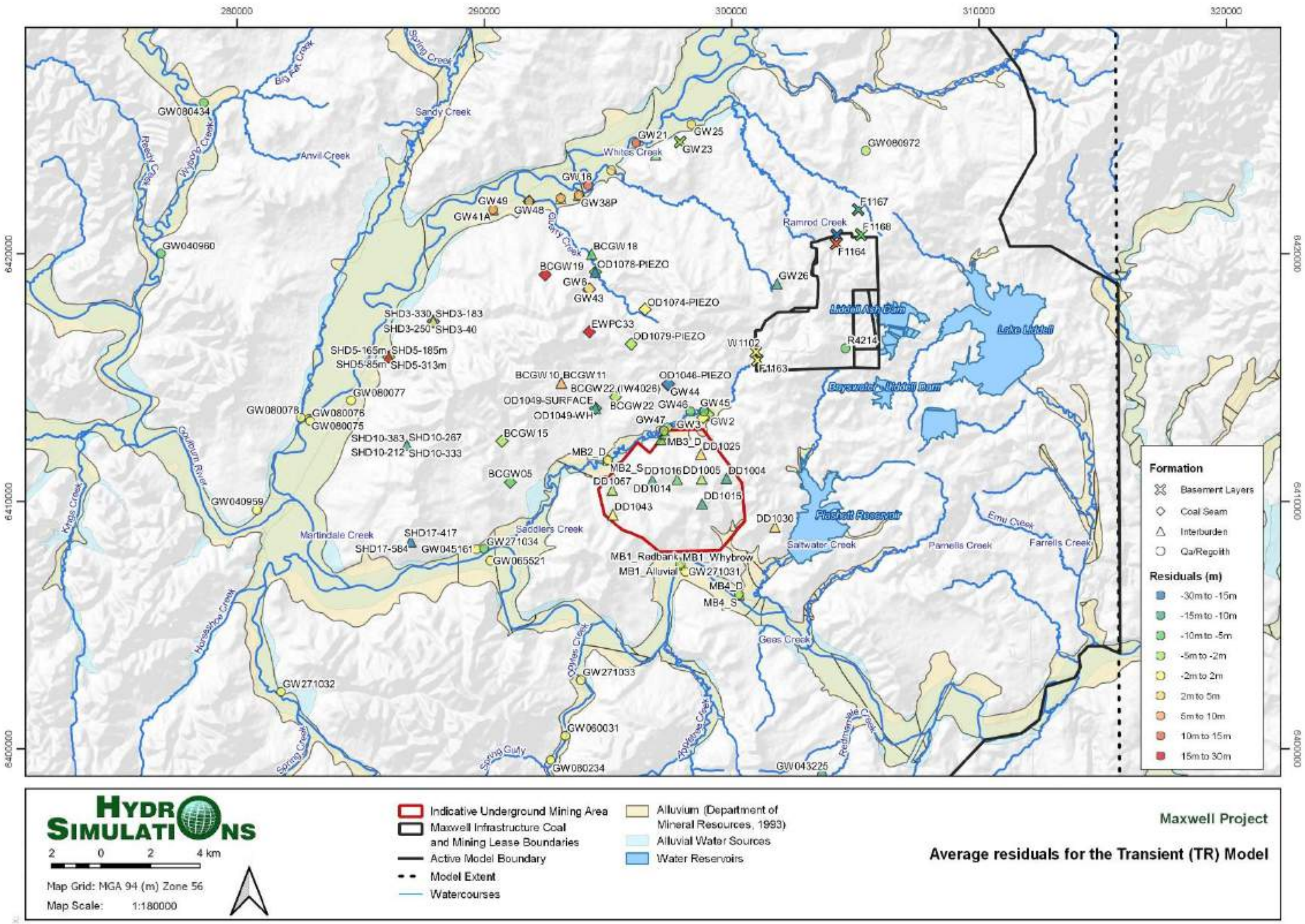


Figure 66 Transient Calibration Residual Map

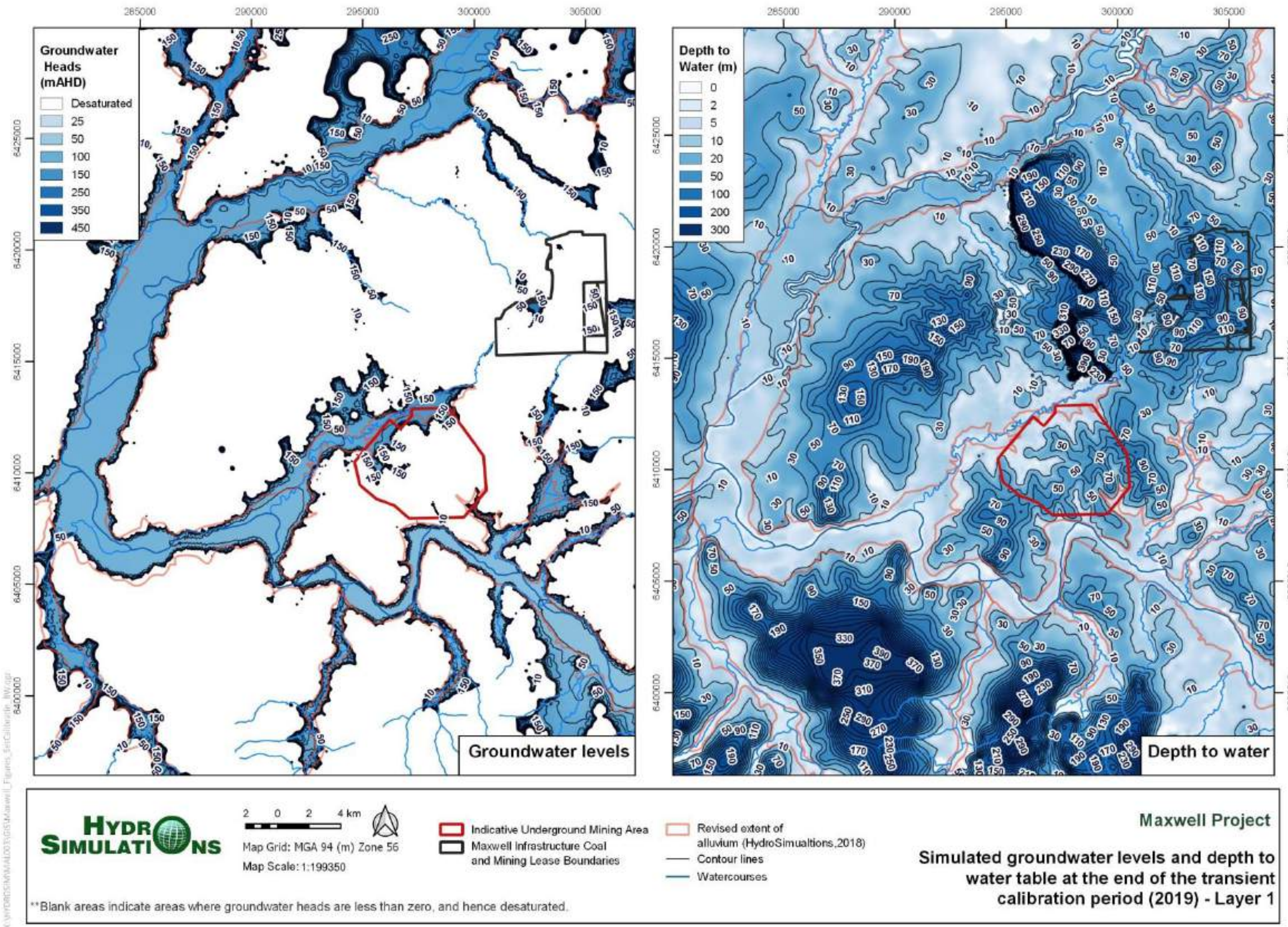


Figure 67 Transient Calibration Predicted Heads and Depth to Water Table 2019 (Saturated Extent) – Layer 1

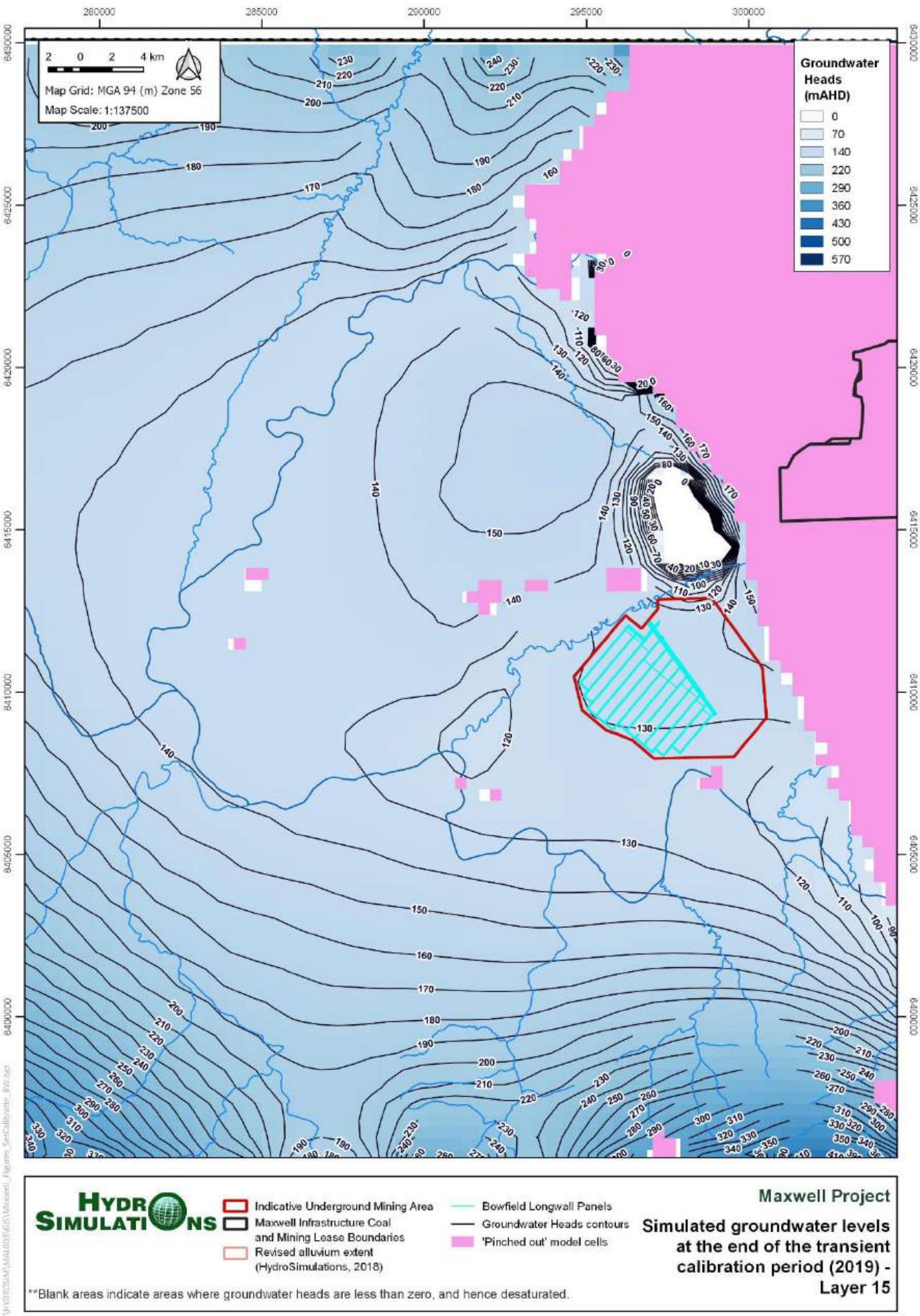


Figure 68 Transient Calibration Predicted Heads 2019 – Layer 15

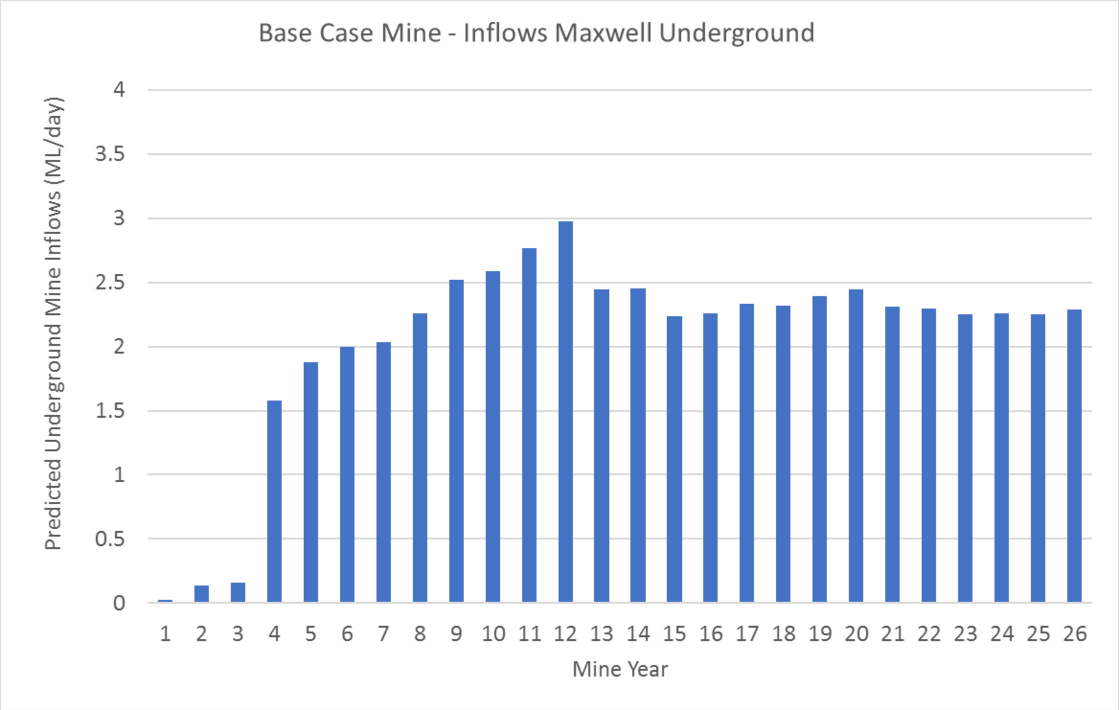


Figure 69 Predicted Inflows to Maxwell Underground – Basecase

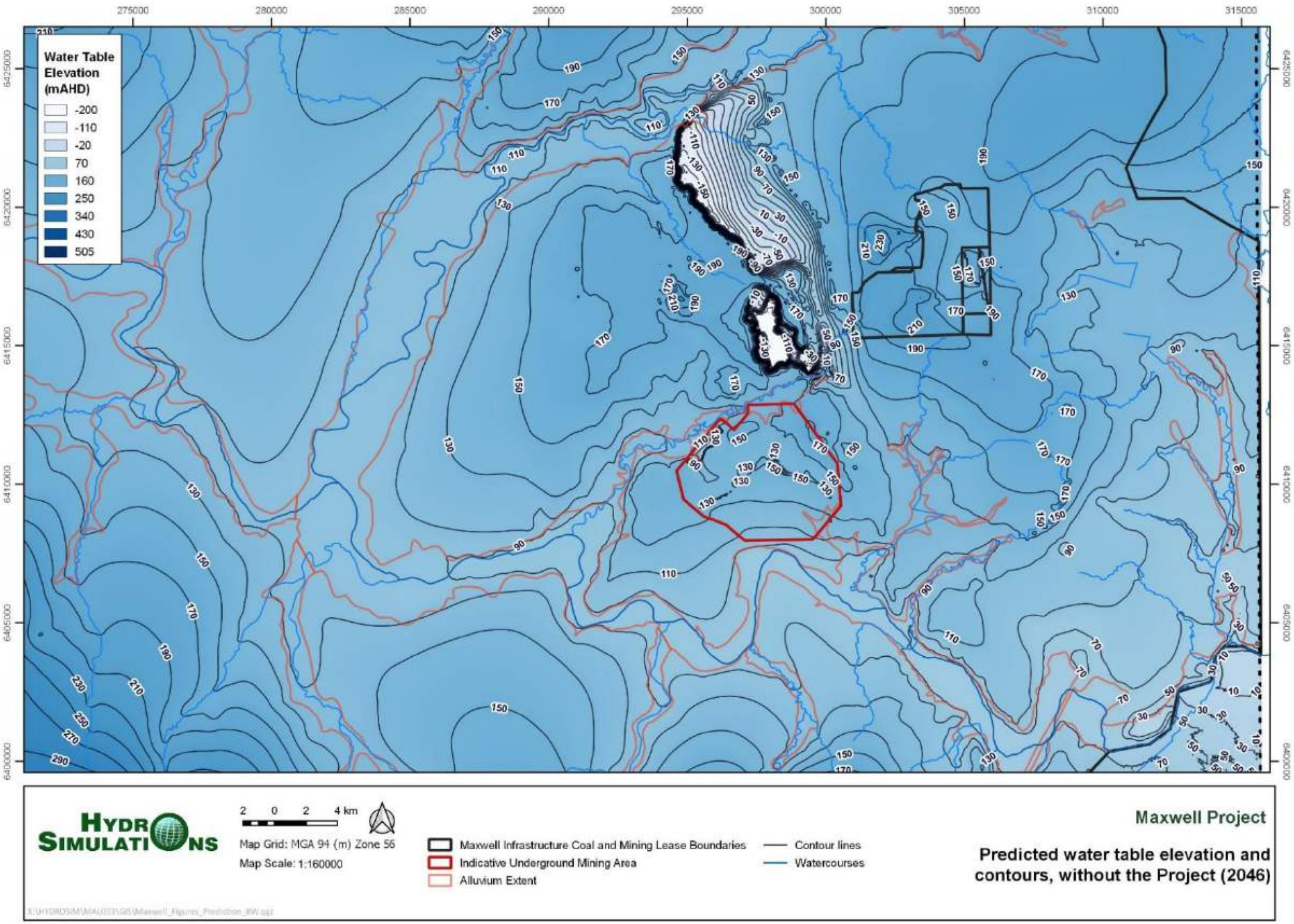


Figure 70 **Predicted water table elevation and contours, without the Project (2046)**

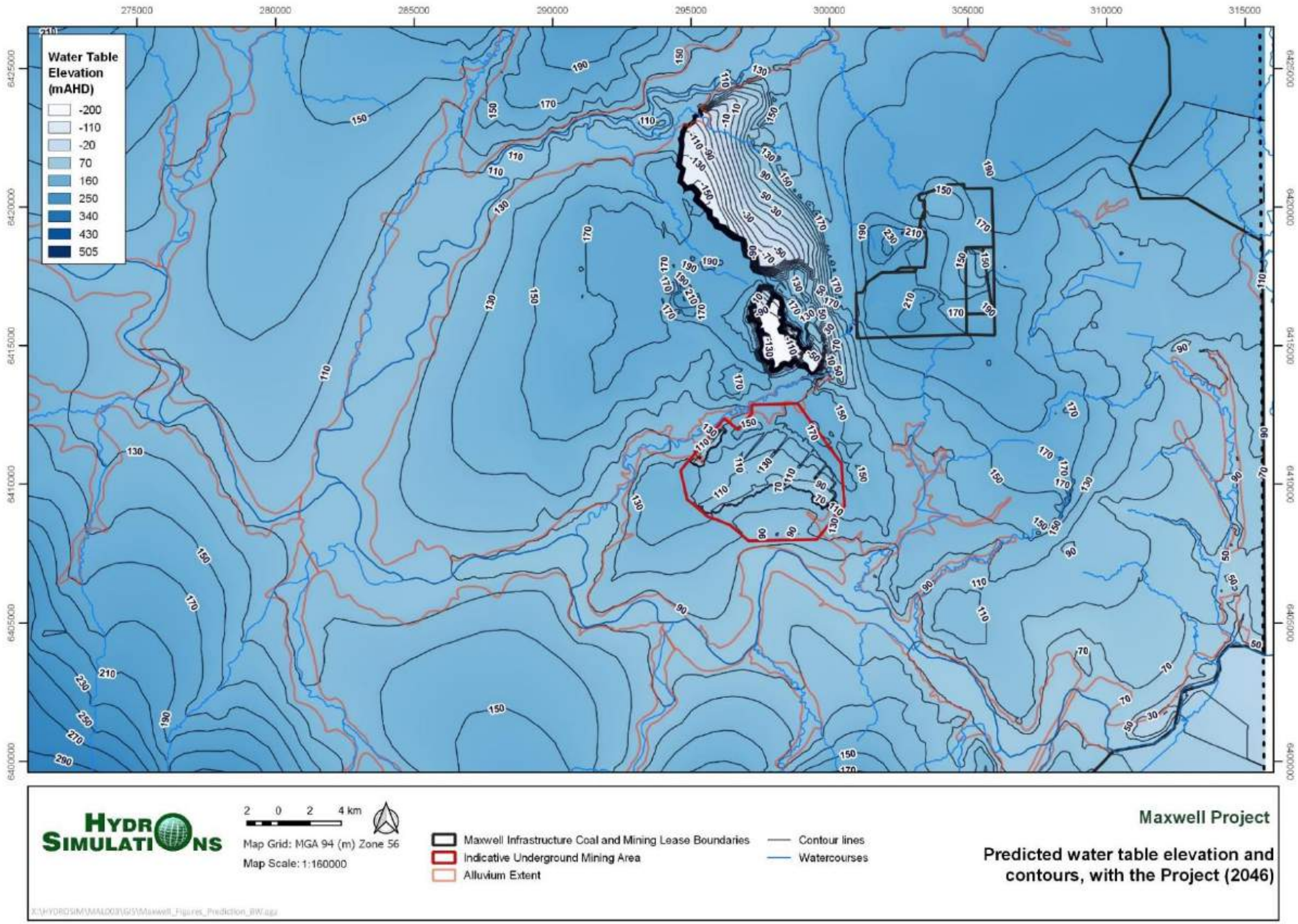


Figure 71 Predicted water table elevation and contours, with the Project (2046)

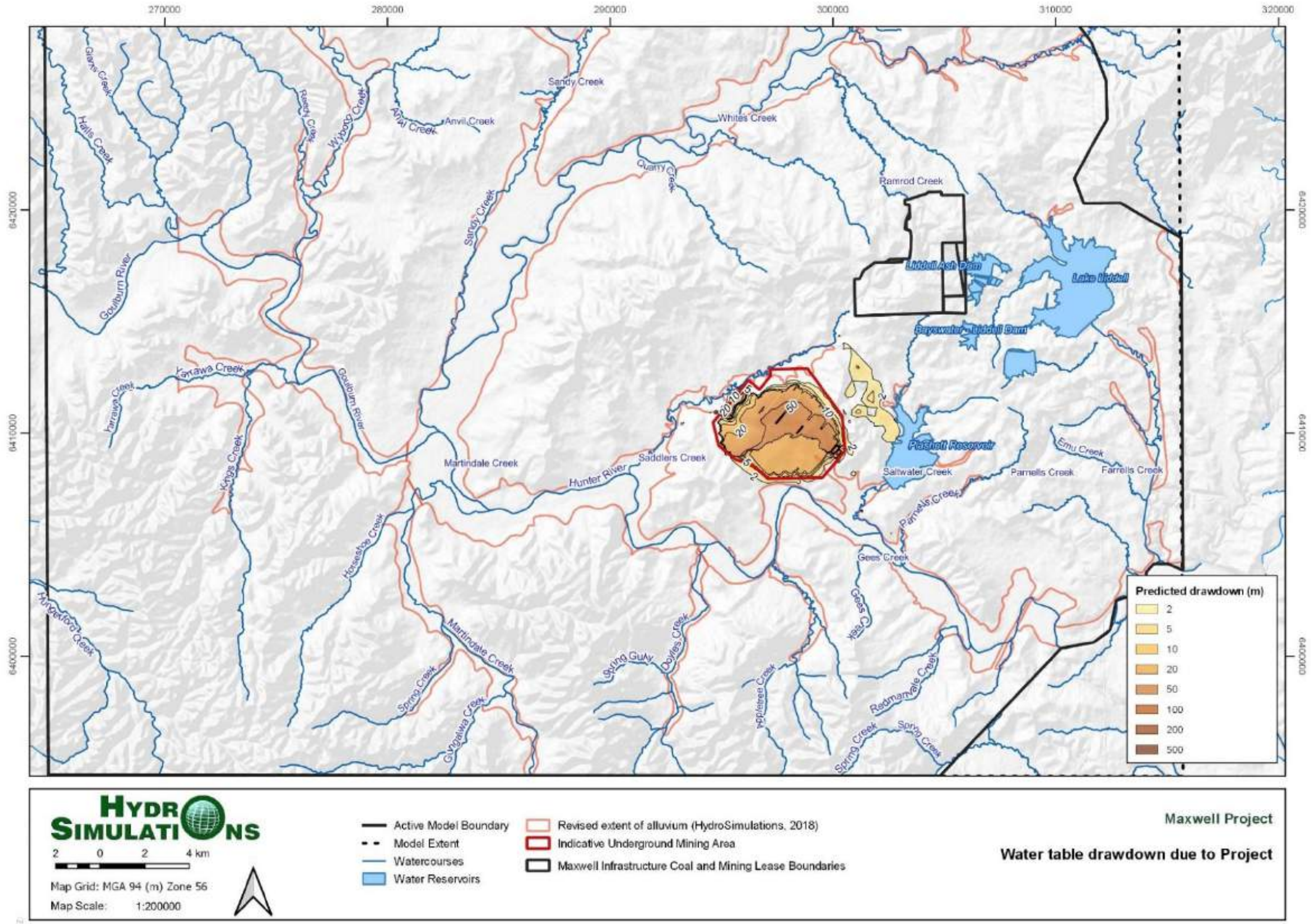


Figure 72 Water table (all layers) drawdown due to Project

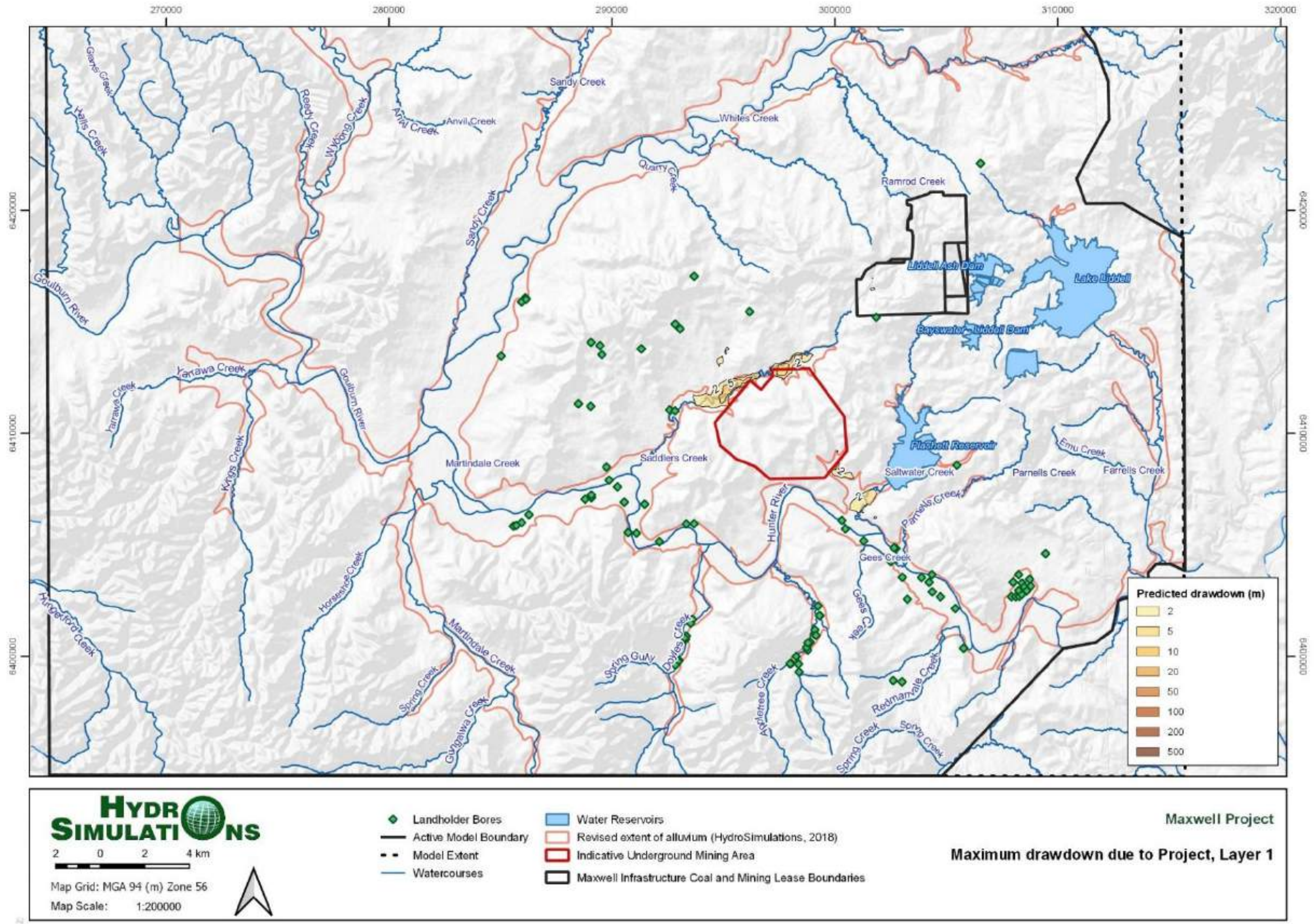


Figure 73 Maximum drawdown due to Project, Layer 1

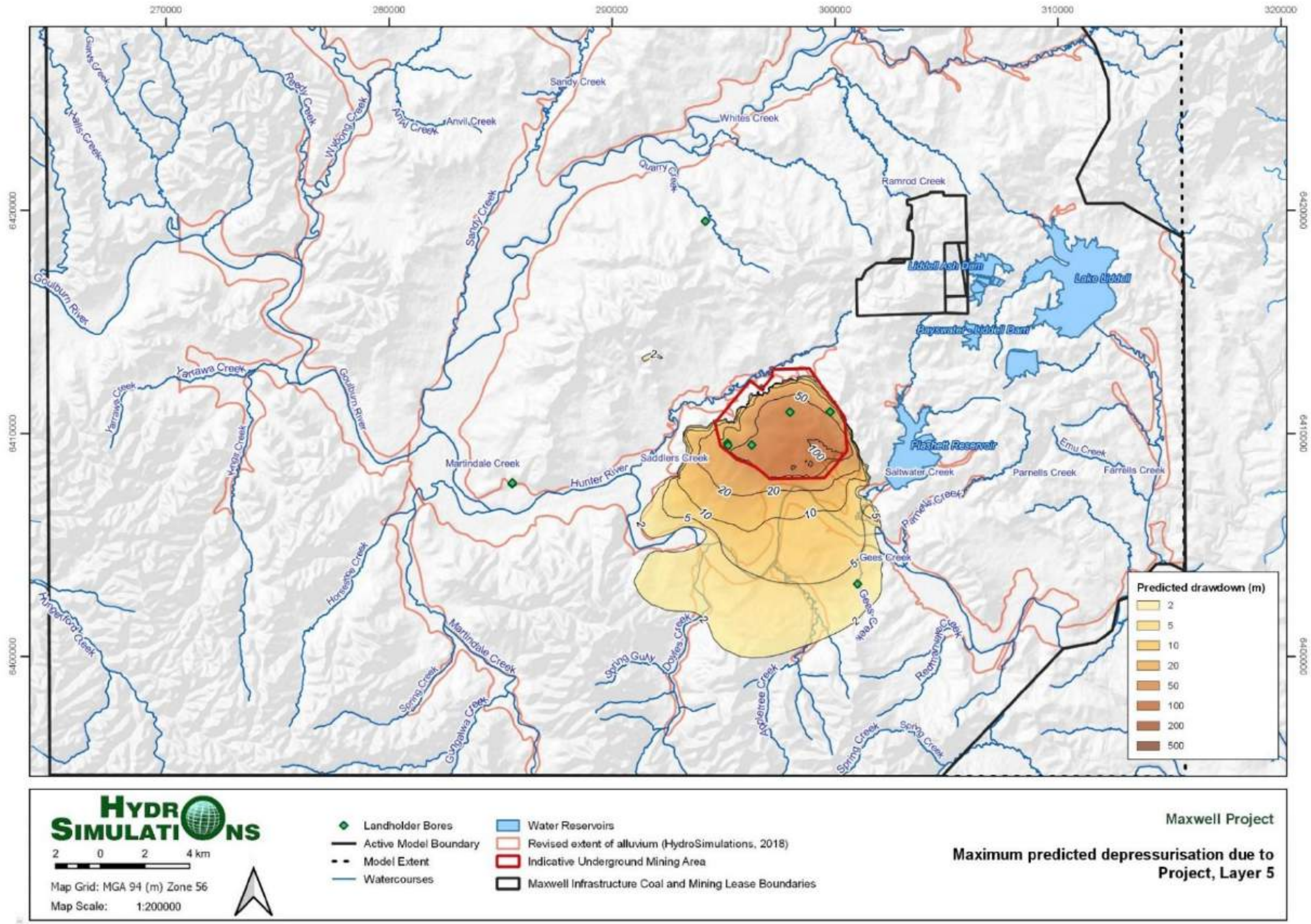


Figure 74 **Maximum predicted depressurisation due to Project, Layer 5**

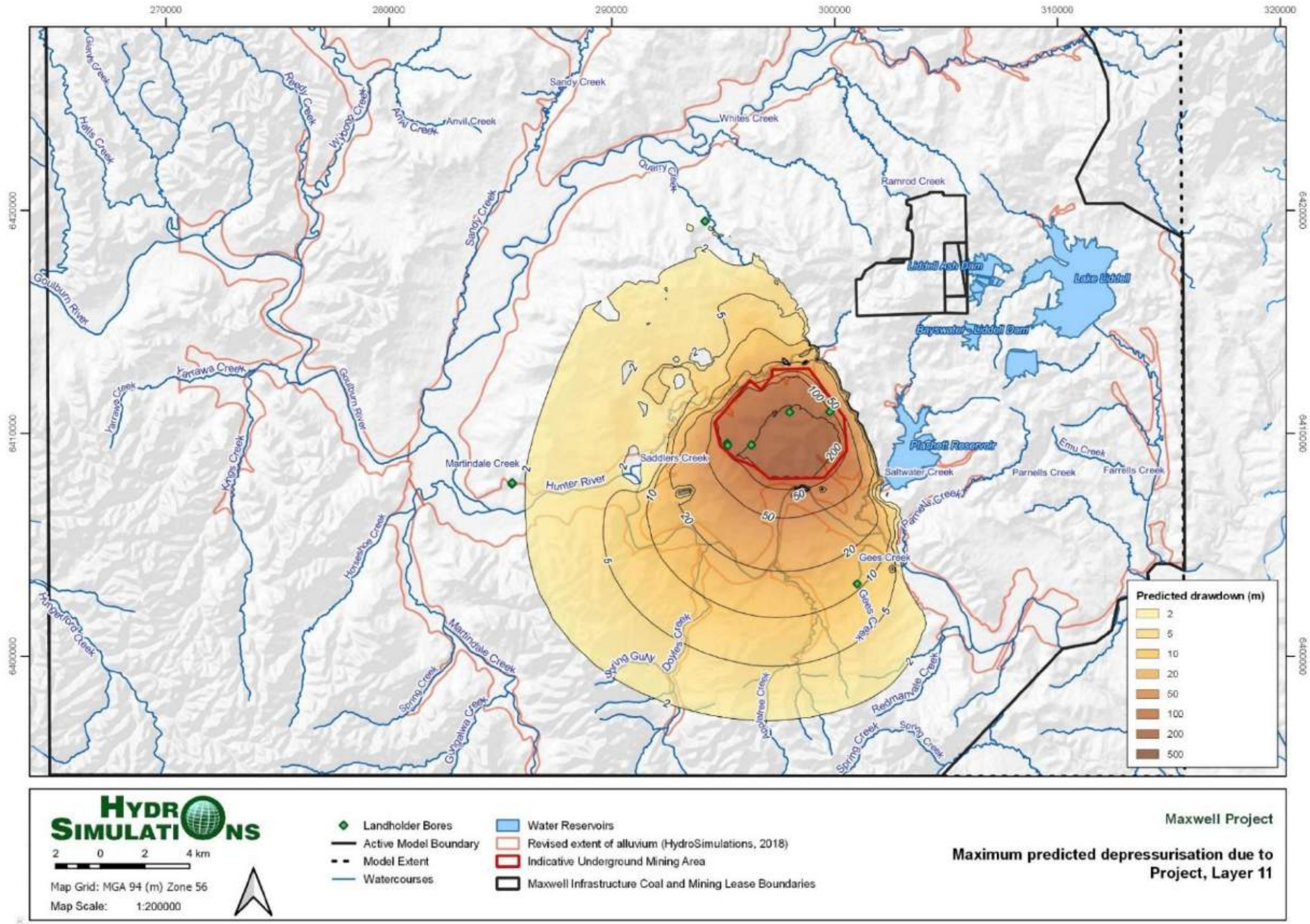


Figure 75 Maximum predicted depressurisation due to Project, Layer 11

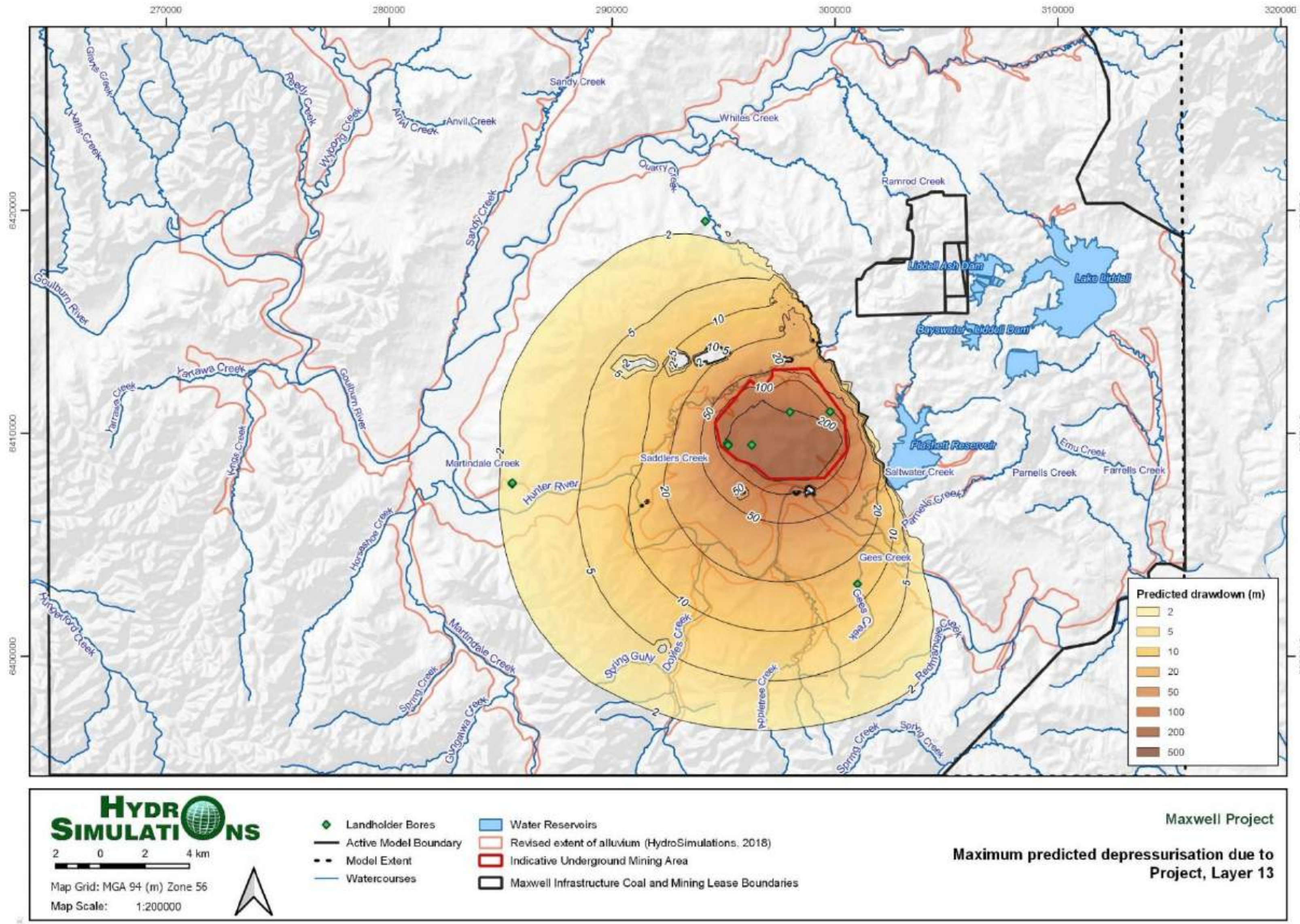


Figure 76 Maximum predicted depressurisation due to Project, Layer 13

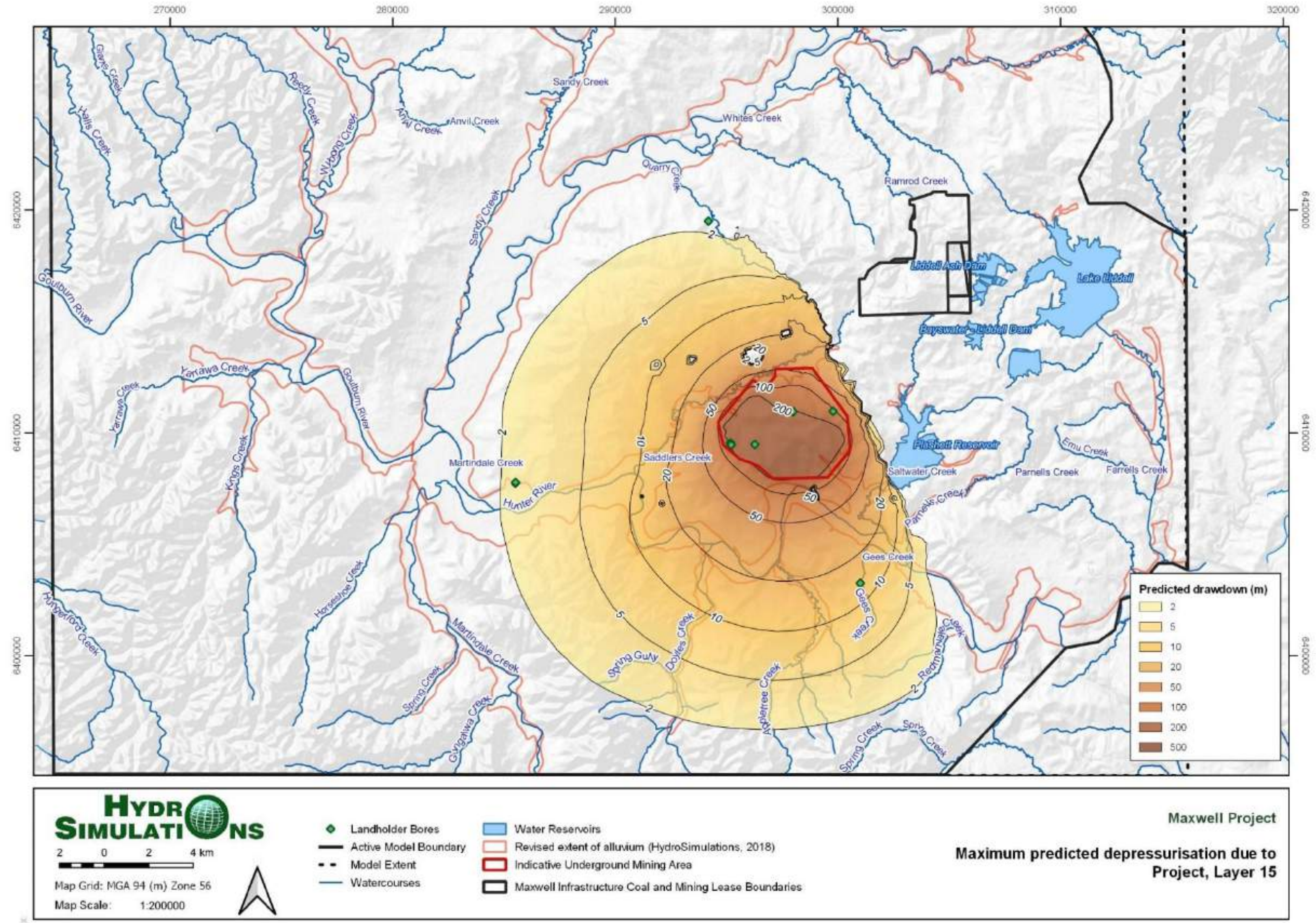


Figure 77 Maximum predicted depressurisation due to Project, Layer 15

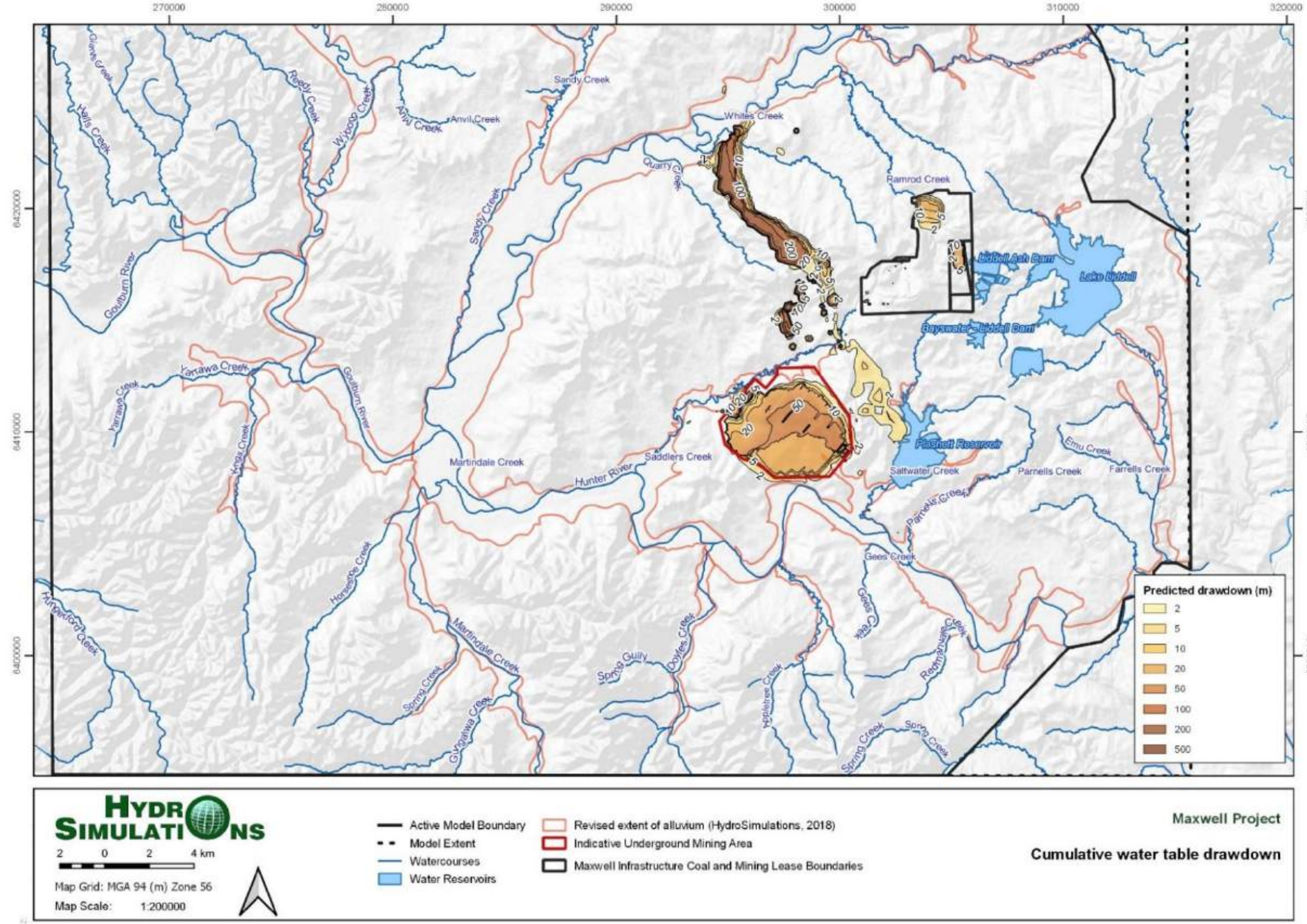


Figure 78 **Cumulative water table (all layers) drawdown**

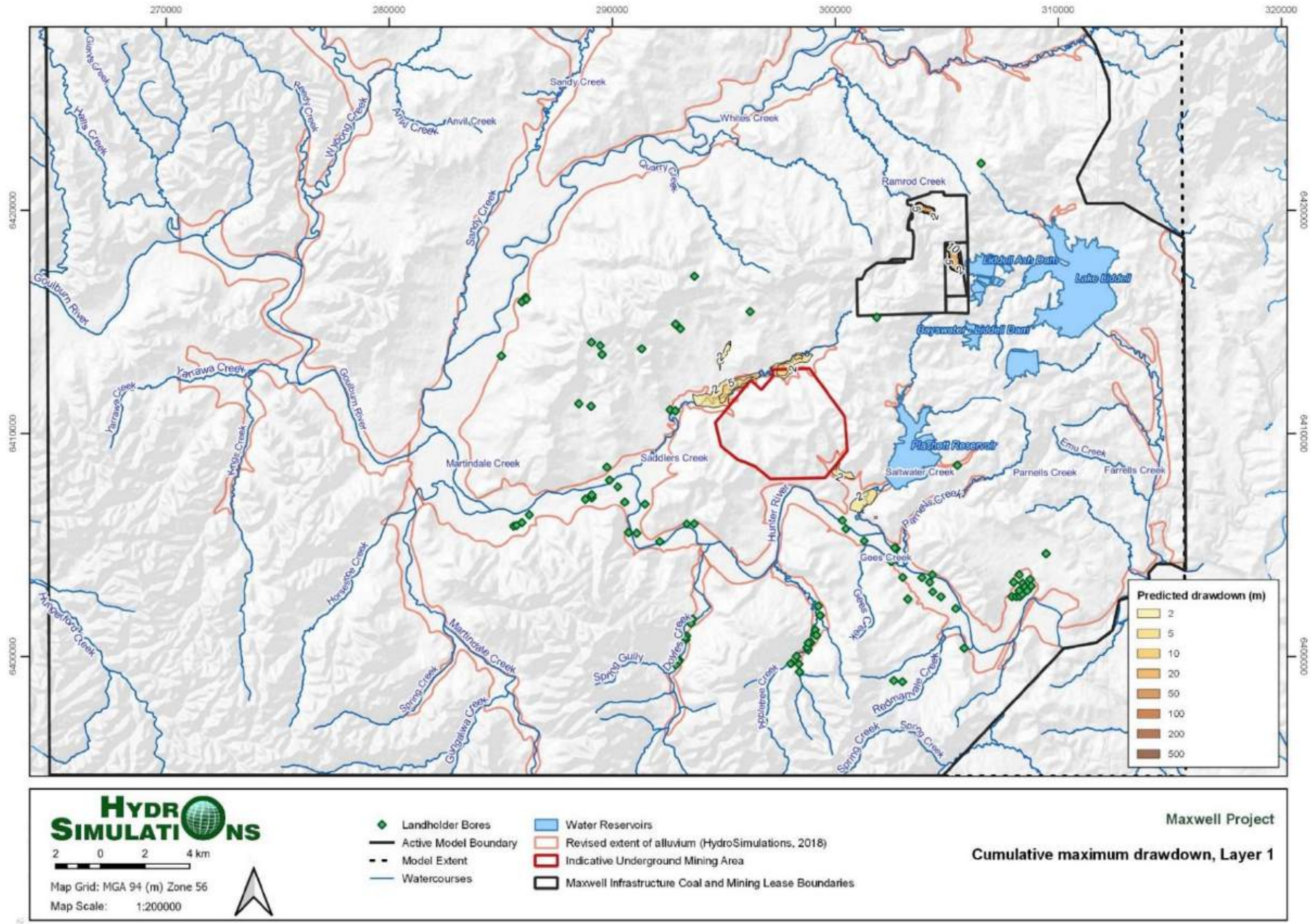


Figure 79 Cumulative maximum drawdown, Layer 1

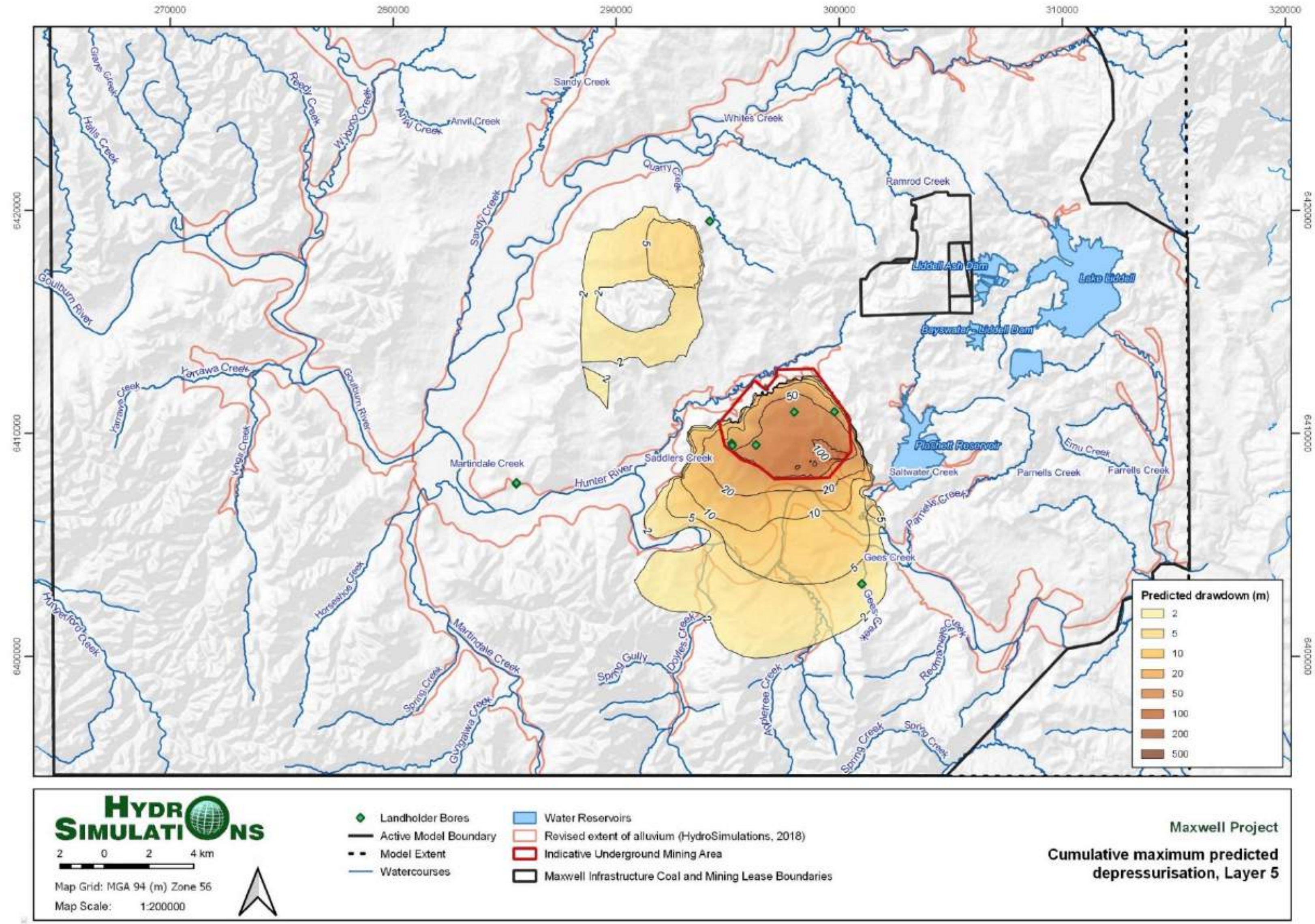


Figure 80 Cumulative maximum predicted depressurisation, Layer 5

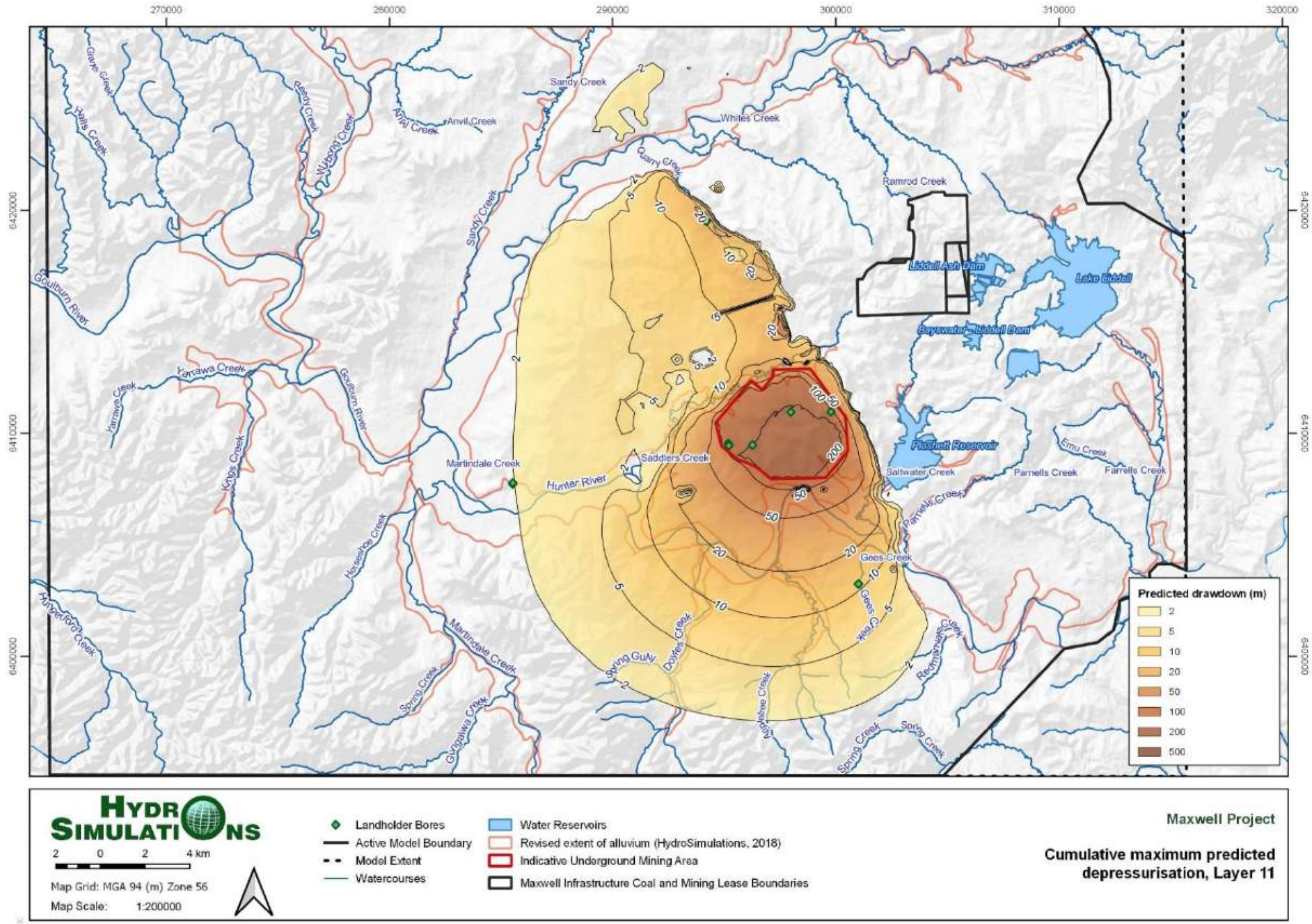


Figure 81 Cumulative maximum predicted depressurisation, Layer 11

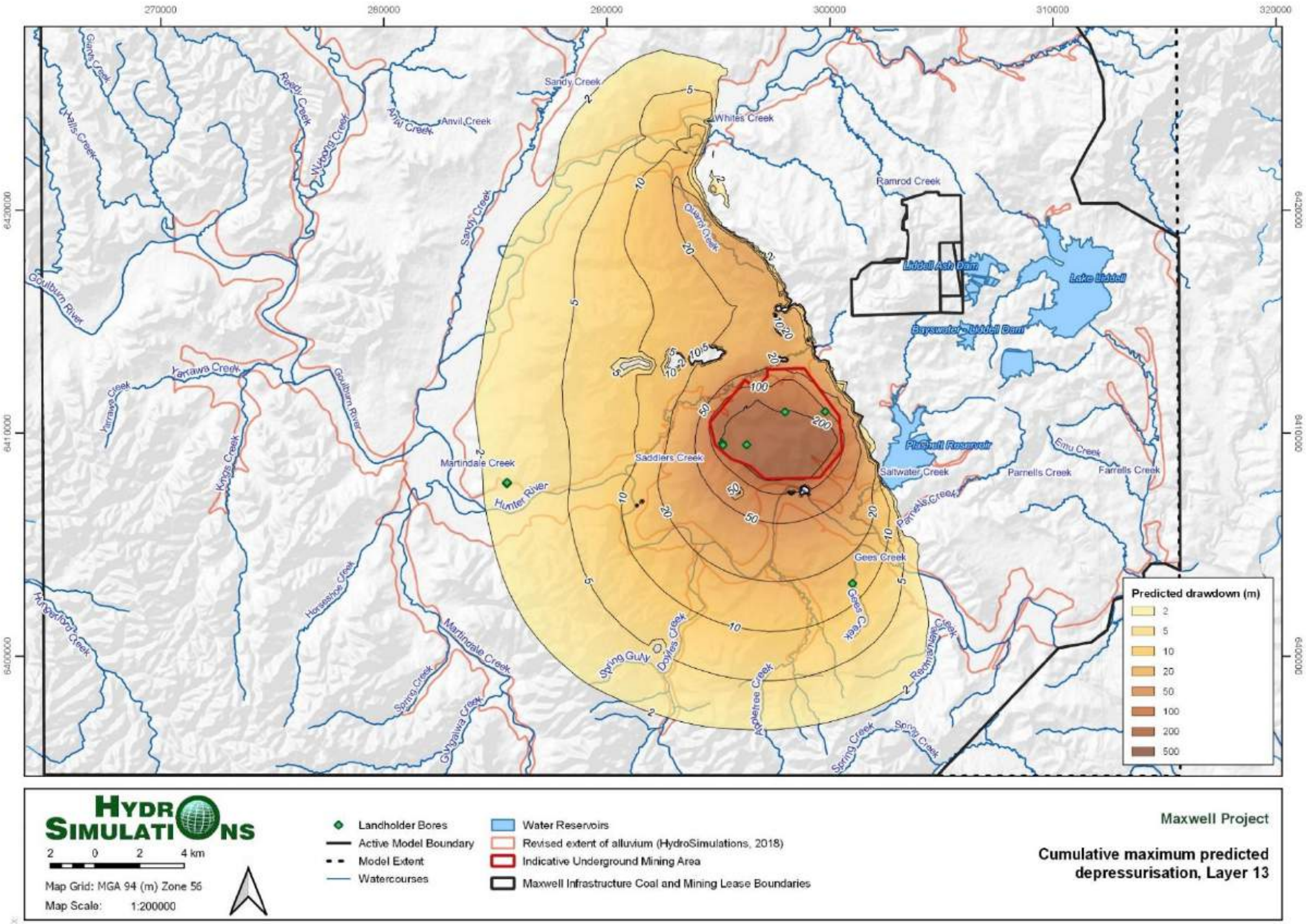


Figure 82 Cumulative maximum predicted depressurisation, Layer 13

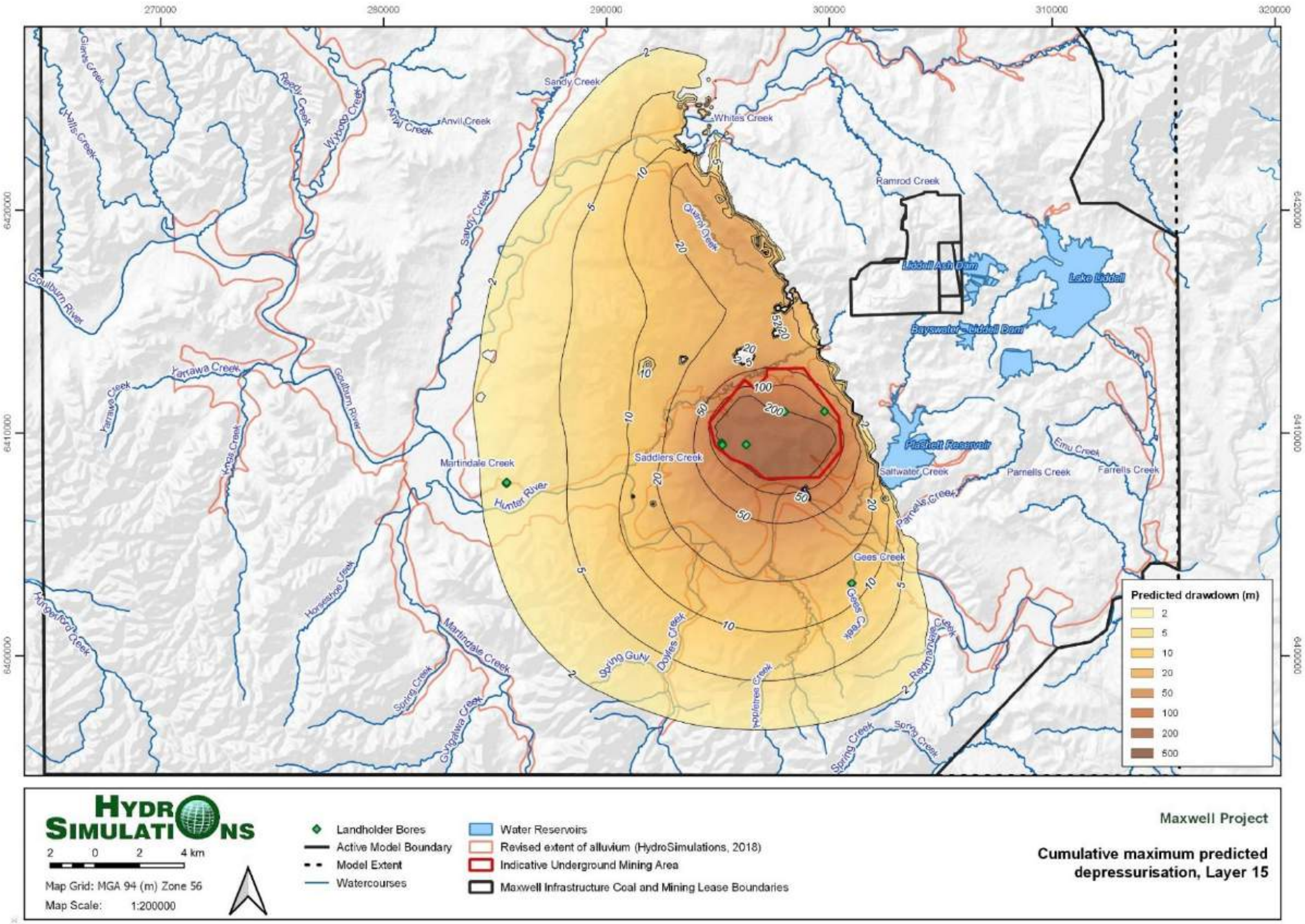


Figure 83 Cumulative maximum predicted depressurisation, Layer 15

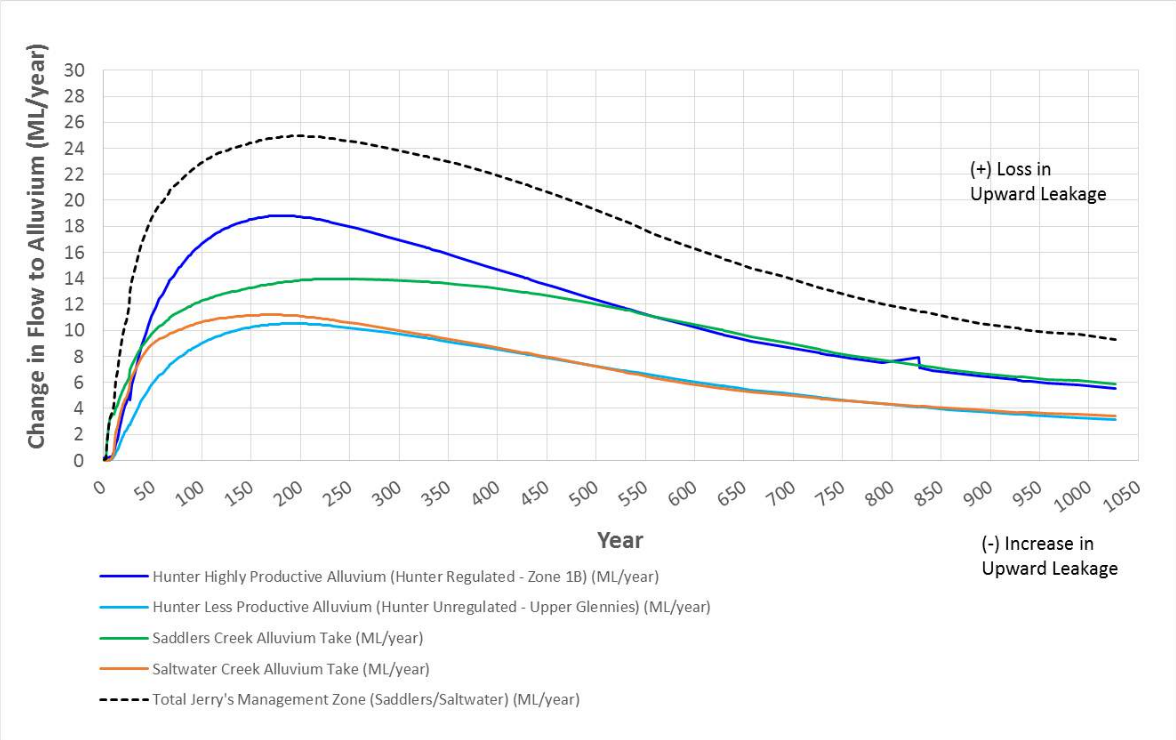


Figure 84 Predicted whole of model fluxes in alluvium

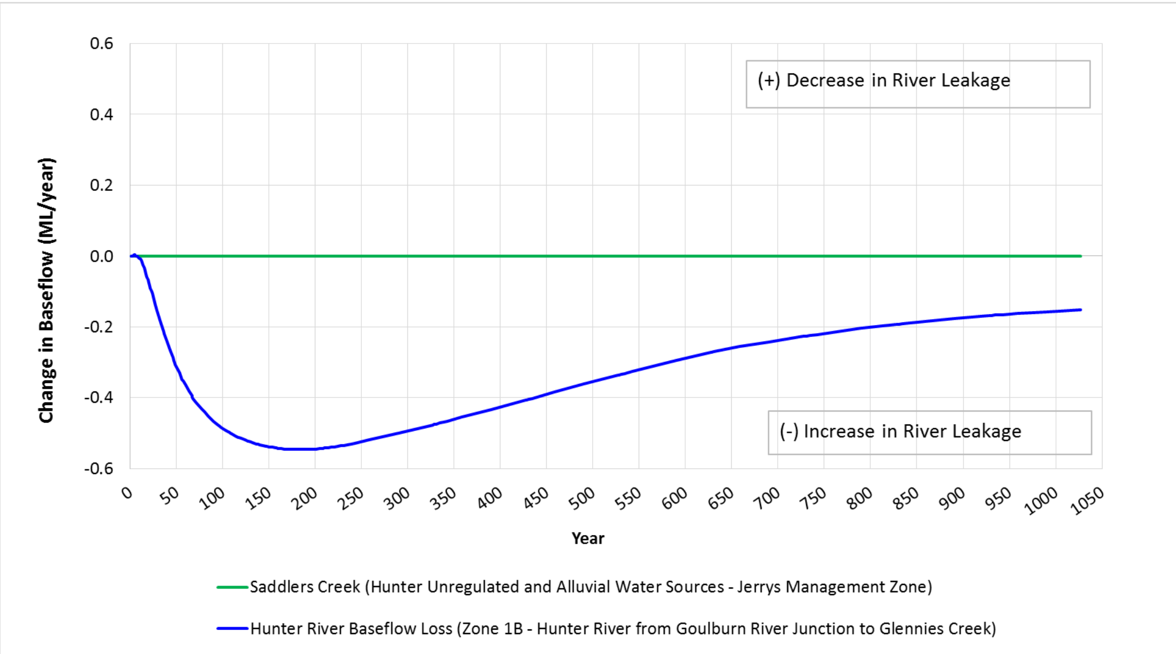


Figure 85 Predicted whole of model fluxes in the Hunter River and Saddlers Creek

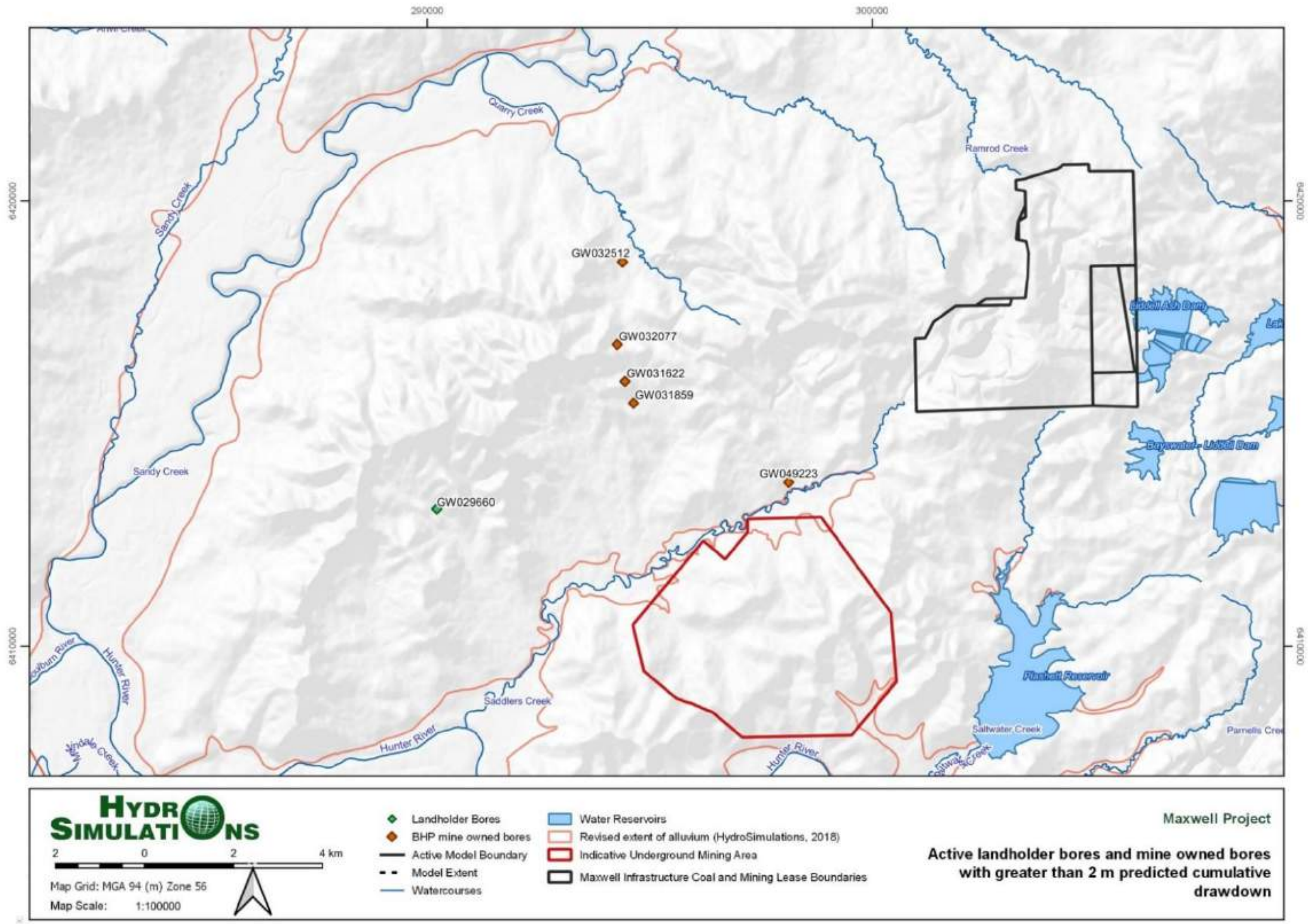


Figure 86 Active landholder bores and mine owned bores with greater than 2 m predicted cumulative drawdown

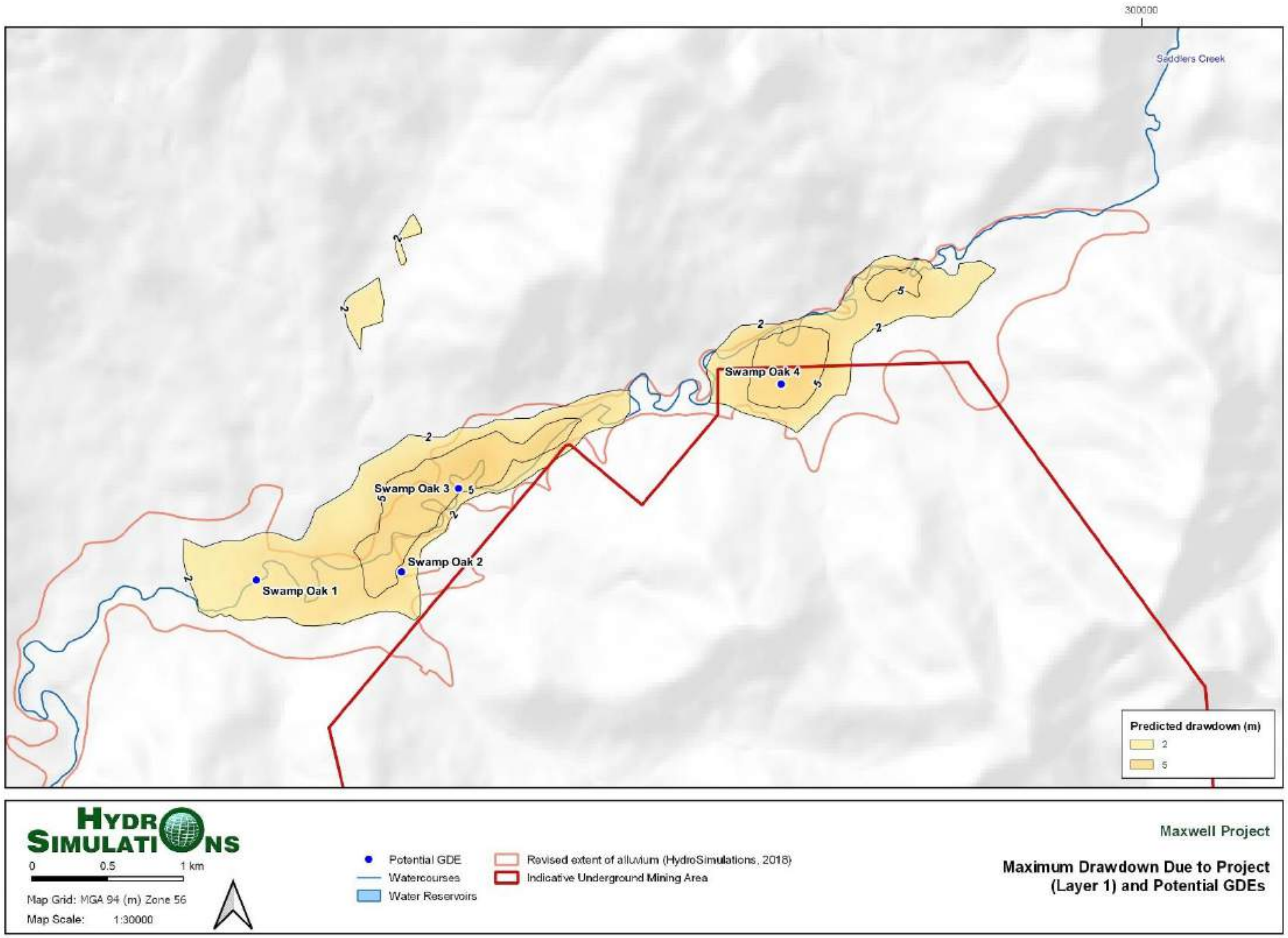


Figure 87 Maximum Drawdown Due to Project (Layer 1) and Potential GDEs

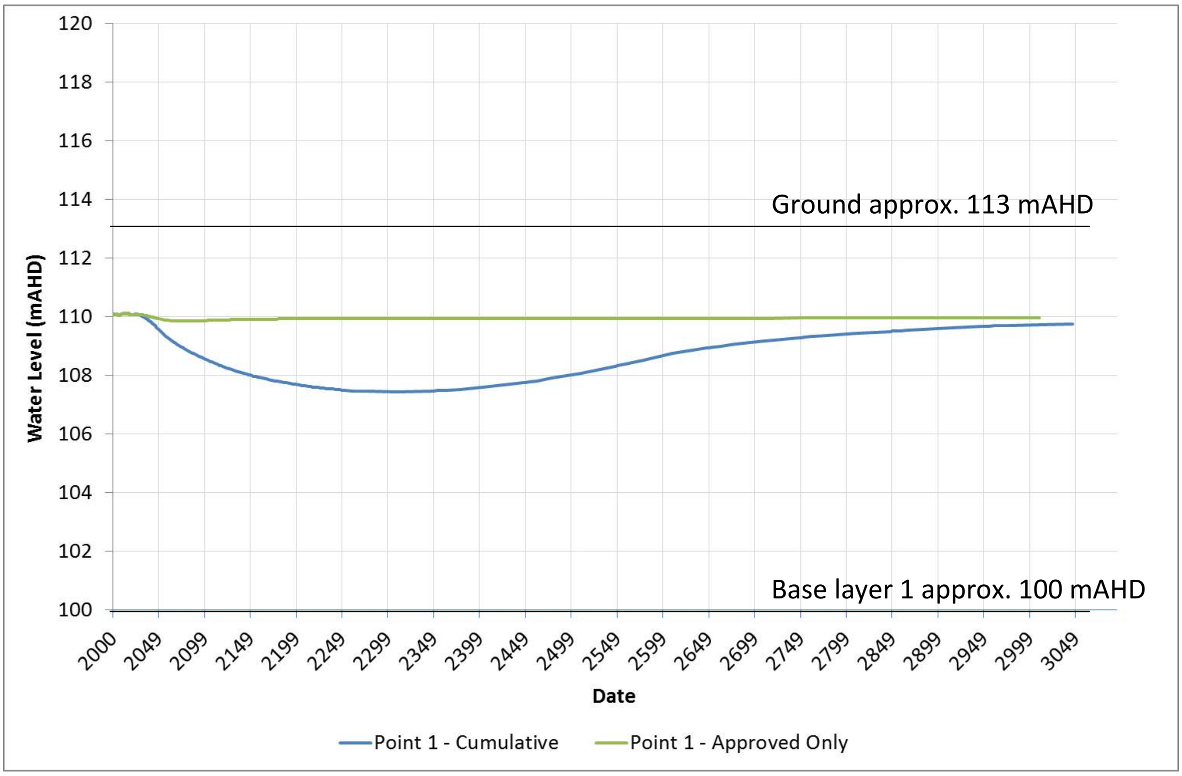


Figure 88 Model Predicted Hydrograph – Swamp Oak 1

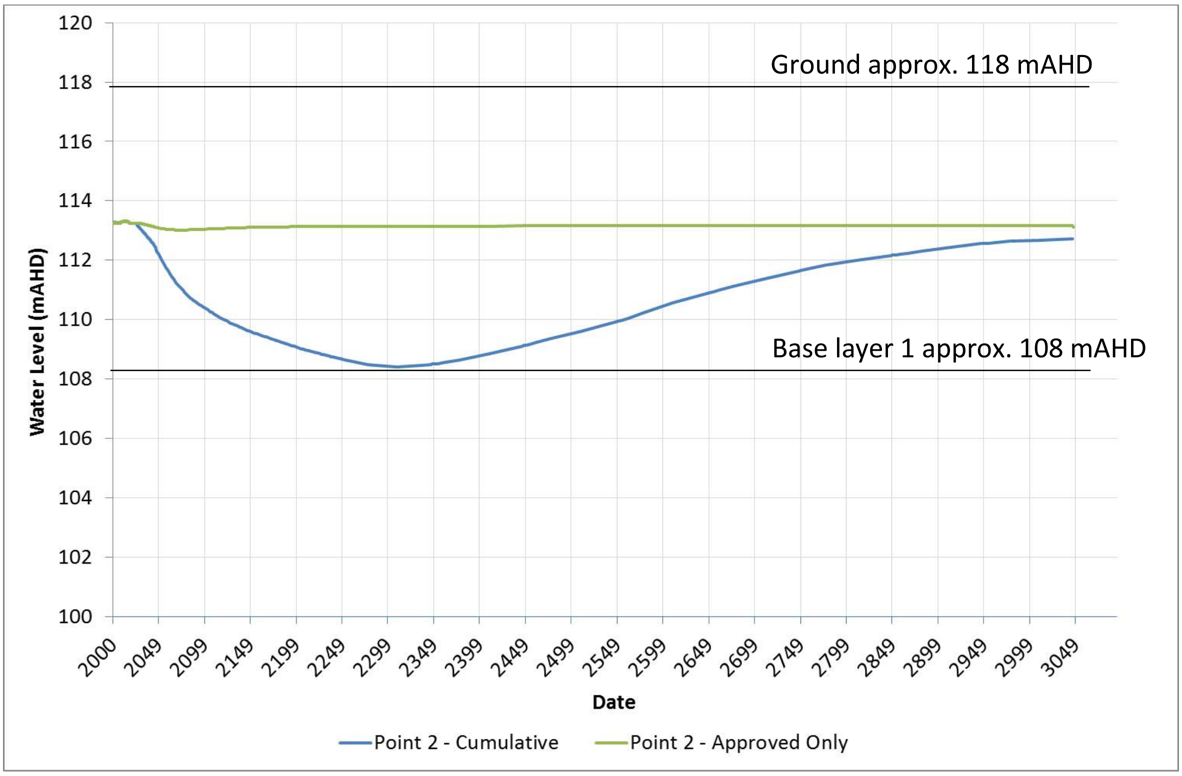


Figure 89 Model Predicted Hydrograph – Swamp Oak 2

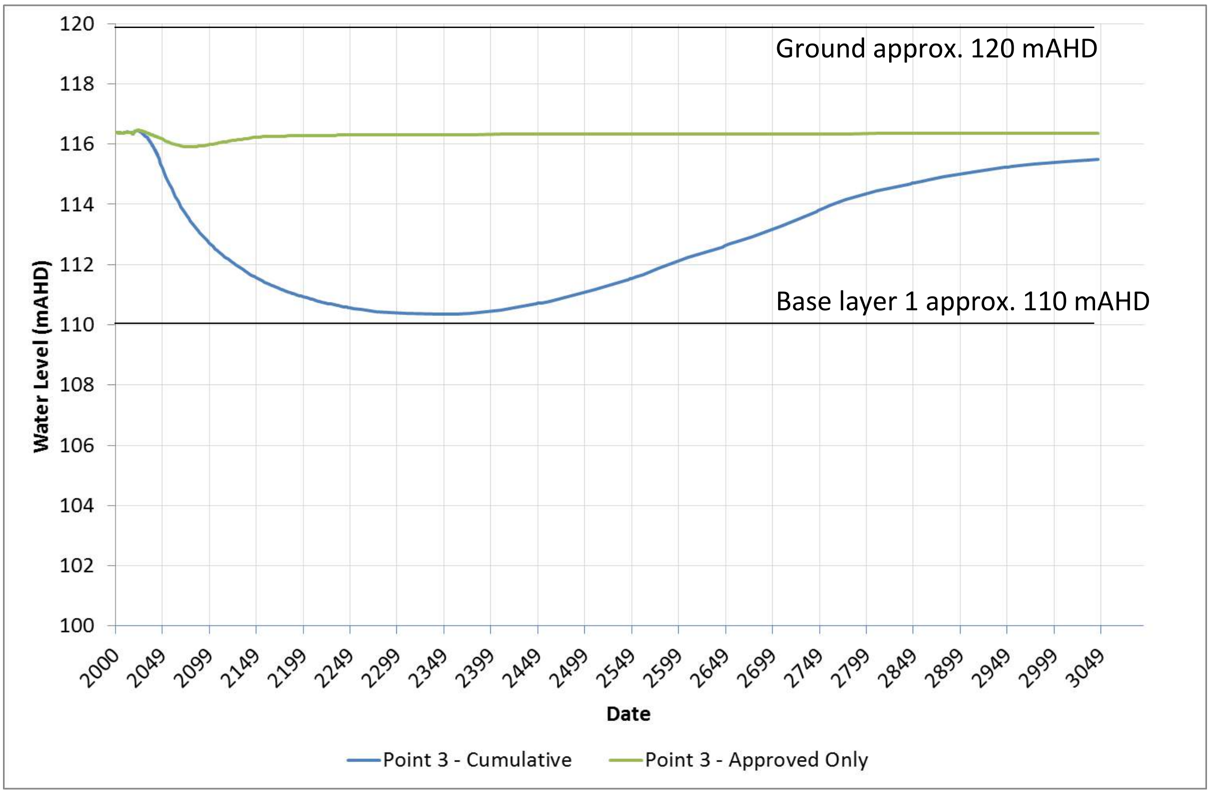


Figure 90 Model Predicted Hydrograph – Swamp Oak 3

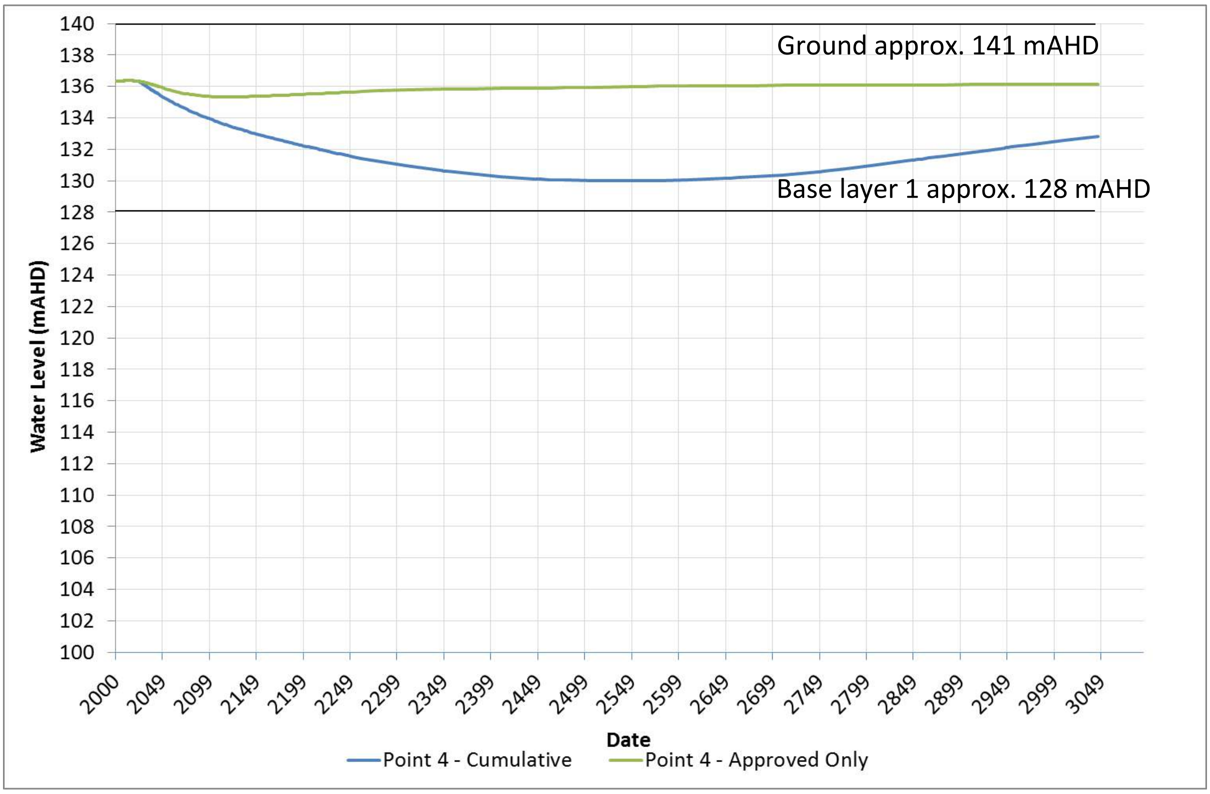


Figure 91 Model Predicted Hydrograph – Swamp Oak 4

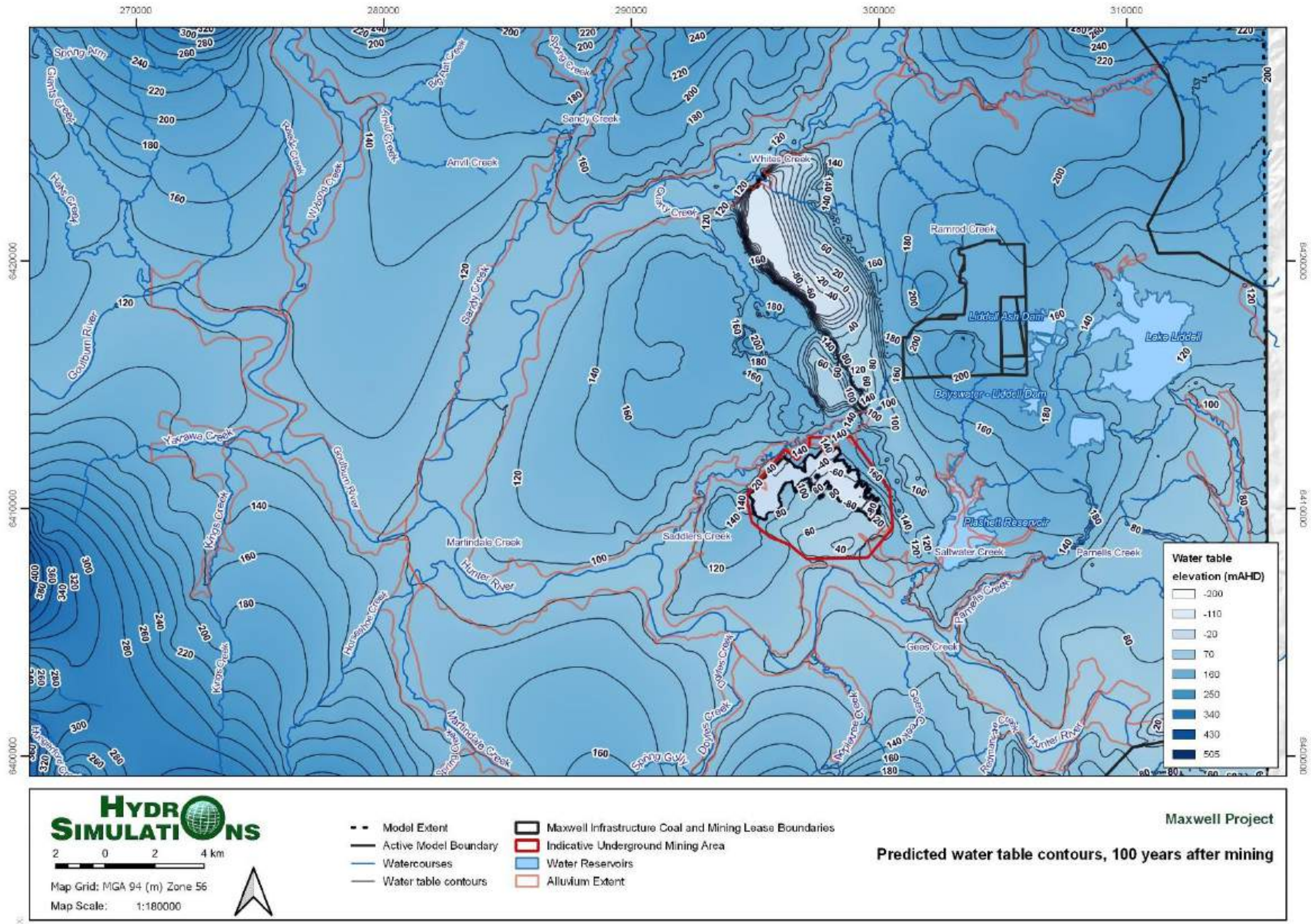


Figure 92 **Predicted water table contours, 100 years after mining**

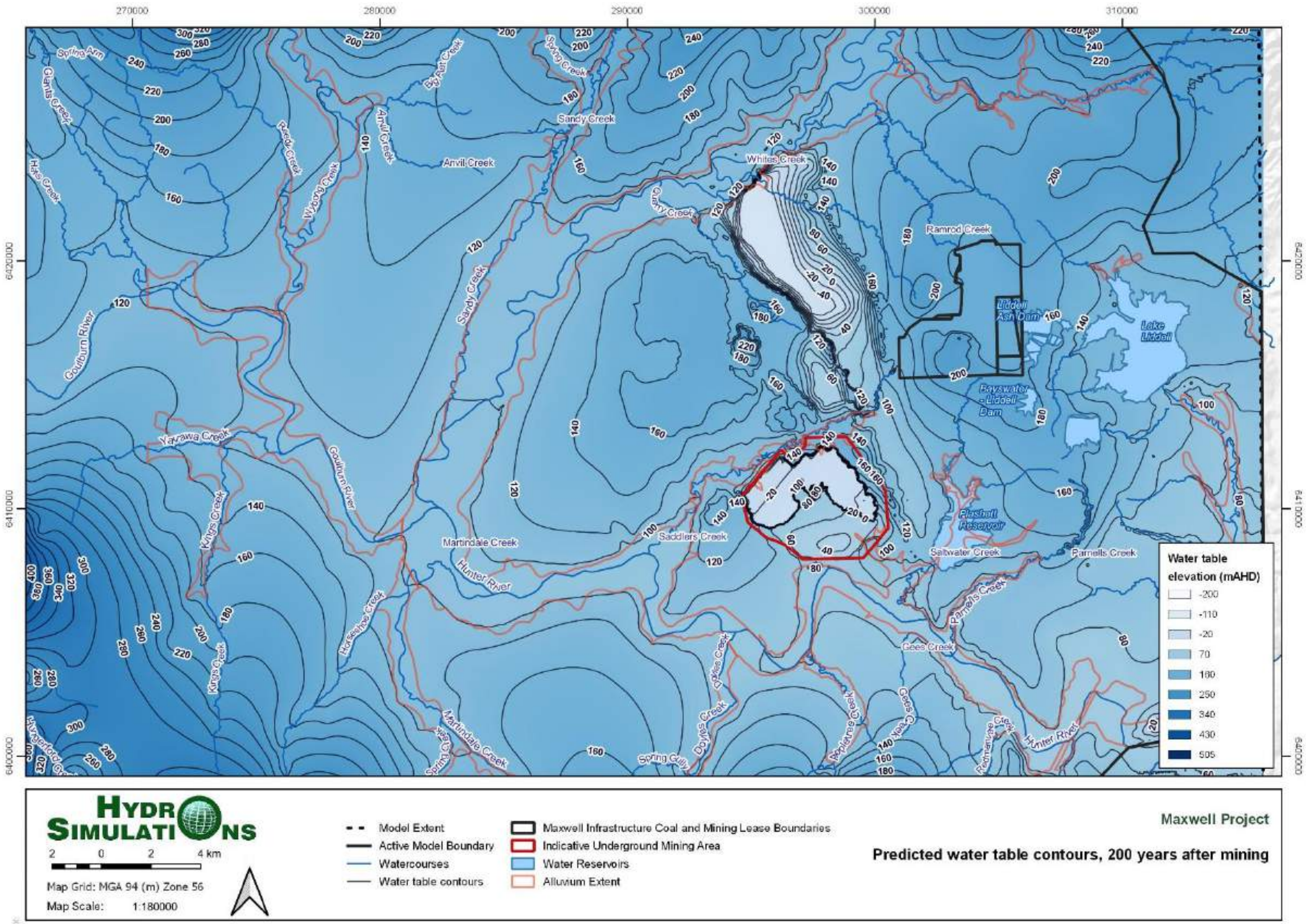


Figure 93 Predicted water table contours, 200 years after mining

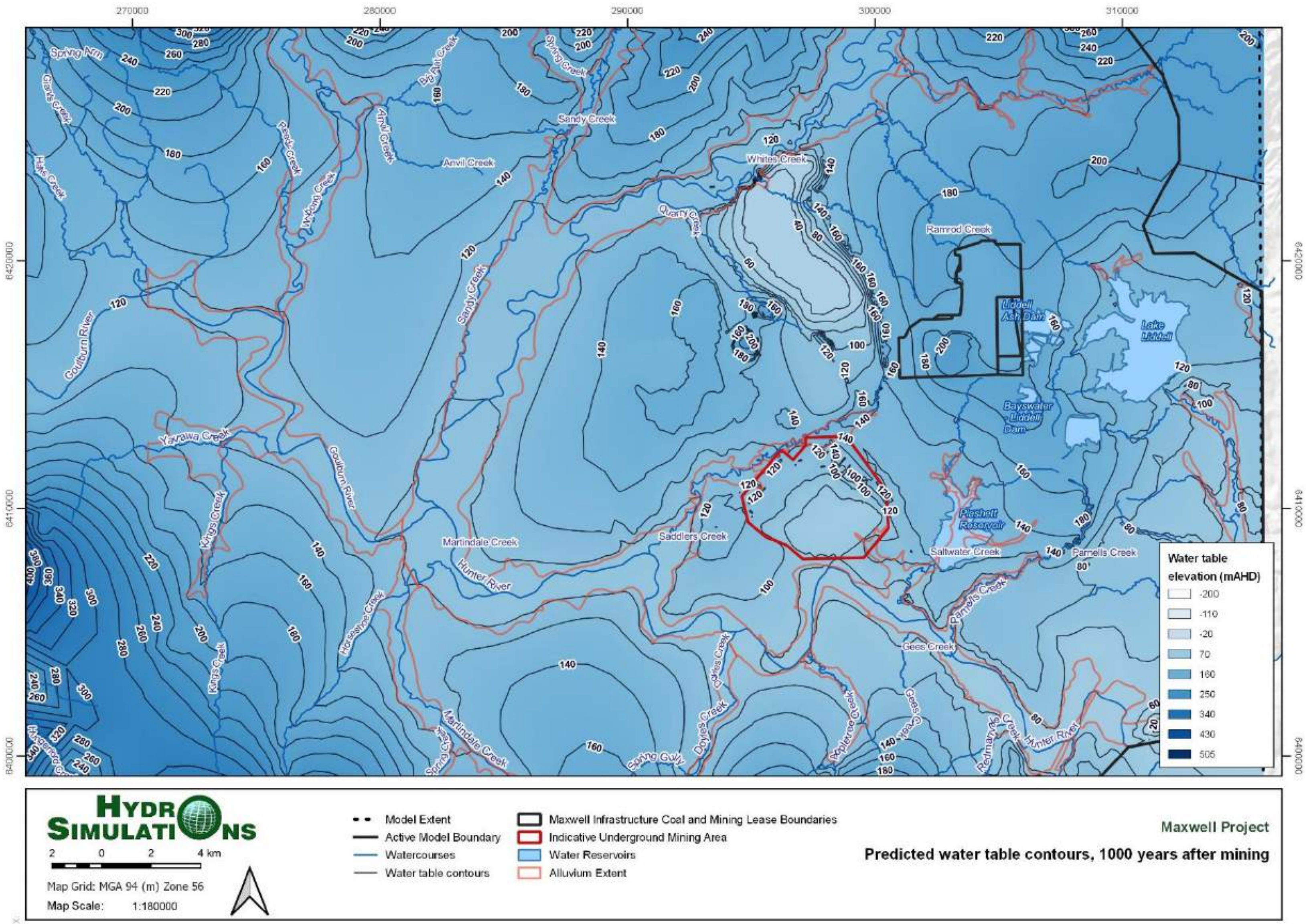


Figure 94 Predicted water table contours, 1,000 years after mining

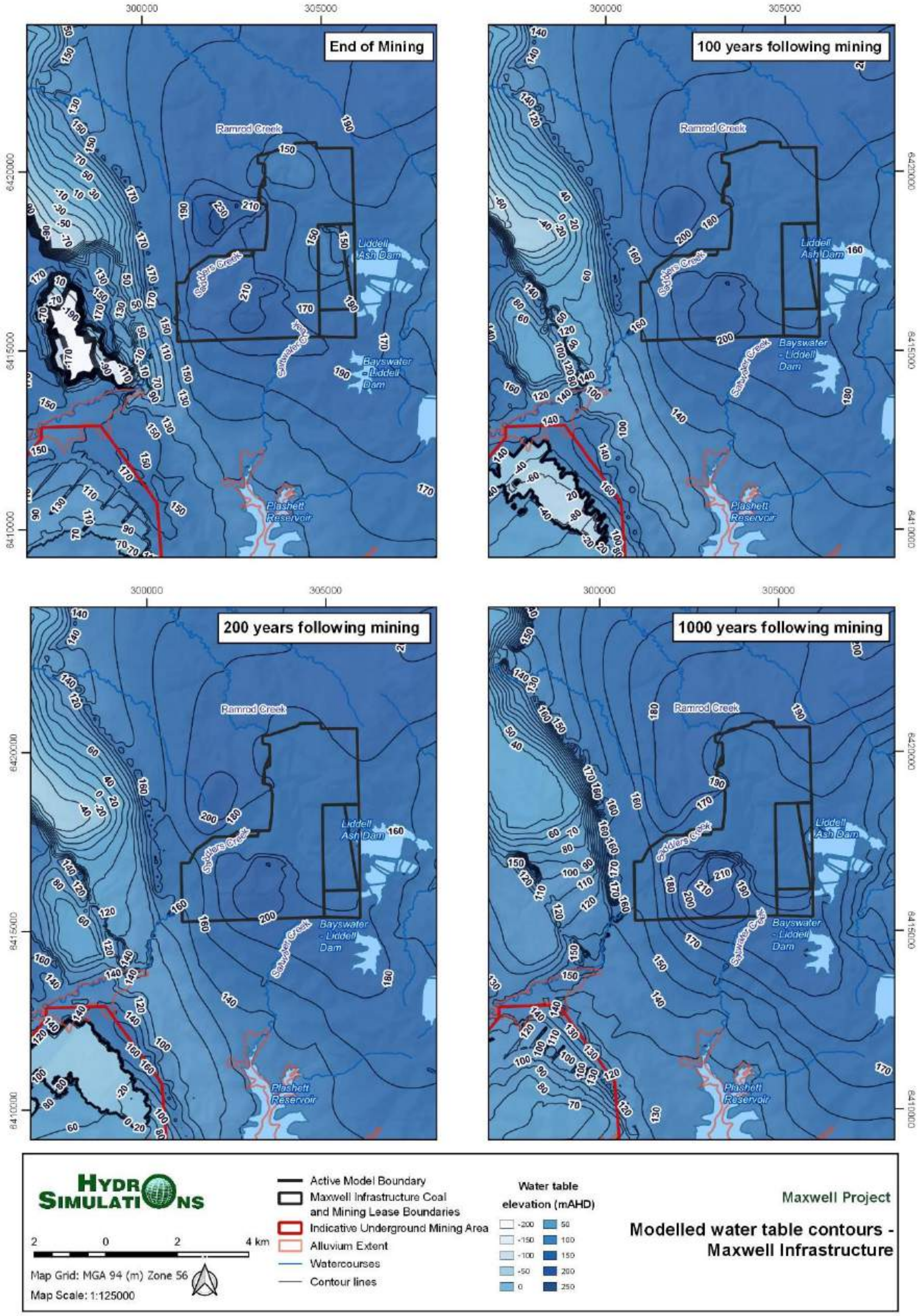


Figure 95 **Maxwell Infrastructure – Water Table Trends Over Time**

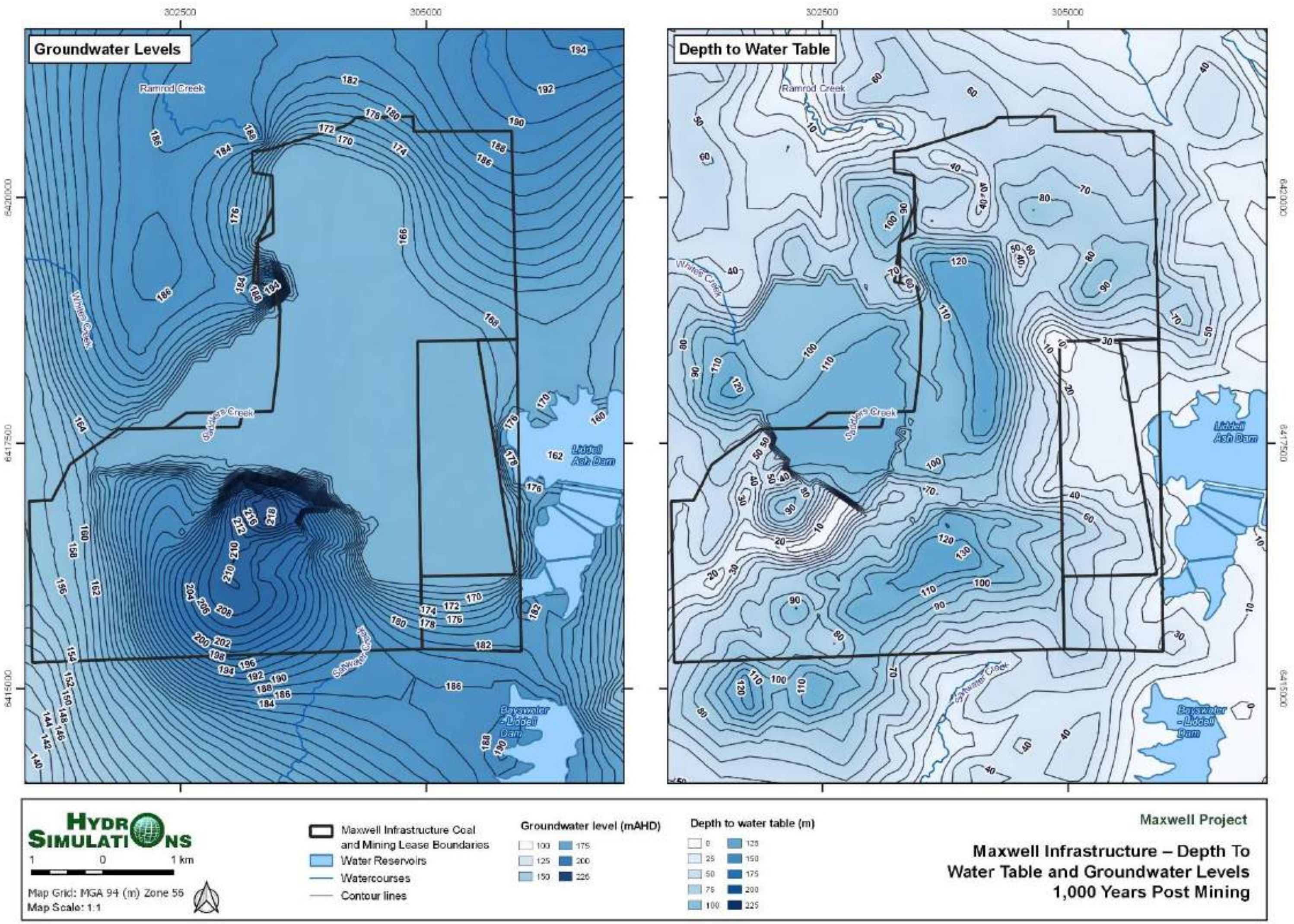


Figure 96 Maxwell Infrastructure – Depth To Water Table and Groundwater Levels 1,000 Years Post Mining

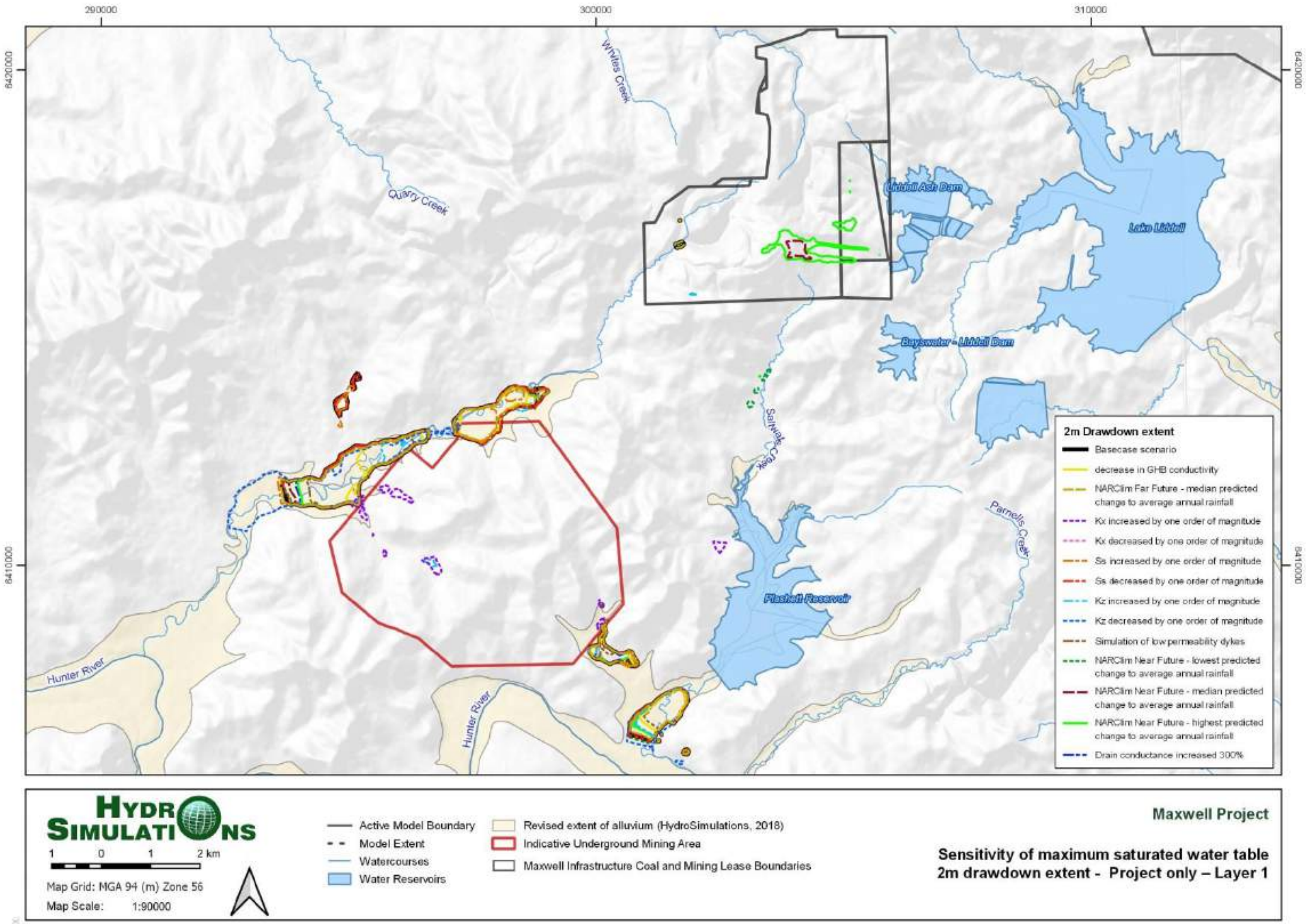


Figure 97 **Sensitivity of maximum saturated water table 2m drawdown extent - Project only – Layer 1**

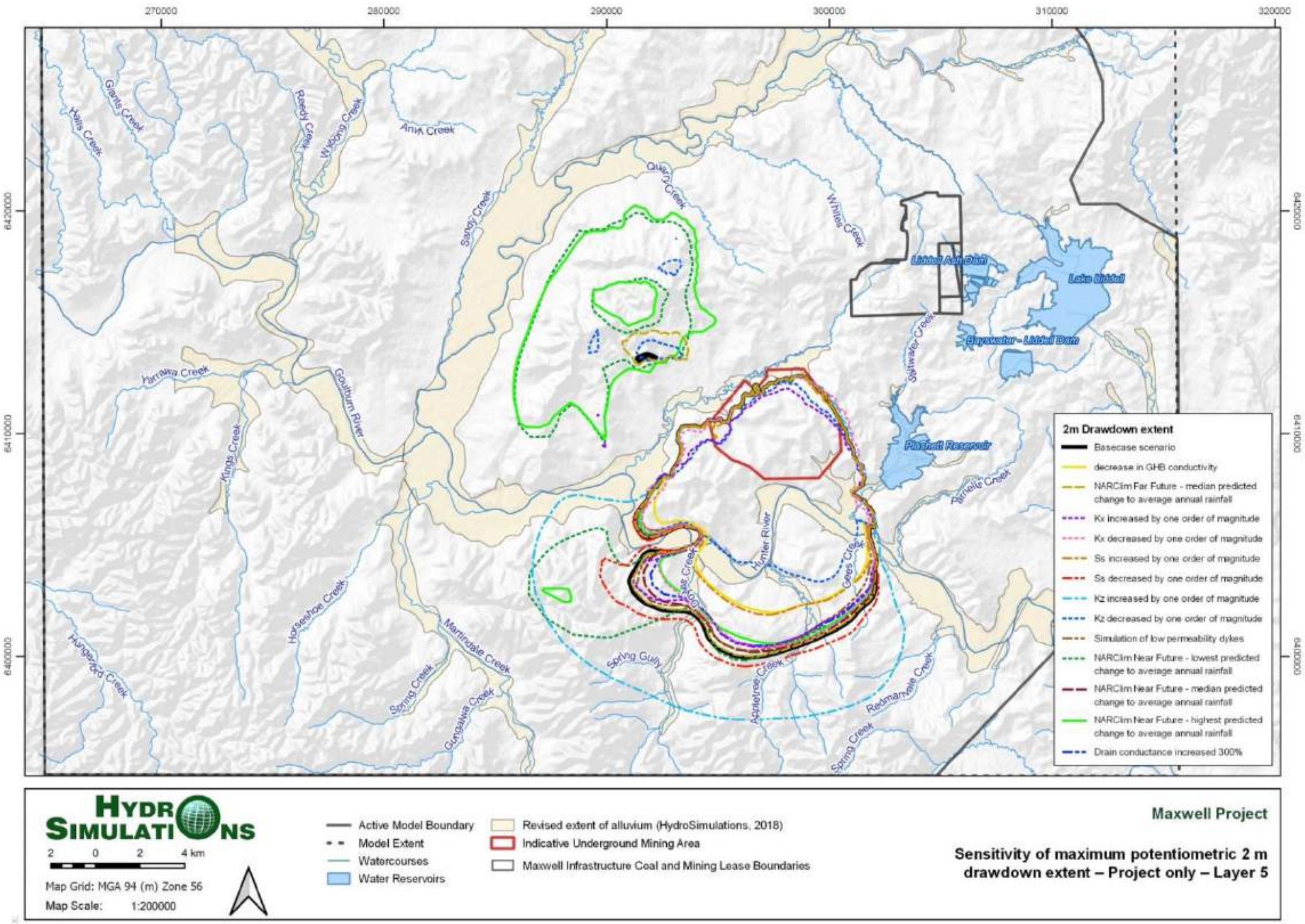


Figure 98 **Sensitivity of maximum potentiometric 2 m drawdown extent – Project only – Layer 5**

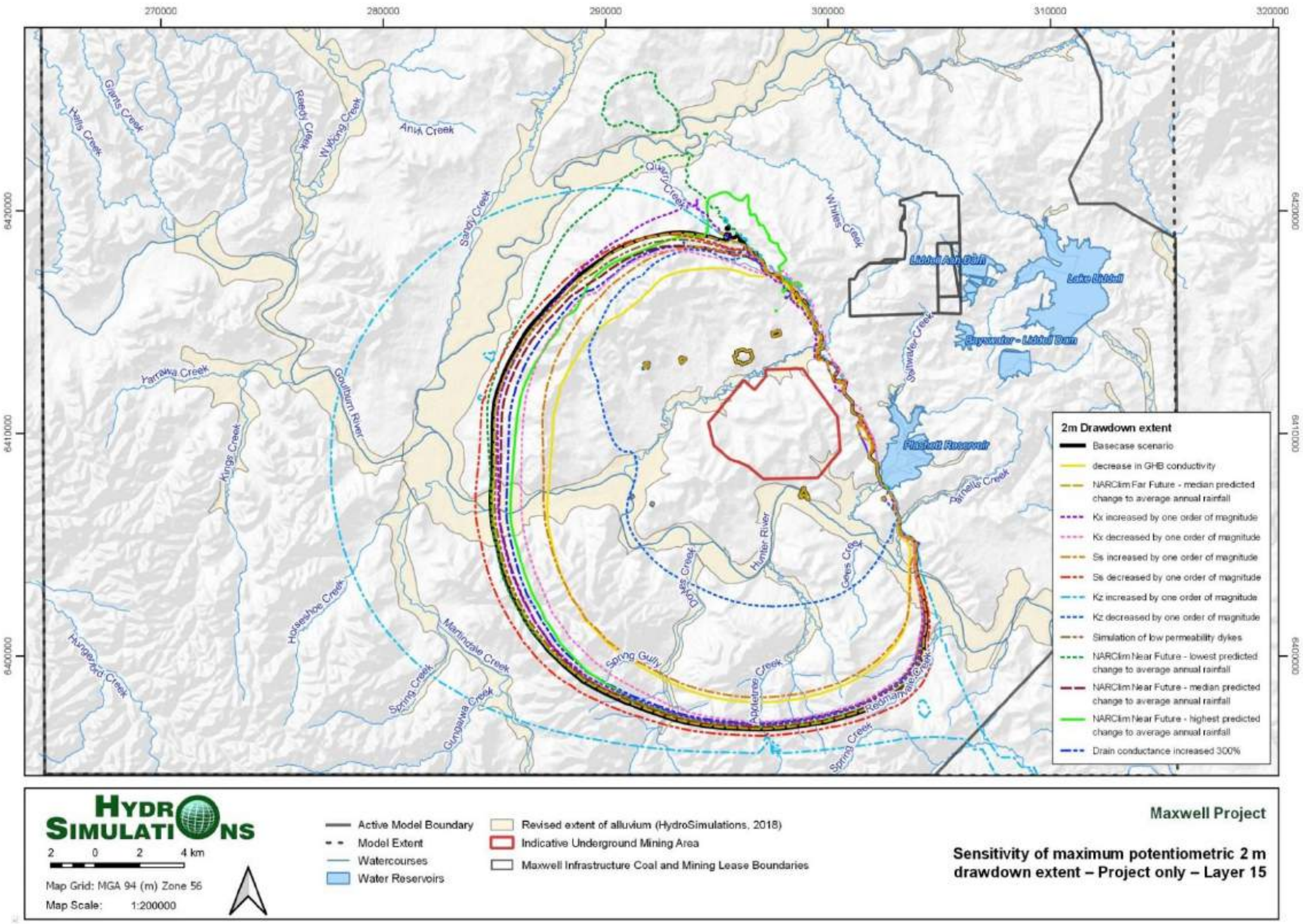


Figure 99 Sensitivity of maximum potentiometric 2 m drawdown extent – Project only – Layer 15

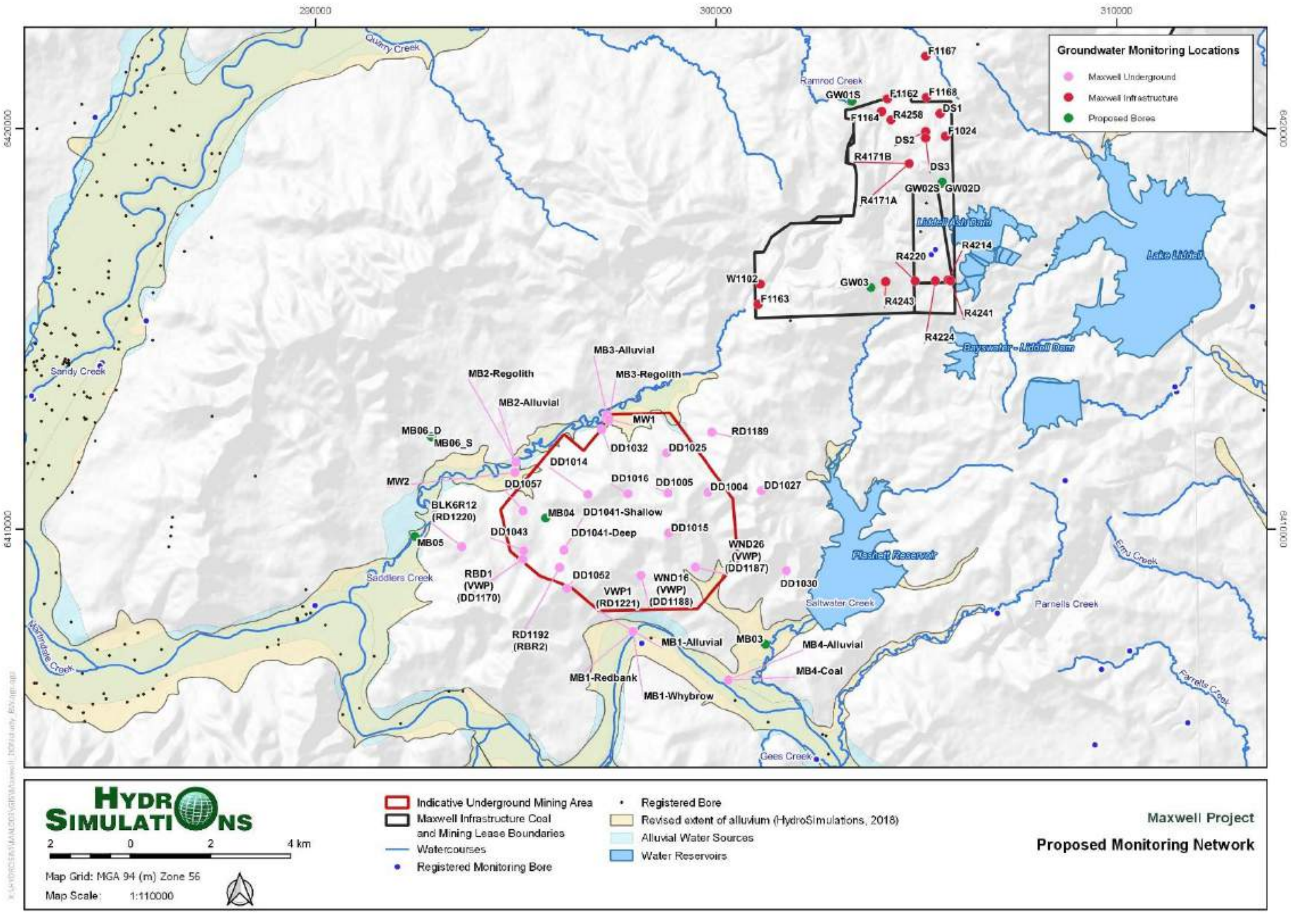


Figure 100 Proposed Monitoring Network

APPENDIX A

IESC INFORMATION GUIDELINE– SUMMARY CHECKLIST

IESC Information Needs Summary	Section Addressed
Description of the Proposal	Section 1
Statutory Context	Sections 2 & 8
Risk Assessment	Section 2.3
Groundwater – Context and Conceptualisation	Sections 3 & 4
Groundwater – Analytical and Numerical Modelling	Section 5
Uncertainty Analysis and Sensitivity Analysis	Section 7
Groundwater – Impacts to Water Resources and Water-dependent Assets	Sections 6 & 8
Groundwater – Data and Monitoring	Sections 4.3, 4.6 & 9
Surface Water – Context and Conceptualisation	Section 3.3 & 4.5
Surface Water – Analytical and Numerical Modelling	Surface Water Assessment and captured in groundwater model (Section 5)
Surface Water – Impacts to Water Resources and Water-dependent Assets	Surface Water Assessment and Section 6.3
Surface Water – Data and Monitoring	Sections 3.3 & 4.5
Water-dependent Assets – Context and Conceptualisation	Section 4.6
Water-dependent Assets – Impacts, Risk Assessment and Management of Risks	Sections 6.7 & 8.2
Water-dependent Assets – Data and Monitoring	Sections 4.6 & 9
Water and Salt Balance, and Water Quality	Surface Water Assessment
Cumulative Impacts – Context and Conceptualisation	Sections 1.3, 6 & 8.2
Cumulative Impacts – Impacts	Sections 6 & 8.2
Cumulative Impacts – Mitigation, Monitoring and Management	Sections 9 & 10
Subsidence – Underground Coal Mines and Coal Seam Gas	Subsidence Assessment
Final Landforms and Voids – Coal Mines	Section 6.8
Acid-forming Materials and Other Contaminants of Concern	Section 6.9
CSG Well Construction and Operation	Not Applicable

APPENDIX B

IESC ADVICE ON GATEWAY APPLICATION – CHECKLIST FOR GROUNDWATER RELATED ADVICE

ADVICE TO DECISION MAKER ON COAL MINING PROJECT		RELEVANT SECTION
IESC 2018-098: MAXWELL PROJECT – EXPANSION		
DATE OF ADVICE: 9TH NOVEMBER 2018		
SUMMARY	The proposed Maxwell project is an underground coal mine extension to be developed in the Hunter Valley, NSW. The project involves underground mining of four coal seams, the shallowest seam to be mined using bord and pillar methods with the deeper three coal seams to be longwall-mined. Coal will be handled at the existing Maxwell infrastructure site with coal rejects, tailings and brine to be deposited within the existing open cut East Void.	-
KEY POTENTIAL IMPACTS	long-term changes, which are severe and irreversible, to Permian hard rock aquifers and surface watercourses, due to subsidence fracturing;	Section 6
	changes to groundwater levels in alluvial aquifers due to leakage through shallow, hard rock fractures into hard rock aquifers;	Section 6
	changes to surface water flow regimes and an increase in sediment deposition (particularly in Saddlers Creek and its tributaries) due to surface effects of subsidence, the extent of which is unable to be determined as a surface water assessment was not included in the Gateway Certificate Application;	Section 6.3 and Surface Water Assessment and Geomorphology Assessment
	groundwater drawdown impacts to groundwater-dependent ecosystems (GDEs), the extent of both are uncertain due to the limited information; and,	Section 6.7
	decreased groundwater and surface water quality should seepage occur from the rejects, tailings and brine in the East Void.	Section 6.9
THE IESC IS CONCERNED THAT THE INHERENT UNCERTAINTY INVOLVED IN MODEL CONCEPTUALISATION AND PARAMETERISATION DOES NOT WARRANT THE UNREALISTICALLY HIGH CONFIDENCE WITH WHICH SUBSIDENCE AND GROUNDWATER IMPACTS ARE PRESENTED.		Section 7
THE KEY AREAS IN WHICH ADDITIONAL WORK IS REQUIRED TO ADDRESS THE POTENTIAL IMPACTS ARE SUMMARISED (BELOW).		
	Given the potentially irreversible and severe impacts to groundwater resources (and surface watercourses), explicit consideration of the uncertainty involved in predicting subsidence and ground movements is needed. This should include greater transparency on how these uncertainties transfer to groundwater impact predictions using traditional equivalent porous media groundwater models (such as MODFLOW).	Sections 5.2 and 7 and Appendix I
	Provision of geological modelling of the interburden, distribution of lithologies and process deposition that will influence vertical subsidence and fracture heights above each mined seam and their impact on groundwater predictions.	Sections 4.1, 4.4.3 and 5.2 and Appendix J
	Provision of site-specific information or relevant peer-reviewed case studies that address the general lack of understanding on how best to quantify the effects of ground movement, subsidence and fracturing on water movement and storage.	Sections 4.4.3 and 5.2 and Appendix J
	Collection of groundwater observation data and relevant down-borehole information to verify empirical approaches used to estimate the height of fracturing above extracted seams.	Sections 4.4.3 and 5.2 and Appendix J
	An assessment that gives due consideration to the large inherent uncertainties in the potential impacts (e.g. through subsidence fracturing, ponding and/or erosion) on flow regimes, water quality and instream biota in surface water	Section 6

ADVICE TO DECISION MAKER ON COAL MINING PROJECT		RELEVANT SECTION
	systems such as Saddlers Creek and its tributaries that drain the region of predicted subsidence. This should include long-term case studies for comparison.	
	Baseline (pre-mining) information on surface water quantity and quality (e.g. suspended solids), channel geomorphology and aquatic biota is needed to inform risk assessments and, if needed, suitable mitigation strategies.	Surface Water Assessment and Geomorphology Assessment
	An assessment of the extent and condition of relevant groundwater-dependent ecosystems and their biota, complemented with an appropriate risk assessment, monitoring program and feasible mitigation strategies for those impacts that cannot be avoided.	Sections 4.6, 6.7 and 9 and Biodiversity Development Assessment Report
	Provision of site-specific surface water, geochemical and risk assessments supported by a site-specific water balance and cumulative impact assessment, the latter to include relevant reaches of the Hunter River.	Surface Water Assessment and Geochemistry Assessment
RESPONSE TO QUESTIONS		
QUESTION 1: IT WOULD BE APPRECIATED IF THE IESC COULD ADVISE ON THE POTENTIAL LIKELIHOOD AND SIGNIFICANCE OF ANY IMPACTS OF THE PROPOSAL ON WATER RESOURCES.		
1	The limited level of detail in the project documentation at the Gateway stage restricts the ability of the IESC to assess the extent and likelihood of most of the proposed project’s potential impacts to water resources. Consequently, this advice is only able to provide general advice on the potential likelihood and significance of impacts of the proposed project, a number of which have been identified in the documentation accompanying the Agricultural Impact Assessment (AIA).	-
2	Key potential impacts include those caused by subsidence and groundwater dewatering. A detailed subsidence assessment has been provided which provides adequate consideration of physical subsidence impacts, while the Preliminary Groundwater Assessment (AIA, Attachment C) provides an indication of the potential groundwater drawdown impacts. However, limited information is available on surface water impacts, ecological impacts (including to groundwater-dependent ecosystems (GDEs)) and potential impacts associated with the proposed final landform and backfilled East Void. Several strategies and assessments to address these identified information gaps are provided in response to Question 4.	Subsidence Assessment, Groundwater Assessment, Surface Water Assessment, Geomorphology Assessment and Biodiversity Development Assessment Report
SUBSIDENCE		
3	Given the number of vertically successive coal seams to be mined, the proposed Maxwell Project will result in a range of potential subsidence-related impacts to water resources. These would include changes to surface watercourse gradients, flows and erosion, and surface ponding as well as surface and shallow fracturing. The maximum conventional vertical subsidence is predicted to be 5.8 m where all four coal seams are proposed to be extracted. However, conventional vertical subsidence will occur progressively as each subsequently deeper coal seam is mined. The seam with the greatest individual contribution to subsidence is predicted to be the Woodlands Hill Seam (AIA, Attachment B, p. 27), which is the second to be mined, is the first series of longwalls and the first to undermine the bord and pillar workings within the Whynot Seam. The extraction of three underlying coal seams beneath the Whynot Seam will likely result in the collapse of retained coal pillars, which would likely result in increased subsidence evident at the surface. The IESC notes that elsewhere in the Hunter Valley (North Wambo	Subsidence Assessment

ADVICE TO DECISION MAKER ON COAL MINING PROJECT		RELEVANT SECTION
	Underground Mine, see AIA, Attachment B, pp. 23 – 24) the extraction of longwalls beneath bord and pillar mined seams has resulted in localised subsidence in excess of 100 per cent of the total mining height.	
4	While the subsidence assessment utilises an appropriate methodology for both single- and double-seam subsidence predictions, there is a higher level of uncertainty regarding the predictions for subsidence from the mining of the third and fourth seams. This uncertainty is due to empirical evidence not being available to support model calibration for the mining of three and four vertically successive seams. Given this uncertainty, the IESC considers a risk-based, or precautionary, approach should be used when interpreting total cumulative subsidence, particularly in proximity to geological features (see paragraph 5 below) and important water resources (e.g. the Hunter River and its alluvium).	Subsidence Assessment
5	A number of structural features (igneous sills and fault zones, including the East Graben Fault) have been identified that may result in non-conventional, anomalous or irregular subsidence. These various types of subsidence potentially pose a higher risk to water resources outside of the conventional subsidence (26.5 degree angle of draw) impact zone. The resulting impacts at the surface from these subsidence episodes could be severe where the structural features are associated with water resources such as surface watercourses, alluvial aquifers and other GDEs or groundwater infrastructure (e.g. monitoring bores).	Subsidence Assessment
GROUNDWATER		
6	The potential impacts to groundwater resources (and surface water drainage) are highly likely to be severe and irreversible. Given the lack of adequate methods to assess the potentially severe and irreversible impacts to groundwater (and surface water resources) from subsidence, the current groundwater modelling approach has potentially understated the impacts of the proposed project and overstated the certainty with which the impacts can be predicted.	Sections 5, 6 and 7 and Surface Water Assessment
7	The IESC acknowledges the efforts made by the proponent to model the complex subsidence fracturing and groundwater impacts potentially caused by the proposed multi-seam mining method. However, the traditional porous media groundwater model used (MODFLOW-USG) is incapable of realistically simulating groundwater responses to ground movement of strata. This ground movement could include, but is not limited to, bed separation and subsidence-induced fracturing (which could extend to the ground surface). This is compounded by the limited options available to couple geotechnical and groundwater models and also the limited amount of data available to support the modelling of fracturing for multi-seam extraction. While the groundwater model report has utilised the best available methods to estimate fracture propagation above extracted coal seams, both the Tammetta (2013) and Ditton equations contain a number of assumptions that may not be appropriate to inform groundwater modelling in multi-seam mining operations. The IESC acknowledges that work to review and verify these methods is needed to expand the empirical data on which these methods rely.	Sections 5, 6 and 7
8	The IESC considers that the groundwater model predictions contain a high degree of uncertainty for the following reasons.	-

ADVICE TO DECISION MAKER ON COAL MINING PROJECT		RELEVANT SECTION
8A	The extent of ground movement (e.g. subsidence, fracturing, bedding shear) above any longwall panel is uncertain and difficult to identify and predict (see Galvin 2017). The uncertainties are compounded by multi-seam extraction. The impacts on groundwater are even more uncertain given the likely tortuous flow paths through various fracture networks. Evidence from a number of other longwall mines (e.g. in the Southern and Western Coalfields of NSW; PSM 2017) shows that groundwater responses to the extent of subsidence fracturing cannot be accurately predicted	Sections 5, 6 and 7
8B	Limited detail has been provided to describe how the stacked drain process determines changes to hydrogeological parameters within the different fracture zones above extracted coal seams. Further, the groundwater model is highly sensitive to the vertical hydraulic conductivity through the fractured zones above (and between) each of the mined seams and no empirical evidence or data has been provided to support the application of this method.	Section 4.4.3.1 and 5.2 and Appendix J
9	The groundwater model results appear to contain some systematic bias whereby groundwater levels are overpredicted compared to observed groundwater levels. For example, the calibration and verification of water level data points presented in Figures 36 to 39 of the AIA (Attachment C) are consistently at a higher elevation compared to the observed water levels, many by more than 50 m.	Section 4.7, 5.3, 5.6 and Appendices G, H and I
10	The uncertainties identified in paragraphs 6 to 9 above make it difficult for the IESC to confidently determine the likelihood and significance of potential impacts. However, the IESC considers it is reasonable to conclude that long-term hydrogeological changes would be likely to the North Coast Fractured and Porous Rock aquifers (as defined by NSW Government 2016) between the Bowfield seam and the surface within the mining area, given the magnitude of the predicted subsidence and subsurface deformation, and the number of vertically consecutive coal seams to be mined.	Section 5.2.7
11	The predicted impact to the alluvium over the entire model domain is the loss of approximately 0.28 ML/day (98.8 ML/year) (AIA, Attachment C, Figure 43 and p. 65). Given the uncertainty in the magnitude and hydrogeological effect of shallow hard rock and surficial fracturing, and the above noted sensitivity of the model to the vertical conductance of the fractured zone above each of the extracted seams, the potential impacts to alluvial aquifers may well be greater than predicted. Finer-scale modelling of alluvium and detailed representation of alluvial impacts will be needed in future modelling. Further, confirmation of alluvium extent (e.g. using geophysics), will be particularly important where the Hunter River Alluvium is close to the southern edge of the proposed mining area.	Sections 4, 5 and 6 and Attachments A, B and C
12	The groundwater model predicts significant depressurisation and dewatering of the Permian coal seams, extending for up to 9 km to the west, south and north. Vertical propagation of this depressurisation is predicted to result in a maximum predicted water table drawdown of approximately 20 m but the two-metre drawdown contour is not predicted to extend beyond the mining lease.	Section 6.1
13	The preliminary groundwater model predicts groundwater drawdown impacts to 29 existing groundwater user bores within the model domain, two of which are within the mining lease area. Of the 29 bores, only one is predicted to experience drawdown impacts greater than two metres due to the proposed Maxwell project. The potential impacts to landholder bores will need to be re-assessed following more detailed groundwater modelling and cumulative	Sections 4.6.1 and 6.5

ADVICE TO DECISION MAKER ON COAL MINING PROJECT		RELEVANT SECTION
	impact assessment. The IESC considers that the process to determine 'make good' arrangements for cumulative impacts shared between mine sites needs to be established and documented.	
SURFACE WATER		
14	The preliminary groundwater model predicts leakage from the Hunter River and Saddlers Creek to peak at approximately 50.0 ML/year and 45.4 ML/year respectively approximately 80 – 100 years post mining (AIA, Attachment C, pp. 64 – 65). The volume of water lost from surface watercourses will be highly dependent on whether non-conventional, anomalous or irregular subsidence occurs. Fracturing of rock bars due to valley closure and upsidence may also exacerbate the potential impacts to surface watercourses and waterbodies. No consideration has been given to the sensitivity of key assumptions on the estimated leakage rates. Accordingly the IESC has little confidence in the estimated likelihood and significance of the impacts on surface water resources.	Sections 6.2, 6.3 and 7 and Surface Water Assessment
15	Subsidence fracturing within the shallow substrate beneath alluvial sediments will be less readily detectable than surface cracks or cracks in rock bars in drainage lines. Fracturing under alluvial sediments, particularly deep sediments associated with the Hunter River, are likely to be irreversible and could result in substantial losses of surface water flows via the alluvial aquifers.	Sections 6.2, 6.3 and 7, Appendix J and Subsidence Assessment
16	The proponent has not provided any information on the project's mine water management measures or whether controlled releases to surface watercourses will be required. Coal mines in the Hunter Valley are required to discharge mine water in accordance with the Hunter River Salinity Trading Scheme (HRSTS). While the HRSTS is designed to minimise salt loads in the Hunter River, it does not prevent discharges of water high in other contaminants and toxicants. Controlled and uncontrolled (spills) releases have the potential to impact the downstream environment. However, it is not possible to determine the potential likelihood and significance of downstream surface water impacts without a site-specific water balance and a surface water quantity and quality assessment.	Surface Water Assessment
GROUNDWATER-DEPENDENT ECOSYSTEMS (GDES)		
17	A detailed assessment of ecological assets and GDEs has not been provided. However, the proponent (AIA, Attachment C, p. 68) acknowledges the water-dependent asset register for the Hunter subregion (Macfarlane et al. 2016) of the Northern Sydney Basin Bioregional Assessment for providing guidance for identification of various GDEs including surface and subsurface waters and groundwater-dependent vegetation. Based on the results of the preliminary groundwater modelling, shallow groundwater exists near Saddlers Creek, Saltwater Creek, the Hunter River and a number of minor drainages and tributaries. At least two types of GDEs are potentially impacted:	Sections 4.6 and 6.7 and Biodiversity Development Assessment Report
17A	Type 1 – Aquifer and cave ecosystems. Stygofauna are known from the alluvial aquifers and hyporheic zones of the Hunter River and its tributaries (Hancock 2006; Hancock and Boulton 2009) and may be affected by altered groundwater regimes. Surveys (Eco Logical 2015 and 2018 cited in Attachment C, pp. 32 – 33) for stygofauna in the Hunter River alluvium and Saddlers Creek alluvium near the proposed project found one known stygofaunal taxon (Syncarida, Notobathynella sp.) from the Hunter River alluvium and two likely stygofaunal taxa (Cyclopoida and Ostracoda) in the Hunter River and Saddlers Creek alluvium.	Sections 4.6 and 6.7 and Biodiversity Development Assessment Report

ADVICE TO DECISION MAKER ON COAL MINING PROJECT		RELEVANT SECTION
17B	Type 3 – Ecosystems dependent on subsurface presence of groundwater. Groundwater-dependent vegetation is likely to occur, especially along riparian zones and on floodplains of Saddlers Creek, Saltwater Creek, the Hunter River and other relevant tributaries in the predicted areas of groundwater drawdown. Further assessment is needed to determine which vegetation in these areas is dependent on groundwater (see response to Question 4, paragraph 39), and how it may be affected by the proposed mining and associated drawdown. In particular, assessments are needed on the possible impacts to EPBC Act-listed critically endangered ecological communities (e.g. White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland, Central Hunter Valley eucalypt forest and woodland) which may contain species that are opportunistically dependent on groundwater.	Sections 4.6 and 6.7 and Biodiversity Development Assessment Report
18	Rejects, tailings and brine are proposed to be deposited in the East Void at the existing Maxwell mine. While the IESC considers that this is an appropriate way to handle coal waste for the proposed project, the waste-filled void may pose a long-term legacy risk to both surface water and groundwater quality if appropriate monitoring and management measures are not implemented.	Section 6.8 and 6.9
QUESTION 2: IT WOULD BE APPRECIATED IF THE IESC COULD ADVISE ON THE BOUNDARY CONDITIONS USED IN THE GROUNDWATER MODEL.		
19	The IESC has noted a number of sources of uncertainty in the preliminary groundwater model in response to Question 1 (paragraphs 6 to 9). These sources of uncertainty have a more profound influence on groundwater modelling predictions than the adopted groundwater boundary conditions. Nevertheless, the groundwater model's boundary conditions are also subject to multiple sources of uncertainty due to model non-uniqueness. Insufficient justification is provided for the selection and location of general head boundaries, particularly to describe their sporadic or patchy placement around the model domain. Moreover, it is stated that the groundwater model lateral boundary conditions are sufficiently far from the mine to have no impact on model predictions. It is therefore unclear why the applied general head boundary conditions are even needed.	Section 5.2.1
20	Boundary conditions identified within the preliminary groundwater impact assessment include general head boundaries, no flow boundaries (prescribed by inactive cells), river boundaries and drains as well as recharge and evapotranspiration (AIA, Attachment C, pp 42 – 45).	Section 5.2.1
21	The IESC notes that the groundwater model is preliminary and agrees with the recommended improvements listed in the AIA (Attachment C, p. 83). In addition to these recommendations, future models that are produced should provide the following details to support the prescription of boundary conditions.	Section 5.2.1
21A	Further detail on the location and parameterisation of general head boundaries (or other boundary conditions if used). This should include which bore/s or datasets (e.g. predicted groundwater levels from other groundwater models and the associated data used to generate the predictions) are used to determine appropriate boundary conductance and to provide the water level data from that bore.	Section 5.2.1
21B	Confirmation of geological outcrop and strata pinch-out to inform the location of no-flow boundaries and inactive groundwater model cells. While the preliminary groundwater assessment appears to have followed geological and exploration mapping, a dedicated geological assessment is needed (as detailed in paragraph 29) to confirm the	Section 5.2.1

ADVICE TO DECISION MAKER ON COAL MINING PROJECT		RELEVANT SECTION
	hydrogeological conceptualisation, the representation of interburdens and the geological structures using no-flow boundaries that prevent the lateral flow of groundwater.	
21C	Information on recharge rates as a proportion of rainfall (particularly for the alluvium) that are independent of the groundwater model. This information should be compared to, if possible, other studies that consider environmental tracers or soil water balance modelling and consider a range of evaporation extinction depths greater than two metres.	Section 5.2.4
21D	Detailed river reach and geophysics mapping that identifies river bed materials. This information should support the chosen river bed conductance values applied in the groundwater model. River boundary conditions can also be compared to surface water runoff-flow models and baseflow calculations to justify the choice of conductance.	Section 4.1 and Attachments B and C
22	It is recommended that both sensitivity and uncertainty analysis should be undertaken for the parameterisation of boundary conditions including, for example, recharge, evapotranspiration (including extinction depth), river bed conductance (including representation of natural heterogeneity along the river), drain conductance and strata conductance at general head boundaries. These analyses should prioritise examination of the relative importance of general head boundaries, recharge and drain conductance to the overall water balance to identify values that significantly influence drawdown distribution in all hydrogeological units in the groundwater model.	Section 7
QUESTION 3: IT WOULD BE APPRECIATED IF THE IESC COULD ADVISE ON THE APPROPRIATENESS OF THE PROPOSED MITIGATION MEASURES.		
23	Given the preliminary nature of the water resource assessments provided to satisfy the Gateway Certificate process, the mitigation measures detailed are mostly high level and lack the specificity needed for the IESC to determine their appropriateness.	-
24	The available documentation (Malabar Coal, 2018, pp. 17 – 20; AIA, pp. 58 – 59) describes preliminary monitoring and management measures for subsidence but provides limited information on most other mitigation measures.	Subsidence Assessment and EIS Main Text
25	It is probably not feasible to successfully mitigate ground movement impacts that are at depth or that are not visible or accessible at the surface (e.g. below alluvium associated with surface watercourses).	Subsidence Assessment
26	Subsidence mitigation measures are to be detailed within a subsidence management plan and implemented following impact identification through site-specific monitoring. At this stage the identified potential mitigation measures for subsidence-induced surface cracking include ripping, re-grading or in-filling of large to medium surface cracks, re-grading and erosion controls in surface drainage lines and repairing or reinstating damaged groundwater bores. However, the IESC would expect to see more detail on the specific monitoring, management and mitigation measures included within a full environmental assessment. Detailed, long-term and peer-reviewed case studies on successful use of these measures at equivalent locations are essential. Studies should be provided on the relative impacts from grading surface water drainage channels versus letting them “self-heal” after subsidence.	Subsidence Assessment and Geomorphology Assessment
QUESTION 4: THE IESC MAY ALSO RECOMMEND FURTHER STUDIES THAT SHOULD BE UNDERTAKEN IF RELEVANT.		
27	Given the preliminary state of water resource assessments within the AIA and Gateway Certificate Application, the IESC recommends a number of further studies below that should be completed as a component of any future	-

ADVICE TO DECISION MAKER ON COAL MINING PROJECT		RELEVANT SECTION
	assessments. While some of the following studies may not be relevant at the Gateway stage, the IESC considers that they would be critical to inform any future environmental assessment processes. The recommended studies and methods described are based on current understanding and should not be considered exhaustive. When undertaking further studies, the proponent should consider the information needs outlined in the IESC's Information Guidelines (IESC 2018) and relevant IESC Explanatory Notes as they become available.	
GROUNDWATER ASSESSMENT AND GROUNDWATER MODELLING		
28	The preliminary groundwater impact assessment identified a high-level scope for groundwater modelling to inform future environmental assessment (AIA, Attachment C, p. 83). The IESC is generally supportive of the identified future groundwater modelling scope, but recognises the inherent complexities of modelling fracture flow through porous media (see paragraphs 6 to 9). Where justified by monitoring data, consideration should be given to incorporating structural geological features (e.g. faults, dykes, sills, lithological variations in geology) in groundwater modelling undertaken to inform the next stage of environmental assessment.	Structural geological features are discussed in Sections 5.1.4 and 7 and Attachment A
29	A geological assessment is needed to confirm the hydrogeological conceptualisation. The geological assessment should include detailed geological maps of outcrop, subcrop, alluvial extent and regolith extent, bore logs and any geophysical assessments (such as electromagnetic surveys) undertaken to confirm the geological features within the project's impact area.	Section 4.1 and Attachments A, B and C
30	A detailed, independent and peer reviewed assessment of the potential surface-to-seam fracturing with an integrated hazard map (c.f. Herron et. al. 2018) overlaying the GDEs, BSAL areas, geological structures and drainage lines close to the Hunter River alluvium is needed.	Section 5.2 and Appendix J
31	There is a high degree of uncertainty associated with the groundwater modelling, including the stacked drain VCOND method used to estimate the influence of the fractured zone on groundwater. This method is unable to directly simulate fracturing to the surface (AIA, Attachment C, p. 47) and is not supported by any case-study evidence (because there are no detailed groundwater case studies for the effects of the extraction of more than three coal seams) (see also paragraph 4). Given the lack of evidence or case studies for this number of consecutive seam extractions, it is critical that appropriate monitoring and investigative down-borehole information data should be collected to reduce uncertainty in future predictions.	Modelling approach is discussed in Section 5.2 and Appendix J and monitoring and mitigation measures are discussed in Sections 9 and 10
32	Confirmation of the depth and extent of the Hunter River alluvium and its associated groundwater levels are needed as its alluvial material is near the predicted watertable drawdown extent as well as along Saddlers Creek and a tributary of Saltwater Creek. This assessment could occur using the methods described in paragraph 29 and should be accompanied by finer-scale groundwater modelling. Confirming the alluvial extent and water levels will be particularly important given the uncertainty in the magnitude of surficial and shallow hard rock fracturing caused by subsidence and the sensitivity of the groundwater model to the vertical hydraulic conductivity within fractured zones of the deeper geology.	Section 4.1 and Attachments B and C For groundwater flow see Section 4.4
33	Future groundwater impact assessments should provide greater transparency around the source hydrogeological data used to parameterise the groundwater model including, but not limited to, the boundary conditions (see	Section 4.4.3

ADVICE TO DECISION MAKER ON COAL MINING PROJECT		RELEVANT SECTION
	response to Question 2), the hydrogeological conceptualisation and hydrogeological parameters. This should include clearly presenting the hydrogeological data, the collection method (e.g. pump test, packer test) and any important information or statistics that inform how it was used in parameterisation of the groundwater model. Where sourced from existing studies, methods and data should be reproduced to justify their application in the future groundwater assessments.	
34	Consideration should be given to using recently developed in-situ methods to measure specific storage (David et al. 2017; Rau et al. 2018) and applying the resulting values to better constrain the results of future groundwater models. There are multiple combinations of hydraulic conductivity and specific storage that could materially affect the modelled water balance and drawdown of a transient model.	Sections 4.4.3, 5.2 and 5.3
35	The preliminary groundwater model only considered cumulative impacts from the Mt Arthur Mine immediately to the north of the exploration lease. Although existing coal mines to the east are hydrogeologically separated by geological structure and outcropping, groundwater modelling to inform the next stage of assessment should include all mines within the model area unless exclusion is clearly justified and supported by geological and groundwater data. These mines include the proposed Spur Hill project, Mt Arthur (and extension) projects, Bengalla, Mangoola and the existing workings/voids within the Maxwell area. Cumulative impact assessment should also consider the results from the Bioregional Assessment for the Northern Sydney Basin, Hunter Subregion.	Sections 4.4.2, 5.4 and 6
36	The proponent has committed to developing a groundwater management plan (including a groundwater monitoring programme) (Malabar Coal 2018 p. 19). Limited groundwater quality data (EC and pH), obtained from other reports and operations, have been provided for the Hunter River Alluvium, Saddlers Creek alluvium and the Permian porous rock aquifers. A full range of parameters should be measured (beyond EC and pH) and included in the proposed groundwater monitoring program to be included in the groundwater management plan. This plan should be presented as a component of any future environmental assessment.	Section 9.1
SURFACE WATER ASSESSMENT		
37	A surface water assessment is needed which:	
37A	uses a risk-based approach to identify key surface water systems with the potential to be impacted (e.g. through subsidence fracturing, ponding or erosion), especially how this may alter the duration of periods of low and zero flow in Saddlers Creek and potentially impact on instream biota;	Surface Water Assessment
37B	identifies the existing (baseline) hydrological regime of all watercourses within the potential zone of hydrological impacts;	Surface Water Assessment
37C	uses appropriate surface water quantity and quality data to inform impacts and risks;	Surface Water Assessment
37D	includes baseline monitoring data over a sufficient time period to enable the derivation of appropriate site-specific water quality guideline values;	Surface Water Assessment
37E	considers geomorphology and the additional impacts potentially caused by the range of potential subsidence effects (e.g. sedimentation and erosion); and	Surface Water Assessment and Geomorphology Assessment

ADVICE TO DECISION MAKER ON COAL MINING PROJECT		RELEVANT SECTION
37F	informs appropriate mitigation strategies (e.g. timing and methods for re-establishing drainage lines to minimise erosion and vegetation damage).	Surface Water Assessment and Geomorphology Assessment
WATER BALANCE MODELLING		
38	A quantitative site-specific water balance is needed which accommodates various sources of uncertainty (e.g. using the Water Accounting Framework for the Australian minerals industry, Minerals Council of Australia 2014). This site-specific approach would describe:	
38A	the total water supply and demand under a range of rainfall, climatic and water demand scenarios to support the uncertainty analysis;	Surface Water Assessment
38B	the required water infrastructure, including infrastructure capacity and transfers;	Surface Water Assessment
38C	volumes of water needed to be discharged (if any), under a range of rainfall scenarios; and	Surface Water Assessment
38D	quantitatively the potential water quality impacts due to the any of the above water management actions.	Surface Water Assessment
GROUNDWATER-DEPENDENT ECOSYSTEMS (GDES)		
39	An assessment of the extent and condition of GDEs and water-dependent flora and fauna is needed, followed by an appropriate risk assessment (e.g. Serov et al. 2012). These studies should consider the ecological water requirements for any water-dependent species and their habitat. The locations of any shallow groundwater discharge points and other GDEs should be included, especially in areas where drawdown is predicted. A systematic approach to the assessment of GDEs is recommended in which:	
39A	the methods from, for example, the Australian GDE Toolbox (Richardson et al. 2011) and Eamus et al. (2015) are used to assess groundwater use by vegetation (especially during dry periods).	Biodiversity Development Assessment Report
39B	the hydrogeological conceptualisation is used to identify areas of shallow groundwater (less than 20 m below ground level) and potential areas of groundwater discharge.	Sections 4.1, 4.4, 4.5 and 4.7
39C	vegetation, seasonal depths to groundwater and shallow groundwater drawdown maps are overlaid to identify areas of potential GDEs. These maps should be supported by monitoring data gathered near the regions occupied by potential GDEs, with the shallow groundwater monitoring locations also plotted on the maps.	Section 6.7 and Biodiversity Development Assessment Report
39D	ecohydrological conceptualisations are used that integrate results from hydrogeological, hydrological, geomorphological and ecological investigations at a spatial and temporal scale that is suitable for predicting potential impacts to GDEs and pathways of likely effects of the proposed development. The identified potential impact pathways should then be used to develop proposed mitigation strategies and to monitoring of these strategies' effectiveness.	Sections 6.7 and 9
FINAL VOID MANAGEMENT		
40	Given the proponent proposes to dispose of coal rejects, tailings and brine in the existing East Void, early consideration of site-closure mitigation and management measures should be included in the form of a restoration plan in future assessment documentation. The restoration plan should include information on:	
40A	the proposed geomorphology and vegetation structure of the final landform, including whether the void will be completely backfilled (with tailings etc.) or will retain a final void.	Sections 4.7.4, 5.5, 6.8 and 6.9

ADVICE TO DECISION MAKER ON COAL MINING PROJECT		RELEVANT SECTION
40B	long-term void water level and water quality modelling if a final void lake is predicted to remain. It is noted that groundwater modelling of the water flow directions from the post-closure East Void is proposed to occur as a component of future groundwater modelling (AIA, Attachment C, p. 83). This modelling should be used to inform restoration measures.	Section 4.7.4, 5.5, 6.8 and 6.9
40C	a final landform groundwater flow and groundwater quality monitoring network, capable of identifying seepage from the East Void following restoration. The post-closure East Void groundwater monitoring network should be installed during operations and be informed by the risk assessment and groundwater modelling described in paragraph 40b.	Sections 9 and 10
40D	measures to ensure long-term landform stability, prevent erosion and ensure the final landform (including above the longwall mining area) does not pose a risk to surface water resources.	Section 6.8 and Surface Water Assessment
GEOCHEMICAL ASSESSMENT		
41	The restoration plan should be informed by an assessment of the geochemical characteristics of the existing waste rock material, coal rejects, tailings and brine within the East Void and the potential for this material to be a contamination source to the surrounding environment.	Section 6.9
42	The geochemical assessment should include soil chemistry analysis (e.g. sodicity, dispersivity, pH) to be used in covering or re-shaping of the East Void during restoration.	Preliminary Rehabilitation and Mine Closure Strategy
RISK ASSESSMENT		
43	Any future environmental assessments for the proposed project should include a stand-alone risk assessment that considers specific water-related risks to the environment, for example, using a methodology similar to that used in the Bioregional Assessments (Herron et. al. 2018). The risk assessment should be informed by the hazard risk mapping described in paragraph 30. This risk assessment should quantitatively assess the likelihood and consequence of identified impacts and the residual risk following application of proposed mitigation measures.	Environmental Risk Assessment

APPENDIX C

SEARs REQUIREMENTS – CHECKLIST FOR GENERAL AND WATER SPECIFIC REQUIREMENTS

and

COMMONWEALTH DEPARTMENT OF ENVIRONMENT AND ENERGY ASSESSMENT REQUIREMENTS – CHECKLIST FOR GENERAL AND WATER RESOURCE REQUIREMENTS

and

GROUNDWATER-RELATED RECOMMENDATIONS OF THE CONDITIONAL GATEWAY CERTIFICATE

SEARs requirements checklist

The (NSW Department of Planning and Environment) Secretary's Environmental Assessment Requirements (SEARs) for the Project (Application SSD 18-95826) were provided by the DP&E in September 2018. Revised SEARs for the Project (Application SSD 18-95826) were provided by the DP&E in January 2019.

The general requirements include:	
	Section addressed
A stand-alone executive summary;	Executive Summary of EIS Main Text
A full description of the development, including:	Section 1.2 and Section 3 of EIS Main Text
Historical mining operations on and nearby the site;	Section 1.3
The relationship and interaction with other existing and previously operating mines;	Section 1.3 and Section 4.4.1
A summary of regional and local geology, and soils;	Section 4.1
A water management strategy;	See Surface Water Assessment
A rehabilitation strategy;	Section 7 of EIS Main Text and Appendix U of EIS
The likely interactions between the development and any other existing, approved or proposed mining development or power station in the vicinity of the site;	Section 1.3 and Section 4.4.1
An assessment of the likely impacts of the development on the environment, focusing on the key issues identified below, including:	See Impact Assessment
A description of the existing environment likely to be affected by the development, using sufficient baseline/background data;	See Section 3 and Section 4
An assessment of the likely impacts for all stages of the development, including any cumulative impacts, taking into consideration any relevant laws, environmental planning instruments, guidelines, policies, plans and industry codes of practice	See Surface Water Assessment
The Key issues identified in the SEARs requirements in relation to water include:	
A detailed site water balance, including a description of site water demands, water disposal methods (inclusive of volume and frequency of any water discharges), water supply infrastructure and water storage structures;	See Surface Water Assessment
Identification of any licensing requirements or other approvals under the Water Act 1912 and/or Water Management Act 2000;	See Impact Assessment
Demonstration that water for the construction and operation of the proposed development can be obtained from an appropriately authorised and reliable supply in accordance with the operating rules of any relevant Water Sharing Plan (WSP) or water source embargo;	See Surface Water Assessment
An assessment of any likely flooding impacts of the development;	See Surface Water Assessment

The general requirements include:	
A salinity investigation study;	See Surface Water Assessment
The measures which would be put in place to control sediment run-off and avoid erosion;	See Surface Water Assessment
An assessment of the likely impacts of the development on the quantity and quality of existing surface and groundwater resources including a detailed assessment of proposed water discharge quantities and quality against receiving water quality and flow objectives;	See Surface Water Assessment See Impact Assessment
An assessment of the likely impacts of the development on aquifers, watercourses, riparian land, water-related infrastructure, and other water users; and	See Surface Water Assessment See Impact Assessment
A summary of proposed surface and groundwater monitoring activities and methodologies.	See Surface Water Assessment See Monitoring and Mitigation Measures

Commonwealth Department of Environment and Energy Assessment Requirements - Checklist of General and Water Resource Requirements

General Requirements		
Relevant Regulations		
5	The Environmental Impact Statement (EIS) must address the matters outlined in Schedule 4 of the EPBC Regulations and the matters outlined below in relation to the controlling provisions.	-
Project Description		
6	The title of the action, background to the action of the action and current status.	Section 1
7	The precise location and description of all works to be undertaken (including associated offsite works and infrastructure), structures to be built or elements of the action that may have impacts on MNES.	Section 1
8	How the action relates to any other actions that have been, or are being taken in the region affected by the action.	Section 1
9	How the works are to be undertaken and design parameters for those aspects of the structures or elements of the action that may have relevant impacts on MNES.	Section 1
Impacts		
10	The EIS must include an assessment of the relevant impacts of the action on the matters protected by the controlling provisions, including:	-
10i	a description and detailed assessment of the nature and extent of the likely direct, indirect and consequential impacts, including short term and long term relevant impacts;	Section 6 and Section 8.2
10ii	a statement whether any relevant impacts are likely to be unknown, unpredictable or irreversible;	Section 6 and Section 8.2
10iii	analysis of the significance of the relevant impacts; and	Section 6 and Section 8.2
10iv	any technical data and other information used or needed to make a detailed assessment of the relevant impacts.	Section 3 to Section 5
Avoidance, mitigation and offsetting		
11	For each of the relevant matters protected that are likely to be significantly impacted by the action, the EIS must provide information on proposed avoidance and	Section 9 and Section 10

General Requirements		
	mitigation measures to manage the relevant impacts of the action including:	
11i	a description, and an assessment of the expected or predicted effectiveness of the mitigation measures,	Section 9 and Section 10
11ii	any statutory policy basis for the mitigation measures;	See Main Report
11iii	the cost of the mitigation measures;	See Main Report
11iv	an outline of an environmental management plan that sets out the framework for continuing management, mitigation and monitoring programs for the relevant impacts of the action, including any provisions for independent environmental auditing;	See Main Report
11v	the name of the agency responsible for endorsing or approving each mitigation measure or monitoring program.	See Main Report
12	Where a significant residual adverse impact to a relevant protected matter is considered likely, the EIS must provide information on the proposed offset strategy, including discussion of the conservation benefit associated with the proposed offset strategy.	Section 8.2
13	For each of the relevant matters likely to be impacted by the action the EIS must provide reference to, and consideration of, relevant Commonwealth guidelines and policy statements including any:	-
13i	conservation advice or recovery plan for the species or community,	See Main Report
13ii	relevant threat abatement plan for a process that threatens the species or community	See Main Report
13iii	wildlife conservation plan for the species	See Main Report
13iv	any strategic assessment.	See Main Report
Key Issues		
Water resource, in relation to coal seam gas development and large coal mining development		-
Comments		
22	DoEE considers the proposed action is likely to have significant impacts on a water resource, and that further assessment will be required to assess the nature and extent of these impacts, including the likely extent of these impacts on listed threatened species and ecological communities.	Section 6 and Section 8.2

General Requirements		
Assessment Requirements		
23	The EIS must provide a description of the location, extent and ecological characteristics and values of the identified water resource potentially affected by the project.	Section 4
24	The assessment of impacts should include information on:	
24i	any substantial and measurable changes to the hydrological regime of the water resource, for example a substantial change to the volume, timing, duration or frequency of ground and surface water flows;	Section 6
24ii	the habitat or lifecycle of native species, including invertebrate fauna and fish species, dependent upon the water resource being seriously affected	See Ecological Assessment
24iii	substantial and measurable change in the water quality and quantity of the water resource—for example, a substantial change in the level of salinity, pollutants, or nutrients in the wetland; or water temperature that may adversely impact on biodiversity, ecological integrity, social amenity or human health.	Section 6
25	The EIS must provide adequate information to allow the project to be reviewed by the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development, as outlined in the *Information Guidelines for Independent Expert Scientific Committee advice on coal seam gas and large coal mining development proposals (IESC, October 2015)*.	This report
Information Sources		
28	For information given in an EIS, the EIS must state the source of the information, how recent the information is, how the reliability of the information was tested; and what uncertainties (if any) are in the information.	This report

Conditional Gateway Certificate requirements checklist

Schedule 2 of the Conditional Gateway Certificate relevantly states:		
More work is also required to establish baseline groundwater conditions. In particular the following is inadequately defined:		
	Potential effects of geological faulting, basalt flows and fracturing on groundwater movement;	Section 4
	The interaction between surface and groundwater near the Hunter River and Saddlers Creek;	Section 4
	The water transmitting capacity of the weathered zone beneath the Hunter River alluvium;	Section 4
	Hydraulic parameters of model layers.	Section 4 and Section 5
	Groundwater dependent ecosystems.	Section 4.6.2
Using a calibrated transient 3D model, re-quantify the impacts on nearby water assets (bore/well and GDEs). This updated modelling and reporting should:		
	Capture the hydrogeological complexity of the site;	Section 5
	Use temporal input data;	Section 5
	Have distributed input parameters;	Section 5
	Quantify any uncertainties in the groundwater /surface water connection;	Section 5 and Section 7
	Undertake both sensitivity and uncertainty analysis and have the model independently peer reviewed.	Section 7
The Minister for Primary Industries also considered the IESC Advice 2018-098 and in relation to the NSW Aquifer Interference Policy made the following three statements:		
	Obtaining entitlement from the Sydney Basin North Coast Groundwater Source will pose a significant challenge as there are several competing mines similarly seeking entitlement from this water source.	-
	A strategy to manage water level impacts beyond 2m cumulative decline at any water supply work will be required at the EIS stage. Groundwater impact modelling lodged with the EIS will need to include uncertainty analysis.	Section 7
	Malabar will require detailed supporting evidence at the EIS stage demonstrating compliance with the Aquifer Interference Policy with respect to depth and distance to mining beneath aquifers define as 'reliable water supply'	Section 8.1

APPENDIX D

WATER QUALITY SUMMARY

		DEFAULT GUIDELINE VALUES (DGV)	NHMRC DRINKING WATER	ANZECC (2000) FRESH WATER AQUATIC	ANZECC (2000) SHORT TERM IRRIGATION	ANZECC (2000) LONG TERM IRRIGATION	ANZECC (2000) STOCK WATER	QA – HUNTER	QA – SADDLERS	QA – REGOLITH	JV - JURASSIC VOLCANICS	WCM - INTERBURDEN	WCM - COAL	MAITLAND GROUP	GRETA CM	TAILINGS
PH (FIELD) PH UNIT	Av.	-	6.5 - 8.5[b]	6.5 – 8.5	6.0 - 8.5	6.0 - 8.5	-	7.30	7.34	6.96	6.89	6.98	7.61	7.17	7.10	**6.46**
	Med							7.29	7.30	7.00	6.83	6.99	7.47	7.13	7.06	6.50
	Min							5.90	6.76	6.05	6.65	5.89	5.50	6.50	6.85	4.50
	Max							8.88	8.10	7.60	7.16	7.56	12.46	7.97	7.41	7.10
	Pop							555	76	86	9	92	699	23	6	68
EC (FIELD) µS/CM	Av	-	-	120 - 300	-	-	-	1254	5263	8182	5413	5022	4571	5322	4265	5300
	Med							637	5735	6325	5110	4870	4460	7210	4425	5335
	Min.							528	638	1785	4890	3210	70	755	1860	4
	Max							7880	9180	22300	6260	7720	14710	9480	5810	7230
	Pop							3036	76	86	9	92	706	23	6	68
TDS mg/L	Av	-	600[b]	-	-	-	3,000 - 13,000*	791	**3408**	**5434**	**3627**	2966	2659	**3566**	2858	**4167**
	Med							427	3600	4229	3424	2880	2490	4831	2965	4250
	Min							354	302	1196	3276	2090	149	506	1246	2950
	Max							5070	6151	14941	4194	3900	9520	6352	3893	5600
	Pop							3037	76	86	9	92	706	23	6	68
TSS mg/L	Av	-	-	-	-	-	-	313.90	80.21	25.28	-	183.18	69.29	-	-	146.12
	Med							114.00	21.00	11.00	-	34.00	17.00	-	-	37.00
	Min							3.00	2.00	3.00	-	8.00	2.00	-	-	5.00
	Max							4260.00	522.00	160.00	-	3970.00	5540.0 0	-	-	3160.00
	Pop							455	47	29	-	90	682	-	-	68

		DEFAULT GUIDELINE VALUES (DGV)	NHMRC DRINKING WATER	ANZECC (2000) FRESH WATER AQUATIC	ANZECC (2000) SHORT TERM IRRIGATION	ANZECC (2000) LONG TERM IRRIGATION	ANZECC (2000) STOCK WATER	QA – HUNTER	QA – SADDLERS	QA – REGOLITH	JV - JURASSIC VOLCANICS	WCM - INTERBURDEN	WCM - COAL	MAITLAND GROUP	GRETA CM	TAILINGS
CHLORIDE mg/L	Av	-	250[b]	-	-	-	-	**869**	**1102**	**1379**	-	**869**	**883**	-	-	**666**
	Med							925	1120	1400	-	788	695	-	-	669
	Min							46	22	936	-	648	161	-	-	578
	Max							2050	2780	1540	-	1210	3920	-	-	758
	Pop							252	60	40	-	14	298	-	-	26
CALCIUM mg/L	Av	-	-	-	-	-	1,000	118.2	71.0	136.8	-	82.4	34.5	-	-	318.5
	Med							117.0	72.5	172.5	-	75.0	18.0	-	-	326.5
	Min							19.0	30.0	32.0	-	53.0	1.0	-	-	245.0
	Max							233.0	130.0	204.0	-	122.0	310.0	-	-	357.0
	Pop							252	60	40	-	14	298	-	-	26
SODIUM mg/L	Av	-	180[b]	-	-	-	-	**569**	**695**	**940**	-	**752**	**950**	-	-	**699**
	Med							590	574	804	-	714	849	-	-	683
	Min							51	71	654	-	596	379	-	-	606
	Max							1120	1700	1650	-	982	2120	-	-	866
	Pop							252	60	40	-	14	298	-	-	26
MAGNESIUM mg/L	Av	-	-	-	-	-	-	144.8	201.7	211.1	-	159.5	93.7	-	-	293.7
	Med							139.0	238.0	251.5	-	143.0	50.0	-	-	288.0
	Min							16.0	30.0	47.0	-	120.0	1.0	-	-	240.0
	Max							358.0	363.0	360.0	-	262.0	353.0	-	-	354.0
	Pop							252	60	40	-	14	298	-	-	26
SULPHATE mg/L	Av	-	500[a] / **250**[b]	-	-	-	1,000 – 2,400 (pigs)	**272.8**	**220.8**	**303.6**	-	**333.2**	**129.0**	-	-	**2054.8**
	Med							196.0	184.5	293.0	-	298.0	35.0	-	-	2060.0
	Min							4.0	16.0	1.0	-	12.0	1.0	-	-	1550.0
	Max							974.0	495.0	683.0	-	791.0	1130.0	-	-	2450.0
	Pop							247	60	40	-	12	288	-	-	25

		DEFAULT GUIDELINE VALUES (DGV)	NHMRC DRINKING WATER	ANZECC (2000) FRESH WATER AQUATIC	ANZECC (2000) SHORT TERM IRRIGATION	ANZECC (2000) LONG TERM IRRIGATION	ANZECC (2000) STOCK WATER	QA – HUNTER	QA – SADDLERS	QA – REGOLITH	JV - JURASSIC VOLCANICS	WCM - INTERBURDEN	WCM - COAL	MAITLAND GROUP	GRETA CM	TAILINGS
POTASSIUM mg/L	Av	-	-	-	-	-	-	4.7	4.2	7.4	-	11.7	27.0	-	-	21.6
	Med							3.0	5.0	6.0	-	11.0	17.0	-	-	20.0
	Min							1.0	1.0	5.0	-	9.0	2.0	-	-	16.0
	Max							57.0	8.0	16.0	-	20.0	290.0	-	-	33.0
	Pop							252	60	40	-	14	298	-	-	26
BICARBONATE mg/L	Av.	**-**	**-**	-	-	-	-	588.8	662.6	786.3	-	975.8	1152.7	-	-	531.5
	Med.							600.0	765.5	693.5	-	980.0	1165.0	-	-	536.0
	Min.							30.0	304.0	586.0	-	843.0	1.0	-	-	460.0
	Max.							1110.0	991.0	1300.0	-	1100.0	2460.0	-	-	626.0
	Pop.							227	60	40	-	4	256	-	-	21
ALUMINIUM (T) mg/L	Av.	***0.055***	***0.2*** [b c]	*0.055*	*20*	*5*	*5*	**0.20**	0.01	0.01	-	**0.49**	0.06	-	-	**0.45**
	Med.							0.01	0.01	0.01	-	0.17	0.01	-	-	0.56
	Min.							0.01	0.01	0.01	-	0.01	0.01	-	-	0.11
	Max.							13.40	0.03	0.03	-	2.95	1.41	-	-	0.74
	Pop.							244	52	32	-	14	286	-	-	5
ARSENIC (T) mg/L	Av.	As (III) 0.024; As (V) 0.013	0.01[a]	As (III) 0.024 As (V) 0.013	2	0.1	0.5	0.001	0.001	0.002	-	0.002	0.005	-	-	0.002
	Med.							0.001	0.001	0.001	-	0.001	0.001	-	-	0.002
	Min.							0.001	0.001	0.001	-	0.001	0.001	-	-	0.001
	Max.							0.010	0.001	0.016	-	0.005	0.072	-	-	0.004
	Pop.							244	52	32	-	14	286	-	-	20

		DEFAULT GUIDELINE VALUES (DGV)	NHMRC DRINKING WATER	ANZECC (2000) FRESH WATER AQUATIC	ANZECC (2000) SHORT TERM IRRIGATION	ANZECC (2000) LONG TERM IRRIGATION	ANZECC (2000) STOCK WATER	QA – HUNTER	QA – SADDLERS	QA – REGOLITH	JV - JURASSIC VOLCANICS	WCM - INTERBURDEN	WCM - COAL	MAITLAND GROUP	GRETA CM	TAILINGS
BARIUM (T) mg/L	Av.	-	2[a]	-	-	-	-	0.06	0.06	0.19	-	0.42	0.16	-	-	0.02
	Med.							0.05	0.06	0.13	-	0.29	0.12	-	-	0.01
	Min.							0.01	0.01	0.08	-	0.09	0.01	-	-	0.01
	Max.							0.58	0.22	0.52	-	1.80	0.85	-	-	0.05
	Pop.							244	52	32	-	14	286	-	-	26
BERYLLIUM (T) mg/L	Av.	0.00013 (low reliability	0.06[a]	-	0.5	0.1	-	0.001	0.001	0.001	-	-	-	-	-	-
	Med.							0.001	0.001	0.001	-	-	-	-	-	-
	Min.							0.001	0.00	0.00	-	-	-	-	-	-
	Max.							0.001	0.00	0.00	-	-	-	-	-	-
	Pop.							12	12	12	-	-	-	-	-	-
BORON (T) mg/L	Av.	0.37	4[a]	0.37	refer to guideline	0.5	7 (cattle)	0.16	0.15	0.17	-	0.45	0.16	-	-	0.25
	Med.							0.17	0.12	0.15	-	0.48	0.16	-	-	0.25
	Min.							0.05	0.06	0.10	-	0.28	0.05	-	-	0.19
	Max.							0.34	0.35	0.29	-	0.56	0.29	-	-	0.34
	Pop.							219	52	32	-	4	244	-	-	21
CADMIUM (T) mg/L	Av.	0.0002	0.002[a]	0.0002	0.05	0.01	0.01	0.0001	0.0001	0.0001	-	0.0001	0.0001	-	-	0.0001
	Med.							0.0001	0.0001	0.0001	-	0.0001	0.0001	-	-	0.0001
	Min.							0.0001	0.0001	0.0001	-	0.0001	0.0001	-	-	0.0001
	Max.							0.0004	0.0010	0.0001	-	0.0001	0.0002	-	-	0.0001
	Pop.							244	52	32	-	14	286	-	-	1

		DEFAULT GUIDELINE VALUES (DGV)	NHMRC DRINKING WATER	ANZECC (2000) FRESH WATER AQUATIC	ANZECC (2000) SHORT TERM IRRIGATION	ANZECC (2000) LONG TERM IRRIGATION	ANZECC (2000) STOCK WATER	QA – HUNTER	QA – SADDLERS	QA – REGOLITH	JV - JURASSIC VOLCANICS	WCM - INTERBURDEN	WCM - COAL	MAITLAND GROUP	GRETA CM	TAILINGS
CHROMIUM (T) mg/L	Av.	Cr (III) - 0.0033 (low reliability); Cr (VI) 0.0004	0.05[a]	CrIII – ID Cr(VI) 0.001	1	0.1	1	0.002	0.001	0.001	-	0.002	0.002	-	-	0.007
	Med.							0.001	0.001	0.001	-	0.002	0.001	-	-	0.003
	Min.							0.001	0.001	0.001	-	0.001	0.001	-	-	0.003
	Max.							0.040	0.005	0.005	-	0.006	0.027	-	-	0.015
	Pop.							244	52	32	-	14	286	-	-	3
COBALT (T) mg/L	Av.	0.0028 (low reliability)	-	-	0.1	0.05	1	0.011	0.001	0.001	-	-	-	-	-	-
	Med.							0.005	0.001	0.001	-	-	-	-	-	-
	Min.							0.001	0.001	0.001	-	-	-	-	-	-
	Max.							0.033	0.002	0.002	-	-	-	-	-	-
	Pop.							12	12	12	-	-	-	-	-	-
COPPER (T) mg/L	Av.	0.0014	**2[a] / 1[b]**	0.0014	5	0.2	1 (cattle)	**0.004**	**0.002**	**0.001**	-	**0.004**	**0.003**	-	-	**0.004**
	Med.							0.001	0.001	0.001	-	0.004	0.001	-	-	0.003
	Min.							0.001	0.001	0.001	-	0.001	0.001	-	-	0.001
	Max.							0.103	0.013	0.006	-	0.008	0.063	-	-	0.010
	Pop.							244	52	32	-	14	286	-	-	20
IRON (T) mg/L	Av.	0.3 (ID - interim indicative working level)	0.3[b]	-	10	0.2	-	-	0.13	**1.75**	-	-	**0.56**	-	-	-
	Med.							-	0.06	0.61	-	-	0.27	-	-	-
	Min.							-	0.05	0.26	-	-	0.07	-	-	-
	Max.							-	0.57	6.77	-	-	2.94	-	-	-
	Pop.							-	12	12	-	-	17	-	-	-

		DEFAULT GUIDELINE VALUES (DGV)	NHMRC DRINKING WATER	ANZECC (2000) FRESH WATER AQUATIC	ANZECC (2000) SHORT TERM IRRIGATION	ANZECC (2000) LONG TERM IRRIGATION	ANZECC (2000) STOCK WATER	QA – HUNTER	QA – SADDLERS	QA – REGOLITH	JV - JURASSIC VOLCANICS	WCM - INTERBURDEN	WCM - COAL	MAITLAND GROUP	GRETA CM	TAILINGS
LEAD (T) mg/L	Av.	0.0034	0.01[a]	0.0034	5	2	0.1	0.001	0.001	0.001	-	0.005	0.002	-	-	0.006
	Med.							0.001	0.001	0.001	-	0.003	0.001	-	-	0.005
	Min.							0.001	0.001	0.001	-	0.001	0.001	-	-	0.001
	Max.							0.029	0.001	0.001	-	0.020	0.135	-	-	0.014
	Pop.							244	52	32	-	14	286	-	-	5
MANGANESE (T) mg/L	Av.	0.19	0.5[a] / **0.1**[b]	1.9	10	0.2	-	**2.54**	**0.13**	**0.12**	-	-	0.04	-	-	-
	Med.							1.85	0.06	0.09	-	-	0.03	-	-	-
	Min.							0.001	0.005	0.002	-	-	0.01	-	-	-
	Max.							8.22	0.47	0.31	-	-	0.10	-	-	-
	Pop.							10	10	10	-	-	15	-	-	-
MERCURY (T) mg/L	Av.	0.0006	-	0.0006	0.002	0.002	0.002	0.0001	0.0001	0.0001	-	0.0001	0.0001	-	-	0.0001
	Med.							0.0001	0.0001	0.0001	-	0.0001	0.0001	-	-	0.0001
	Min.							0.0001	0.0001	0.0001	-	0.0001	0.0001	-	-	0.0001
	Max.							0.0003	0.0004	0.0001	-	0.0001	0.0002	-	-	0.0001
	Pop.							219	52	32	-	4	244	-	-	1
MOLYBDENUM (T) mg/L	Av.	0.034 (low reliability)	0.05[a]	-	0.05	0.01	0.15	0.005	0.001	0.001	-	0.002	0.004	-	-	0.002
	Med.							0.002	0.001	0.001	-	0.001	0.001	-	-	0.002
	Min.							0.001	0.001	0.001	-	0.001	0.001	-	-	0.001
	Max.							0.049	0.003	0.001	-	0.009	0.075	-	-	0.008
	Pop.							232	40	20	-	14	268	-	-	21

		DEFAULT GUIDELINE VALUES (DGV)	NHMRC DRINKING WATER	ANZECC (2000) FRESH WATER AQUATIC	ANZECC (2000) SHORT TERM IRRIGATION	ANZECC (2000) LONG TERM IRRIGATION	ANZECC (2000) STOCK WATER	QA – HUNTER	QA – SADDLERS	QA – REGOLITH	JV - JURASSIC VOLCANICS	WCM - INTERBURDEN	WCM - COAL	MAITLAND GROUP	GRETA CM	TAILINGS
NICKEL (T) mg/L	Av.	0.011	0.02[a]	0.011	2	0.2	1	0.007	0.004	0.002	-	-	0.002	-	-	-
	Med.							0.005	0.004	0.001	-	-	0.002	-	-	-
	Min.							0.001	0.002	0.001	-	-	0.001	-	-	-
	Max.							0.026	0.008	0.007	-	-	0.003	-	-	-
	Pop.							12	12	12	-	-	5	-	-	-
SELENIUM (T) mg/L	Av.	Total - 0.011; Sel (IV) - ID	0.01[a]	Total – 0.011 SelIV - ID	0.05	0.02	0.02	0.01	0.01	0.01	-	0.01	0.01	-	-	-
	Med.							0.01	0.01	0.01	-	0.01	0.01	-	-	-
	Min.							0.01	0.01	0.01	-	0.01	0.01	-	-	-
	Max.							0.02	0.01	0.01	-	0.01	0.02	-	-	-
	Pop.							219	52	32	-	4	244	-	-	-
ZINC (T) mg/L	Av.	0.008	3[b]	0.008	2	2	20	0.01	0.01	0.01	-	0.03	0.02	-	-	0.05
	Med.							0.01	0.01	0.01	-	0.02	0.01	-	-	0.04
	Min.							0.01	0.01	0.01	-	0.01	0.01	-	-	0.02
	Max.							0.13	0.06	0.02	-	0.10	0.51	-	-	0.12
	Pop.							244	52	31	-	14	286	-	-	26
IRON (D) mg/L	Av.	0.3 (ID - interim indicative working level)	-	-	-	-	-	0.16	0.06	0.14	-	2.11	2.00	-	-	4.43
	Med.							0.05	0.05	0.05	-	0.52	0.09	-	-	3.86
	Min.							0.01	0.05	0.05	-	0.04	0.01	-	-	0.01
	Max.							10.70	0.28	0.63	-	36.60	204.00	-	-	12.60
	Pop.							532	52	32	-	90	670	-	-	59

APPENDIX E

REGISTERED BORES WITHIN 10 KM OF THE APPLICATION AREA

Data from 2018 bore census (ENRS 2018b)

Notes:

East and North refer to eastings and northings values, m, MGA 94 zone 56

All elevations or water levels are m, AHD

Use abbreviations:

TEST	Monitoring/ test bore
DOM	Domestic stock bore
N/A	Unknown, not available
IRRIG	Irrigation bore
IND	Industrial bore
MUN	Municipal/ public bore

GW No.	EAST	NORTH	WATER ENTRY LEVEL	SWL	YEAR_DRILLED	USE
GW011873	287404	6417282	11.0	NULL	1950	DOM
GW011896	285943	6415895	12.2	NULL	1937	DOM
GW013589	301295	6405179	10.7	NULL	1933	N/A
GW017612	292995	6399835	12.2	NULL	1959	N/A
GW017613	292969	6399834	12.2	NULL	1959	N/A
GW018044	299080	6401006	9.1	NULL	1959	N/A
GW018046	303013	6398866	18.3	NULL	1959	N/A
GW018047	302620	6398920	36.3	NULL	1959	N/A
GW018741	285027	6413472	9.1	NULL	1960	N/A
GW018743	285582	6405842	10.3	NULL	1960	IRRIG
GW019786	293678	6405950	12.8	NULL	1961	N/A
GW022686	302739	6404838	13.4	NULL	1965	N/A
GW022688	302660	6404868	13.4	NULL	1965	N/A
GW024396	302800	6404377	14.6	NULL	1966	N/A
GW024473	298265	6400004	10.4	NULL	1966	IRRIG
GW027188	285944	6406003	12.2	NULL	1937	IRRIG
GW027189	286277	6406350	12.2	NULL	1954	N/A
GW029155	305403	6402148	10.1	NULL	1968	N/A
GW029644	289048	6411215	28.7	NULL	1920	DOM
GW029645	289066	6414082	18.3	NULL	1969	N/A
GW029646	292841	6414900	9.1	NULL	1914	N/A
GW029647	291005	6413906	36.6	NULL	1914	DOM
GW029648	290875	6413873	31.1	NULL	1912	DOM
GW029649	291321	6413790	25.9	NULL	1912	N/A
GW029650	286339	6409556	67.1	NULL	1957	DOM
GW029651	286385	6409834	54.9	NULL	1957	DOM
GW029652	286407	6410050	91.4	NULL	1957	DOM
GW029653	286428	6410297	48.8	NULL	1957	DOM
GW029654	289250	6412822	95.1	NULL	1921	DOM
GW029655	290702	6412144	25.3	NULL	1936	DOM
GW029656	289759	6408488	16.5	NULL	1915	DOM
GW029657	288497	6411327	5.8	NULL	1966	DOM
GW029658	289462	6413936	55.8	NULL	1957	DOM
GW029659	289121	6411494	74.7	NULL	1936	DOM
GW029660	290211	6413089	74.7	NULL	1938	DOM
GW029661	293054	6414688	42.7	NULL	1914	DOM
GW031622	294440	6415949	91.4	NULL	1969	DOM
GW031859	294633	6415460	61.0	NULL	1969	DOM
GW032077	294266	6416778	53.3	NULL	1969	DOM

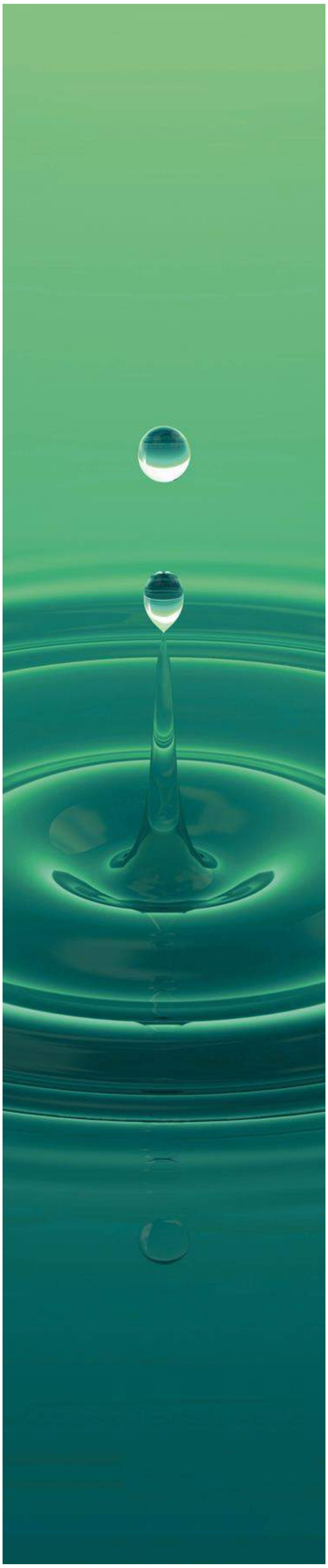
GW No.	EAST	NORTH	WATER ENTRY LEVEL	SWL	YEAR_DRILLED	USE
GW032512	294386	6418629	33.5	NULL	1969	DOM
GW032632	303253	6402568	33.5	NULL	1967	DOM
GW033193	293686	6417043	46.9	NULL	1971	DOM
GW033547	296176	6415461	12.0	NULL	1972	DOM
GW033915	294185	6419509	39.6	NULL	1971	DOM
GW037934	298782	6400292	12.1	NULL	1961	IRRIG
GW038185	298905	6400633	8.5	NULL	1975	IRRIG
GW043225	303653	6398949	22.5	NULL	1973	IRRIG
GW043365	300475	6405718	6.4	NULL	1974	DOM
GW043988	287420	6412814	8.8	NULL	1975	DOM
GW045158	289876	6407905	13.4	NULL	1976	DOM
GW047690	306533	6422105	6.7	NULL	1980	IRRIG
GW049187	303025	6403550	10.0	NULL	1978	IRRIG
GW049223	298120	6413682	67.1	NULL	1979	DOM
GW050849	287404	6417282	27.0	NULL	1980	DOM
GW053347	291466	6406829	14.0	NULL	1981	IRRIG
GW053348	293339	6405943	13.0	NULL		N/A
GW053349	291101	6405527	11.5	NULL		IRRIG
GW053444	288796	6407050	10.3	NULL	1982	IRRIG
GW053533	285712	6405875	12.5	NULL	1982	IRRIG
GW053708	304231	6403327	13.4	NULL	1980	IRRIG
GW053709	304370	6402898	12.2	NULL	1981	IRRIG
GW053710	304355	6403668	12.2	NULL	1981	IRRIG
GW053804	299103	6401192	7.0	NULL		N/A
GW055208	306734	6422540	53.0	NULL	1981	DOM
GW057804	289082	6407118	10.0	NULL	1982	IRRIG
GW057805	289080	6407241	13.0	NULL	1982	IRRIG
GW059178	303887	6403536	13.9	NULL	1983	MUN
GW060029	293610	6401665	5.0	NULL	1981	IRRIG
GW060030	293338	6400920	7.0	NULL		IRRIG
GW060263	301855	6415205	61.0	NULL	1982	IND
GW062557	286731	6416929	45.0	NULL	1986	DOM
GW064232	292128	6405148	6.5	NULL	1988	DOM
GW065014	305777	6400368	14.5	NULL	1991	IRRIG
GW065521	290248	6407604	13.3	3.3	1965	IRRIG
GW078379	308341	6402759	14.0	NULL	1997	TEST
GW078469	292966	6399770	5.0	NULL	1999	DOM
GW078519	290557	6406919	10.8	10.8		DOM
GW078520	290727	6405559	13.7	12.1		DOM
GW078582	299156	6400947	8.0	NULL	1999	IRRIG
GW078583	309452	6404612	21.0	16.24	1997	TEST

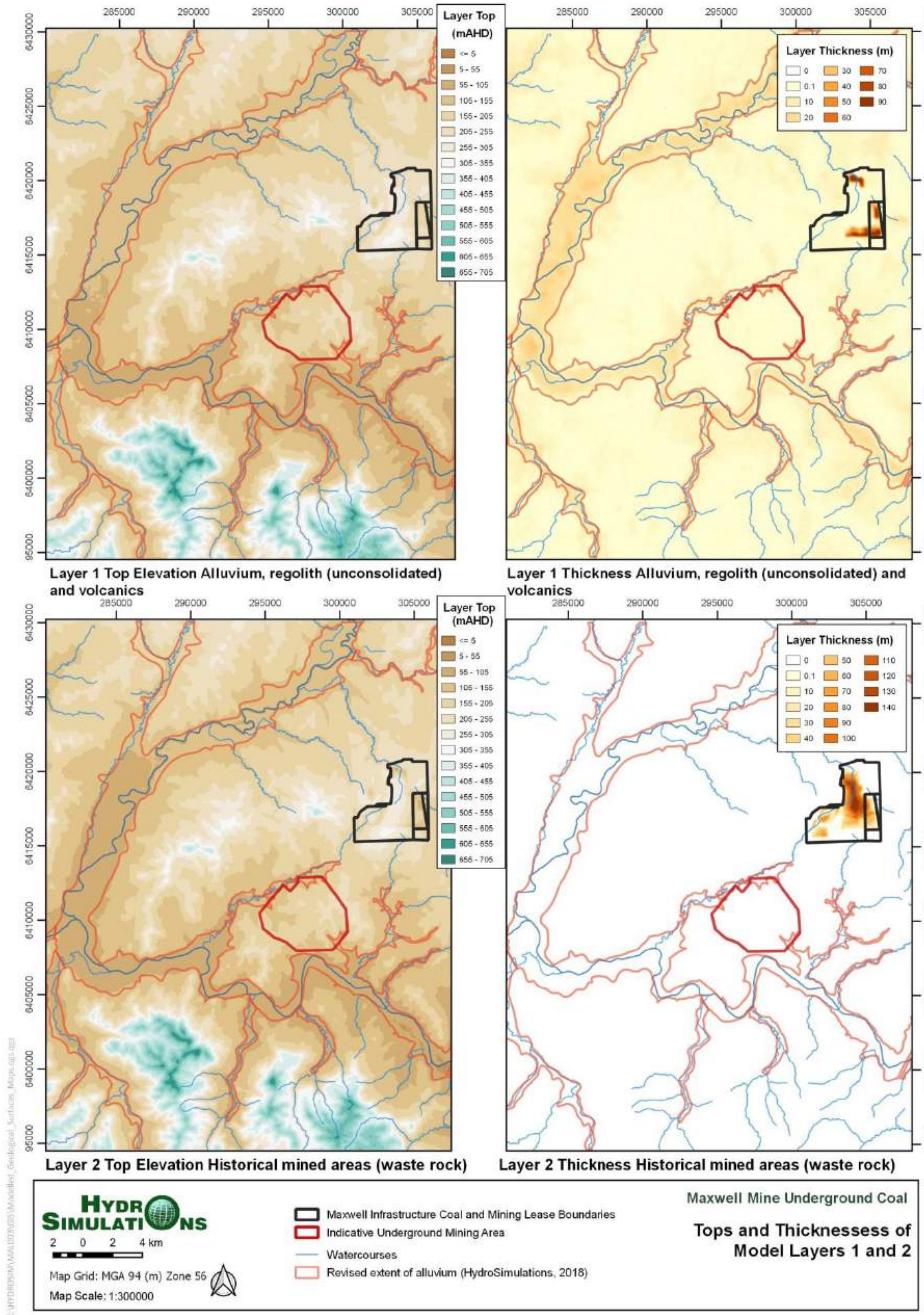
GW No.	EAST	NORTH	WATER ENTRY LEVEL	SWL	YEAR_DRILLED	USE
GW078584	308246	6403667	13.3	10.75	1997	TEST
GW078705	298037	6399691	9.0	NULL		IRRIG
GW078707	289548	6413537	43.0	NULL		DOM
GW078708	290888	6413226	43.0	NULL		DOM
GW078709	290749	6412391	50.0	0.0		DOM
GW078722	304737	6402674	15.0	NULL	1999	DOM
GW080764	307998	6403330	0.0	NULL	2005	N/A
GW080765	308400	6403288	0.0	NULL	2003	N/A
GW080766	308735	6403456	0.0	NULL	2003	N/A
GW080767	308429	6402852	0.0	NULL	2003	N/A
GW080768	308783	6403158	0.0	NULL	2003	N/A
GW080972	305428.8	6424167	24.0	15	2005	TEST
GW200743	305476	6416977	114.0	NULL	2004	N/A
GW200744	305476	6416977	196.0	14	2004	N/A
GW200745	305476	6416977	119.0	9	2004	N/A
GW200746	305371	6416853	133.0	28	2004	N/A
GW200956	307024	6407896	96.6	NULL	2008	TEST
GW200957	308715	6411207	60.0	NULL	2008	MUN
GW201006	307924	6402680	14.4	NULL	2009	TEST
GW201008	308112	6402680	15.0	NULL	2009	TEST
GW201089	299330	6401830	12.0	10	2011	TEST
GW201118	285934	6414712	18.5	7	2010	DOM
GW201122	308502	6403116	12.0	NULL	2009	N/A
GW201123	308277	6402702	15.0	NULL	2009	N/A
GW201124	308272	6402688	34.1	NULL	2009	N/A
GW201125	308386	6402778	12.0	NULL	2009	N/A
GW201126	308609	6402945	13.4	NULL	2009	N/A
GW201127	308239	6402959	14.6	NULL	2009	N/A
GW201183	295165	6423349	282.0	12	2011	TEST
GW201189	295165	6423379	242.0	14	2011	TEST
GW201190	295194	6423364	246.0	14	2011	TEST
GW201266	308715	6411207	60.0	NULL	2008	TEST
GW201267	310326	6406955	43.0	NULL	2008	TEST
GW201272	297992	6399679	19.3	5	2011	TEST
GW201511	298370	6399661	18.0	11	2011	TEST
GW201512	293304	6400768	10.0	8	2011	TEST
GW201513	293530	6401488	12.5	NULL	2011	TEST
GW201514	292850	6399616	11.0	NULL	2011	TEST
GW201515	302508	6404250	14.0	NULL	2011	TEST
GW201517	299241	6402260	17.0	8	2011	TEST
GW201523	299310	6401834	17.0	11	2011	TEST

GW No.	EAST	NORTH	WATER ENTRY LEVEL	SWL	YEAR_DRILLED	USE
GW201531	298399	6399306	15.0	12	2011	TEST
GW201532	301010	6403253	27.0	19	2011	TEST
GW201533	298733	6400406	12.0	8	2011	TEST
GW201534	298787	6400611	9.0	7	2011	TEST
GW201830	287315	6413665	40.0	35	1930	DOM
GW202373	293265	6400830	10.0	8	2011	IRRIG
GW202451	300315	6406100	12.5	6.46	2012	DOM
GW202452	292590	6411060	6.4	3.95	2012	DOM
GW202453	292830	6411010	5.4	2.05	2012	DOM
GW202478	297982	6410956	126.4	58.5	1998	TEST
GW202479	299784	6410971	105.7	77	1998	TEST
GW202480	296267	6409482	387.3	48.8	2001	TEST
GW202481	295174	6409551	342.3	45.2	2002	TEST
GW202518	286135	6416066	11.0	8.4	2012	TEST
GW202519	286111	6416085	11.0	8.3	2012	TEST
GW202523	286149	6416010	5.6	NULL	2012	TEST
GW202524	285517	6407737	11.4	7.12	2012	TEST
GW202526	285521	6407764	11.5	7.2	2012	TEST
GW202527	285523	6407774	11.3	NULL	2012	TEST
GW202528	285526	6407783	11.2	8.3	2012	TEST
GW202673	295204	6409459	47.2	46.8	2002	TEST
GW202777	305476	6408573	854.2	NULL	2013	TEST
GW271031	298140	6407151	12.0	6	2008	TEST
GW271033	293896	6402782	12.0	6	2008	TEST
GW271034	289990	6408086	13.0	8	2008	TEST
Bowfield Bore 2	295182	6410459	N/A	N/A		TEST
Bowfield Bore 3	292714	6410959	5.9	5.6		DOM
Bowfield Bore 4	292732	6411051	3.9	3.1		DOM
Coster Well 2	290754	6406797	7.8	6.8		DOM
Coster Well 4	290739	6405134	10.5	10.4		DOM
Plashett Bore 1	296916	6410270	Dry	N/A		DOM

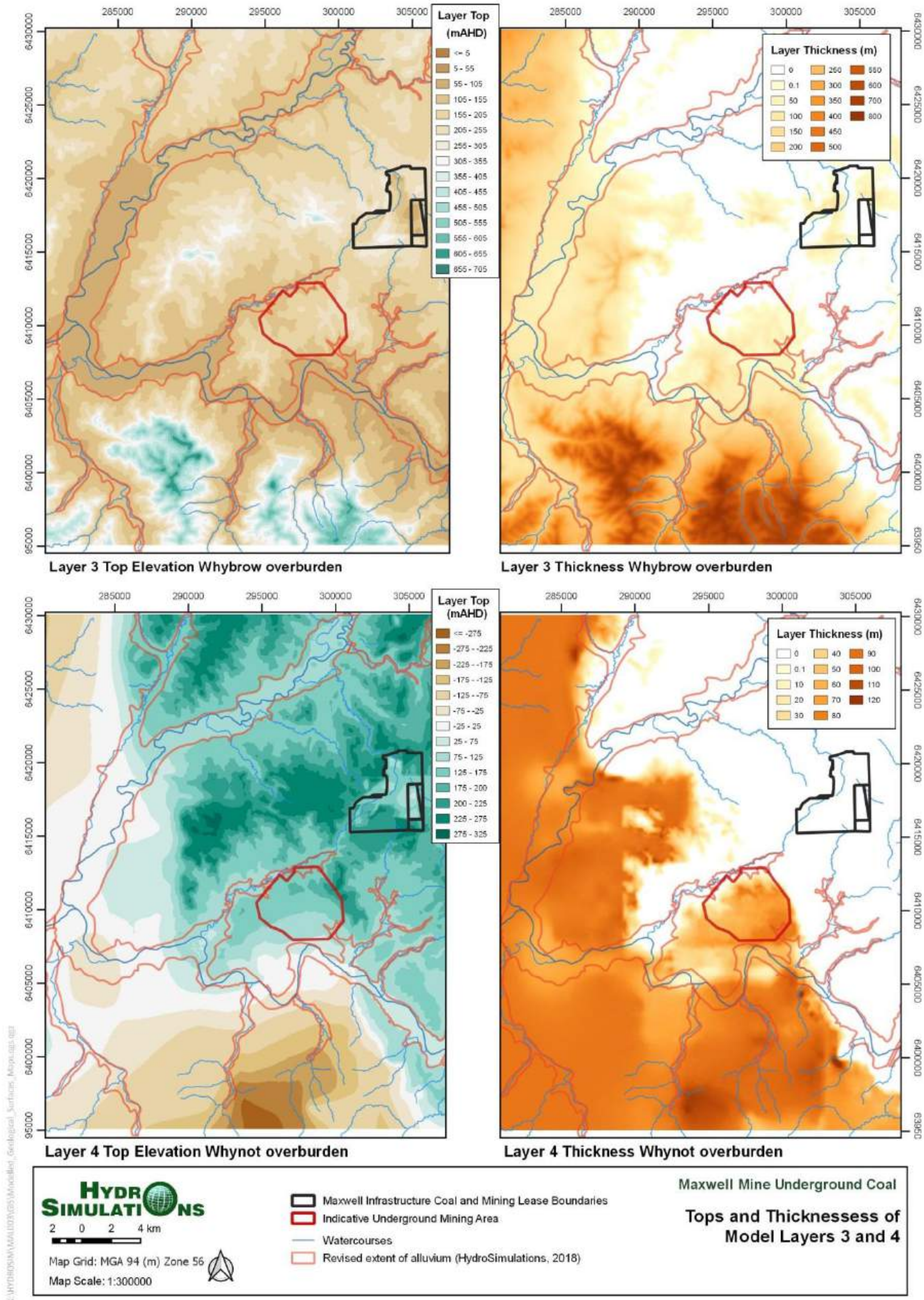
APPENDIX F

LAYER TOP ELEVATIONS AND THICKNESSES

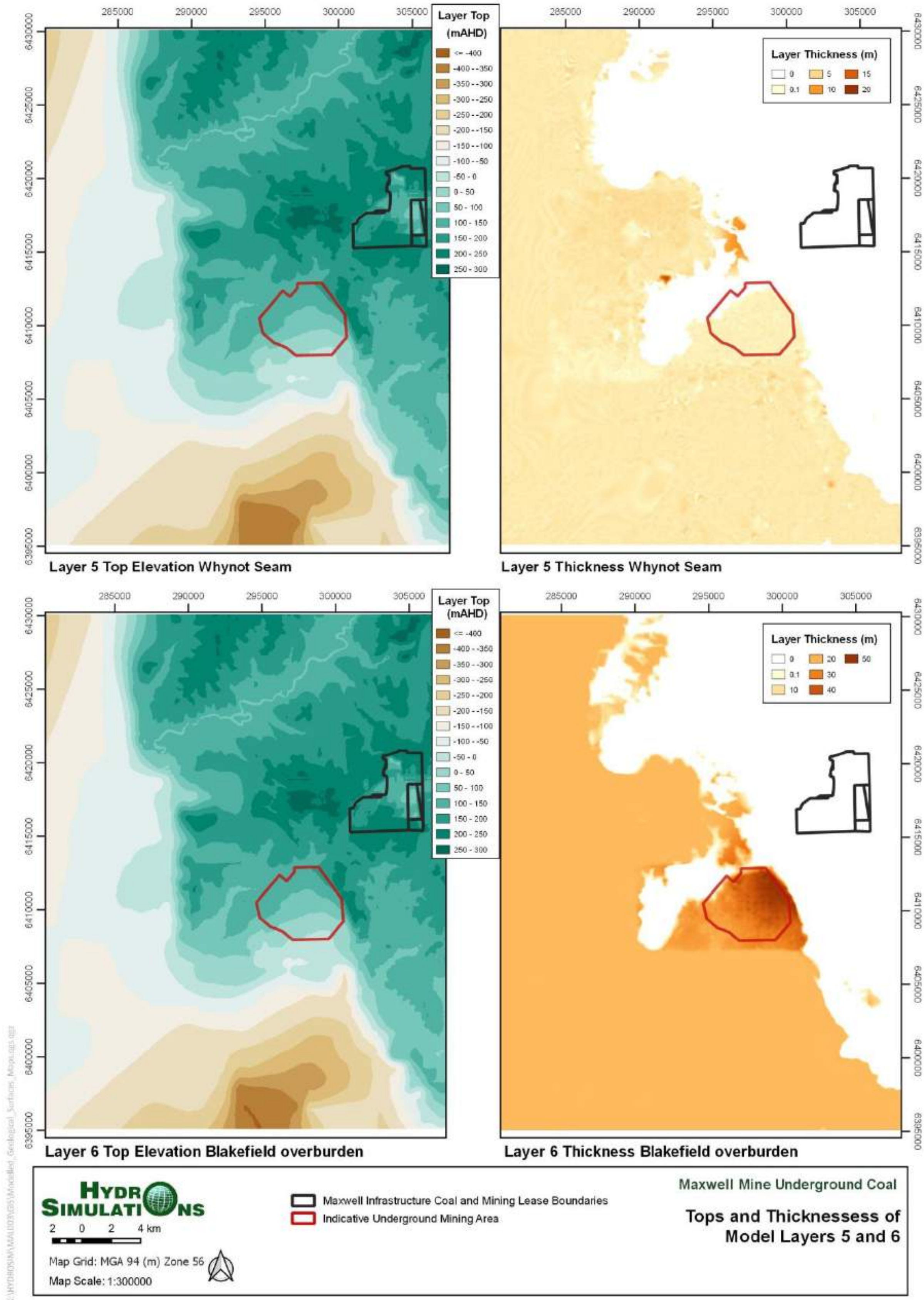




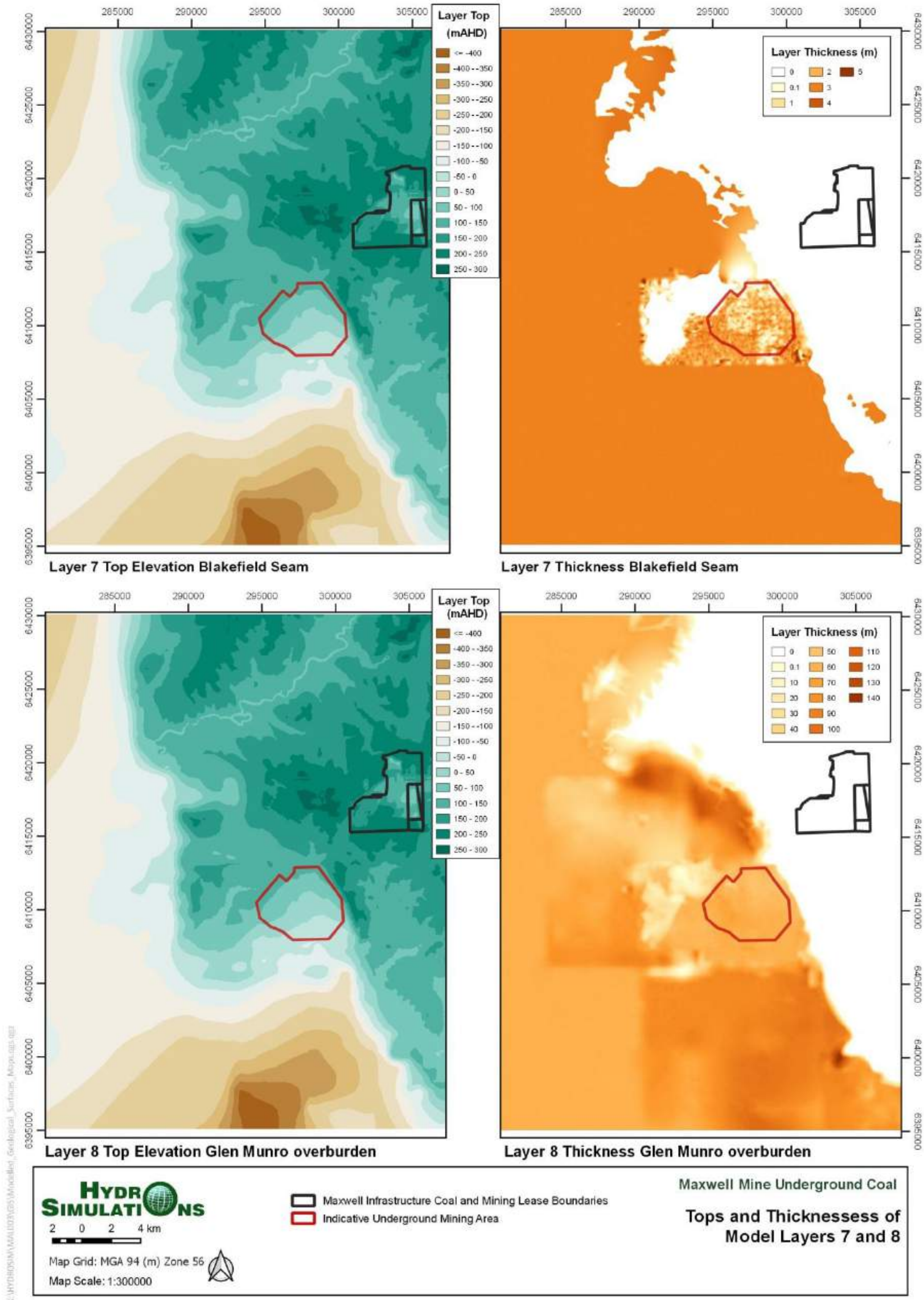
F 1 Layer 1 and 2, top elevation and thickness



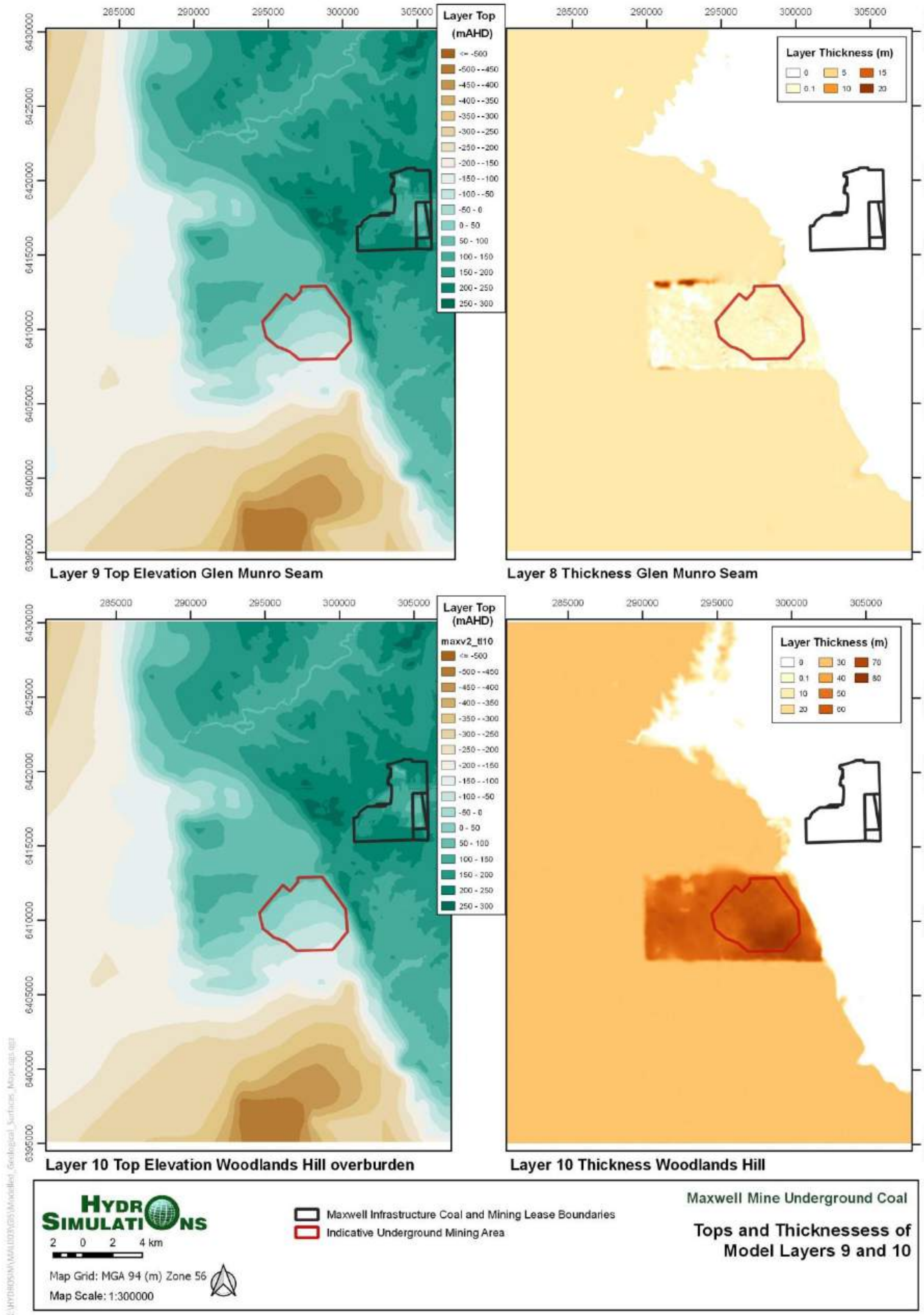
F 2 Layer 3 and 4, top elevation and thickness



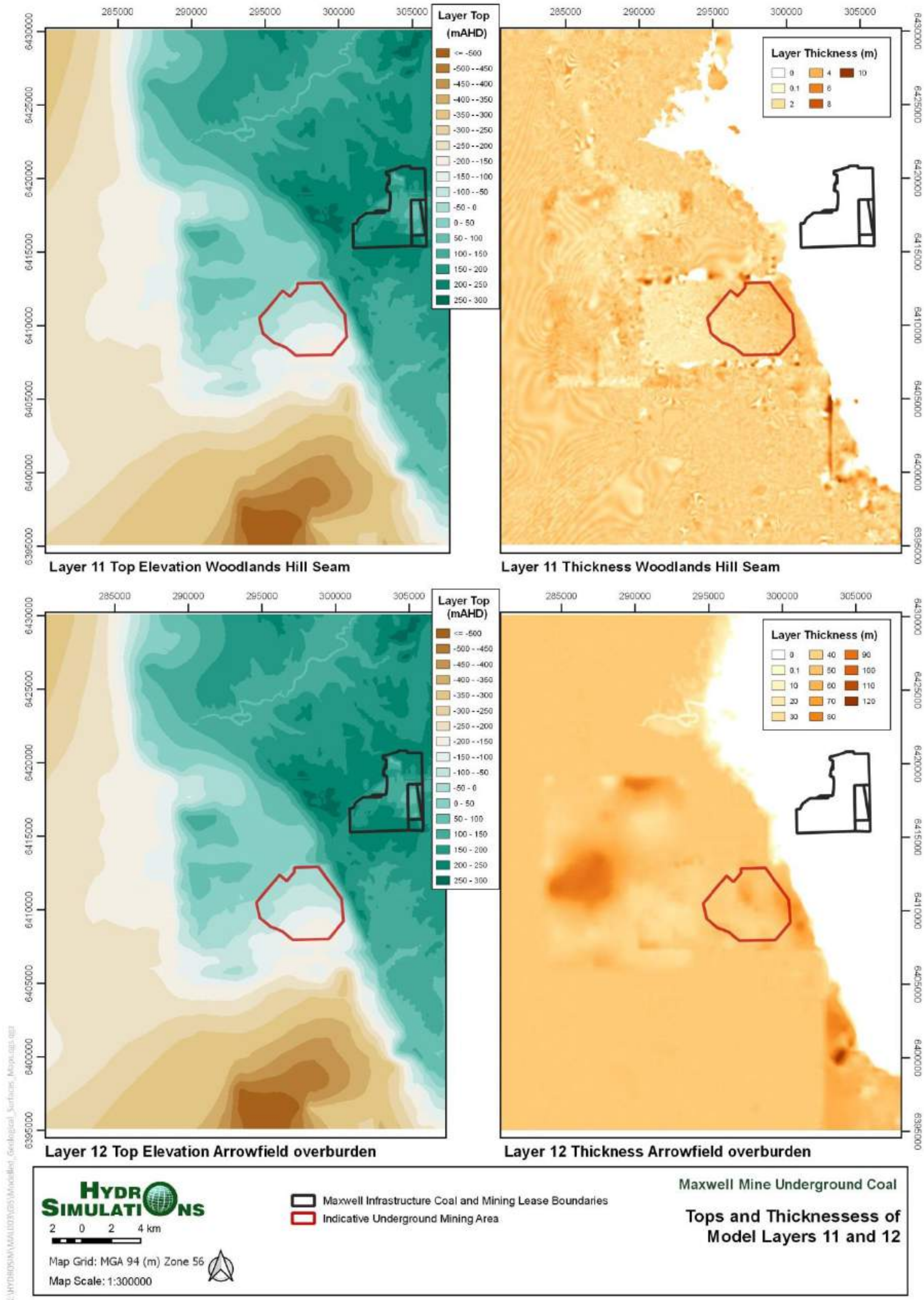
F 3 Layer 5 and 6, top elevation and thickness



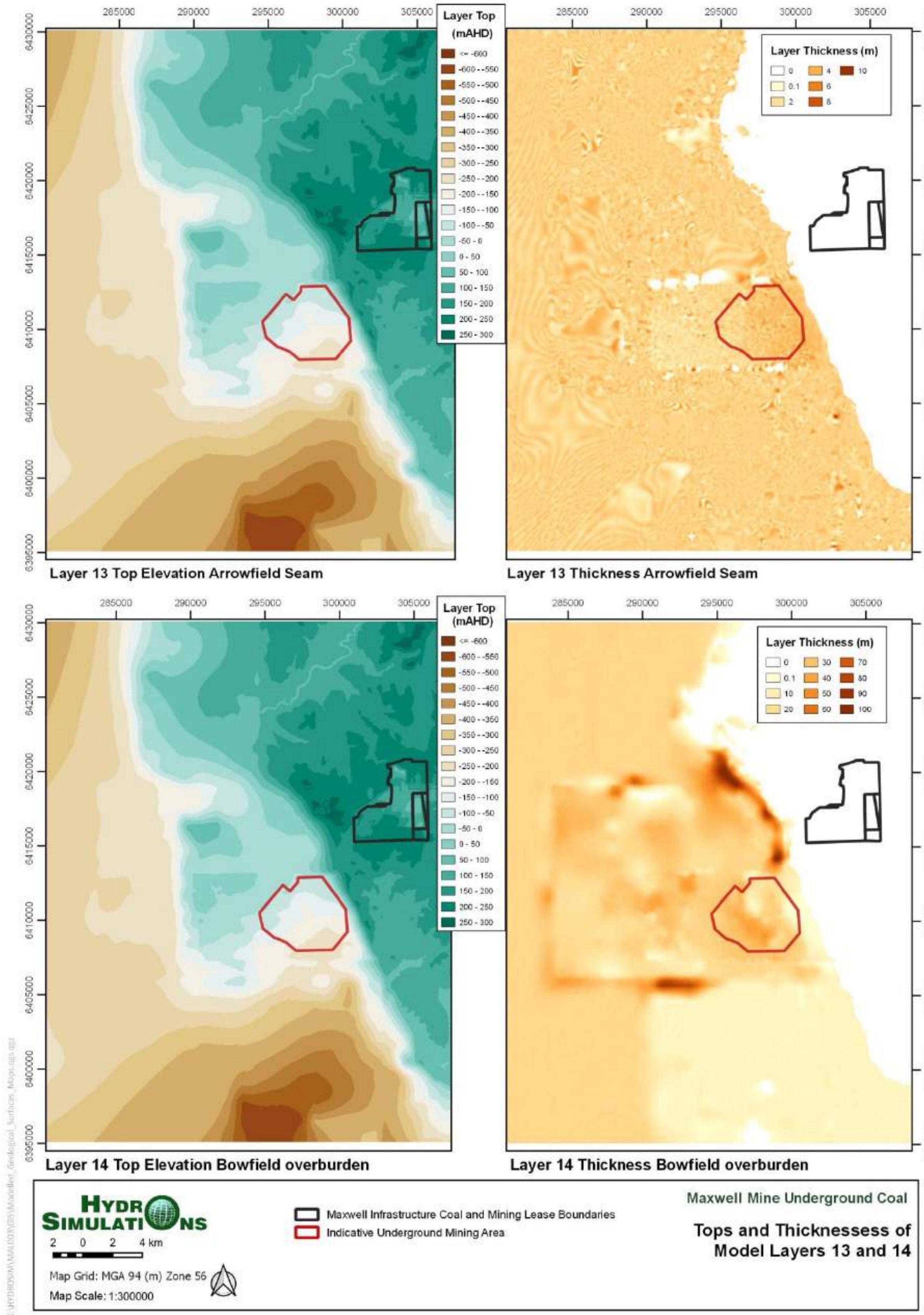
F 4 **Layer 7 and 8, top elevation and thickness**



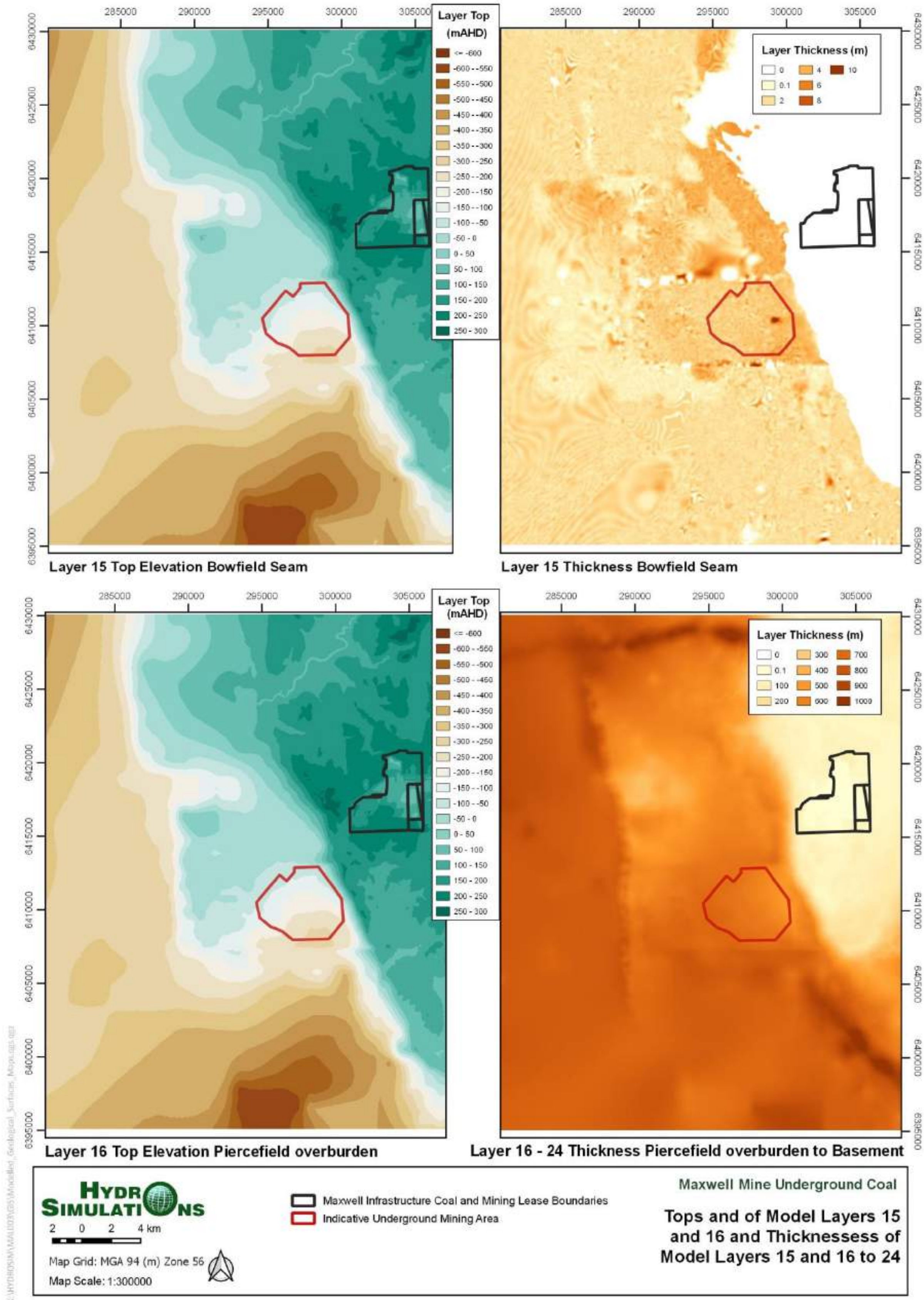
F 5 Layer 9 and 10, top elevation and thickness



F 6 Layer 11 and 12, top elevation and thickness



F 7 Layer 13 and 14, top elevation and thickness



F 8 Layer 15 and 16 to 24, top elevation and thickness

APPENDIX G

STEADY-STATE CALIBRATION RESIDUALS

Calibration bore labels (ID), location (eastings and northings, mAHD MGA94 zone 56), elevations and target water levels (mAHD).

Identifiers:

Label	Location
SH, Census	Spur Hill
DD, VWP, MB	Drayton South (Maxwell)
GW	Mt Arthur
F, R	Drayton Mine

Bore Name	Easting	Northing	Layer	Measured Values	Computed Values	Residual	Weight
DD1004	299797	6406356	6	140.5	151.81	-11.3	1.0
DD1005	298798	6410922	6	154	150.51	3.5	1.0
DD1014	296799	6410902	6	136	145.42	-9.4	1.0
DD1015	298814	6410864	6	129.5	140.80	-11.3	1.0
DD1016	297800	6409900	6	145	147.92	-2.9	1.0
DD1025	298764	6410883	6	160	153.86	6.1	1.0
DD1030	301754	6411902	20	130	128.83	1.2	1.0
DD1032	297143	6408961	16	132	142.20	-10.2	1.0
DD1043	295199	6412496	10	128	128.02	-0.02	1.0
DD1057	295180	6409459	12	127.5	130.10	-2.6	1.0
DD1187_144	299487	6410459	5	145	136.79	8.2	0.5
DD1187_85	299487	6409044	4	140	136.08	3.9	0.5
MB1_Alluvial	297933	6419734	1	73.2	74.50	-1.3	1.0
MB1_Redbank	297931	6407459	4	74.9	81.90	-7.0	1.0
MB1_Whybrow	297928	6407454	3	74.2	74.57	-0.4	1.0
MB2_Alluvial	294999	6407449	1	112.7	113.16	-0.5	1.0
MB2_Regolith	295004	6411669	8	115.9	113.62	2.3	1.0
MB3_Alluvial	297269	6411675	1	129.9	133.32	-3.4	1.0
MB3_Regolith	297328	6412851	8	126.9	138.25	-11.3	1.0
MB4_Alluvial	300302	6412729	1	71.1	73.17	-2.1	1.0
MB4_Regolith	300307	6406234	3	70.9	73.30	-2.4	1.0
RD1192_149	296092	6406231	7	133	126.95	6.1	0.5
RD1192_61	296092	6409038	4	142	135.17	6.8	0.5
RD1220_114	293653	6409038	7	120	126.04	-6.0	1.0
RD1220_25	293653	6409558	4	162	146.12	15.9	1.0
RD1220_87	293653	6409558	5	135	144.63	-9.6	1.0
VWP1_28	297926	6407444	1	66	74.51	-8.5	0.5
VWP1_86	297926	6407444	3	101	74.56	26.4	0.5
VWP1_116	297926	6408420	5	95	87.18	7.8	0.5
VWP1_143	297926	6407444	7	100	117.47	-17.5	0.5
GW040959	280805	6420774	1	96.3	97.96	-1.6	0.5
GW040960	276923	6409639	1	115.8	123.90	-8.1	0.5
GW080075	282915	6400519	1	99.4	98.85	0.6	1.0
GW080076	282965	6413326	1	99.4	98.83	0.6	1.0

Bore Name	Easting	Northing	Layer	Measured Values	Computed Values	Residual	Weight
GW080434	278661	6413369	1	129.4	138.09	-8.7	0.5
GW080972	305433	6426103	1	177.8	182.02	-4.2	0.5
GW271032	281780	6407151	1	110.3	112.31	-2.0	0.5
GW043225	303653	6420003	1	107.6	115.48	-7.9	1.0
GW045161	289685	6398949	1	97	88.34	8.7	1.0
GW060031	293277	6408064	1	91	96.74	-5.7	1.0
GW271031	298140	6418792	1	77.9	74.37	3.5	0.5
GW271033	293911	6402298	1	85.3	85.62	-0.4	0.5
GW271034	289990	6402775	1	87.4	88.13	-0.8	0.5
F1162	304256	6419755	23	171.1	158.48	12.6	1.0
F1163	301045	6420755	22	177.4	177.06	0.3	0.5
F1164	304223	6415695	23	171.9	139.96	31.9	1.0
F1167	305124	6420406	23	195.5	185.65	9.8	1.0
F1168	305235	6421790	23	196.5	182.54	14.0	1.0
W1102	300984	6407444	22	178.1	179.29	-1.2	1.0
GW2	299045	6423477	11	145.9	149.41	-3.6	1.0
GW3	298856	6408087	11	145.6	147.29	-1.7	1.0
GW4	296976	6413389	9	175.5	165.31	10.2	1.0
GW6	294254	6414871	9	174.4	167.63	6.7	1.0
GW8	296993	6418579	21	182.2	170.07	12.2	1.0
GW9	298224	6419486	21	182.7	175.13	7.5	1.0
GW13	295985	6421988	21	161.6	158.14	3.5	1.0
GW15	295466	6420977	21	140.6	148.58	-8.0	1.0
GW16	294197	6421968	1	122.7	112.26	10.4	1.0
GW17	295003	6422759	1	124.5	119.64	4.9	1.0
GW19	295938	6423570	21	137.3	139.45	-2.2	1.0
GW21	296141	6413511	1	127.2	116.70	10.5	1.0
GW22	296930	6424483	20	139.4	137.37	2.0	1.0
GW23	297919	6423998	22	139.5	141.59	-2.1	1.0
GW24	297386	6424515	1	129.6	124.26	5.3	1.0
GW26	301841	6424914	1	188	164.52	23.5	0.0
Census10_GW027189	286181	6406797	1	94.2	91.02	3.2	0.5
Census11	286166	6406296	1	94	90.94	3.0	0.5
Census01	282186	6411760	1	93.1	97.05	-4.0	0.5
Census02	282930	6411760	1	94.1	97.70	-3.6	0.5
Census03	283393	6411667	1	92.9	98.38	-5.5	0.5
Census04	283358	6412201	1	92.7	98.42	-5.7	0.5
Census05	291306	6412303	1	119	132.62	-13.6	0.5
Census06	287746	6411261	1	91	88.48	2.6	0.5

APPENDIX H

TRANSIENT CALIBRATION RESIDUALS

Bore Name	Easting	Northing	Layer	Average Residual (m)	Minimum Residual (m)	Maximum Residual (m)	Weight
BCGW05	291053	6410764	9	-9.7	-10.0	-8.1	0.5
BCGW10	293115	6414781	4	8.5	7.2	10.4	0.5
BCGW11	293118	6414779	4	8.4	7.2	10.2	0.5
BCGW15	290717	6412433	9	-3.1	-6.8	-1.7	0.5
BCGW18	294345	6419985	10	-6.2	-10.3	-3.7	0.5
BCGW19	292462	6419152	9	24.2	22.7	26.4	0.5
BCGW22	295304	6414211	9	-3.9	-5.8	-2.9	0.5
BCGW22 (IW4026)	295304	6414211	9	-2.8	-6.0	-2.0	0.5
DD1004	299797	6410922	6	-11.6	-11.8	-11.5	1
DD1005	298798	6410902	6	-2.4	-3.0	-1.8	1
DD1014	296799	6410864	6	-10.4	-11.1	-9.8	1
DD1015	298814	6409900	6	-14.7	-15.0	-14.2	1
DD1016	297800	6410883	6	-5.3	-5.6	-5.0	1
DD1025	298764	6411902	6	3.5	3.2	3.9	1
DD1030	301754	6408961	20	2.2	1.5	2.4	1
DD1032	297143	6412496	16	-8.3	-9.2	-7.6	1
DD1043	295199	6409459	10	0.3	-0.1	0.8	1
DD1057	295180	6410459	12	-4.2	-4.7	-3.9	1
EWPC33	294253	6416846	7	27.1	22.7	28.9	0.5
F1162	304256	6420755	23	-19.8	-30.3	25.0	0.5
F1163	301045	6415695	22	0.4	0.4	0.4	0.5
F1164	304223	6420406	23	10.5	-8.1	50.3	0.5
F1167	305124	6421790	23	-11.9	-30.1	9.8	0.5
F1168	305235	6420774	23	-5.3	-29.1	14.2	0.5
GW040959	280805	6409639	1	-1.8	-2.0	-1.6	0.5
GW040960	276923	6420003	1	-8.4	-8.8	-7.9	0.5
GW043225	303653	6398949	1	-14.5	-15.8	-14.0	0.5
GW045161	289685	6408064	1	1.4	1.4	1.4	0.5
GW060031	293277	6400519	1	-1.0	-2.0	-0.5	0.5
GW065521	290248	6407604	1	1.5	1.5	1.5	0.5
GW080075	282915	6413326	1	-0.5	-0.7	-0.3	0.5
GW080076	282965	6413249	1	-0.5	-0.7	-0.4	0.5
GW080077	284620	6414073	1	0.8	0.4	1.3	0.5
GW080078	282585	6413369	1	-0.3	-0.6	0.4	0.5
GW080234	292687	6399542	1	-0.1	-0.1	-0.1	0.5
GW080434	278661	6426103	1	-8.7	-8.8	-8.4	0.5

Bore Name	Easting	Northing	Layer	Average Residual (m)	Minimum Residual (m)	Maximum Residual (m)	Weight
GW080972	305433	6424164	1	-3.5	-4.5	-3.2	0.5
GW16	294197	6422759	1	10.4	9.1	12.4	1
GW2	299045	6413511	11	-3.1	-4.7	-1.4	0.5
GW21	296141	6424483	1	10.1	9.3	13.4	1
GW22	296930	6423998	20	-6.9	-28.3	2.2	0.5
GW23	297919	6424515	22	-3.8	-8.9	5.3	0.5
GW25	298376	6425231	1	3.8	3.1	5.1	1
GW26	301841	6418792	3	-12.0	-36.4	17.4	0.5
GW271031	298140	6407151	1	-1.7	-2.2	3.4	0.5
GW271032	281780	6402298	1	-1.5	-2.1	-1.2	0.5
GW271033	293911	6402775	1	-0.2	-0.6	0.0	0.5
GW271034	289990	6408087	1	-6.4	-8.2	-0.9	0.5
GW3	298856	6413389	11	-0.5	-2.1	0.4	0.5
GW38A	293832	6422377	12	2.7	0.1	6.1	0.5
GW38A (IW4030)	293831	6422377	1	6.6	6.5	7.0	1
GW38P	293831	6422384	12	2.0	-0.8	5.7	0.5
GW39A	293094	6422248	1	6.1	5.9	8.1	1
GW39P	293095	6422251	12	-0.1	-2.0	1.3	0.5
GW40A	291815	6422119	1	5.5	5.1	6.1	1
GW41A	290354	6421789	10	7.0	6.5	7.4	0.5
GW41A (IW4029)	290354	6421789	1	8.1	7.7	8.6	1
GW42	295139	6423369	1	4.2	3.5	4.8	1
GW43	294232	6418551	11	3.2	2.4	3.5	0.5
GW44	297422	6414715	11	-18.2	-21.6	-14.0	0.5
GW45	298890	6413630	1	-5.3	-6.4	-3.5	1
GW46	298337	6413629	1	-6.1	-7.0	-5.4	1
GW47	297409	6412974	1	-4.9	-5.5	-4.5	1
GW48	291815	6422119	15	-12.9	-13.2	-12.2	0.5
GW49	290354	6421789	10	6.5	6.4	6.6	0.5
GW6	294254	6418579	9	4.1	1.9	5.7	0.5
GW8	296993	6419486	20	36.1	-4.4	94.2	0.5
MB1_Alluvial	297933	6407459	1	-2.5	-2.9	-1.5	1
MB1_Redbank	297931	6407454	4	-8.3	-8.9	-1.1	1

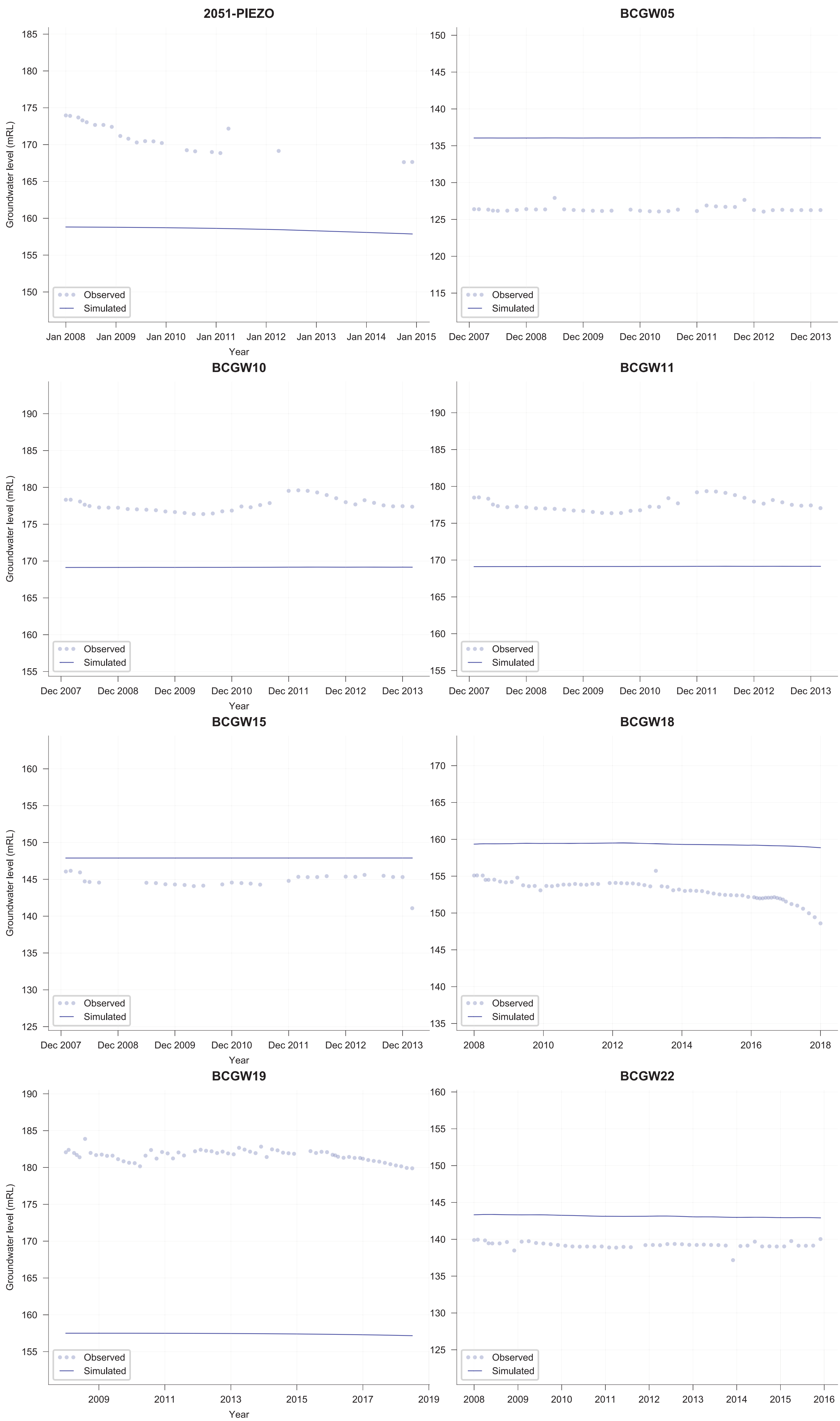
Bore Name	Easting	Northing	Layer	Average Residual (m)	Minimum Residual (m)	Maximum Residual (m)	Weight
MB1_Whybrow	297928	6407449	3	-1.4	-2.0	6.2	1
MB2_D	295004	6411675	8	1.3	0.5	1.8	1
MB2_S	294999	6411669	1	-1.3	-1.5	-1.1	1
MB3_D	297328	6412729	8	-9.0	-9.2	-8.6	1
MB3_S	297269	6412851	1	-4.4	-4.8	-4.0	1
MB4_D	300307	6406231	3	-3.6	-4.1	-2.7	1
MB4_S	300302	6406234	1	-2.6	-3.8	8.2	1
OD1046-PIEZO	297442	6414741	11	-15.7	-23.5	-3.3	0.5
OD1049-SURFACE	294498	6413753	8	-13.2	-13.7	-12.7	0.5
OD1049-WH	294498	6413753	11	-12.5	-13.9	-11.8	0.5
OD1073	293000	6418750	9	39.6	38.0	40.6	0.5
OD1074	296501	6417756	11	24.9	22.5	27.3	0.5
OD1074-PIEZO	296501	6417756	15	-0.2	-1.6	1.9	0.5
OD1078	294495	6419259	10	-16.3	-22.9	-14.1	0.5
OD1078-PIEZO	294495	6419259	15	-9.8	-18.5	-6.8	0.5
OD1079-PIEZO	295946	6416350	9	-3.5	-6.6	0.6	0.5
R4214	304606	6416180	1	-8.7	-25.1	64.8	0.5
SHD10-135	286874	6412265	4	-12.0	-13.1	-8.9	0.1
SHD10-212	286874	6412265	4	-13.8	-32.1	-5.9	0.1
SHD10-225	286874	6412265	8	-19.2	-33.3	-4.6	0.1
SHD10-267	286874	6412265	8	-12.9	-23.1	-7.8	0.1
SHD10-333	286874	6412265	12	-9.7	-11.8	-9.1	0.1
SHD10-383	286874	6412265	12	-10.7	-12.1	-8.7	0.1
SHD17-185	287032	6408365	3	-14.5	-15.7	-10.4	0.1
SHD17-263	287032	6408365	3	-10.2	-10.6	-8.6	0.1
SHD17-305	287032	6408365	4	-7.5	-11.6	-2.0	0.1
SHD17-335	287032	6408365	4	-6.8	-10.7	-4.8	0.1
SHD17-417	287032	6408365	8	-16.8	-20.9	-14.6	0.1
SHD17-584	287032	6408365	16	-23.5	-26.6	-19.4	0.1
SHD3-150	287944	6417265	4	7.2	5.5	11.1	0.1
SHD3-183	287944	6417265	5	4.9	4.3	6.7	0.1

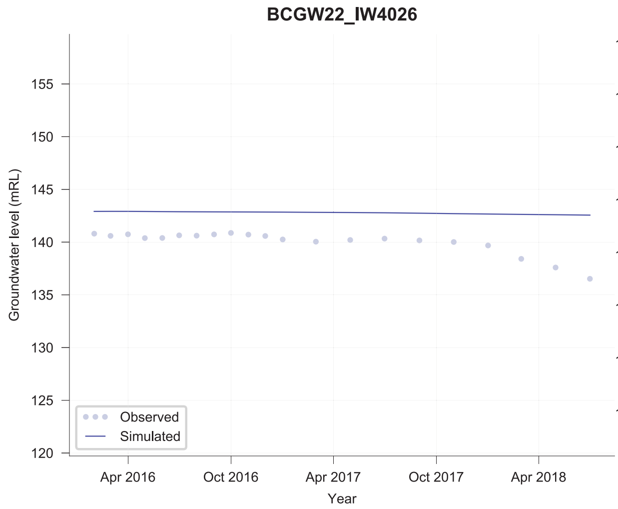
Bore Name	Easting	Northing	Layer	Average Residual (m)	Minimum Residual (m)	Maximum Residual (m)	Weight
SHD3-250	287944	6417265	8	-0.5	-6.3	0.5	0.1
SHD3-287	287944	6417265	11	-4.4	-6.9	2.9	0.1
SHD3-330	287944	6417265	12	-10.3	-10.7	3.8	0.1
SHD3-370	287944	6417265	15	-12.6	-17.2	55.3	0.1
SHD3-40	287944	6417265	16	-4.9	-9.2	1.9	0.1
SHD3-88	287944	6417265	3	3.2	2.1	4.3	0.1
SHD5-165m	286139	6415822	3	9.8	8.5	14.6	0.1
SHD5-185m	286139	6415822	4	5.7	4.4	8.8	0.1
SHD5-262m	286139	6415822	10	-13.8	-15.2	-7.7	0.1
SHD5-313m	286139	6415822	11	-3.8	-6.0	3.2	0.1
SHD5-358m	286139	6415822	13	-35.0	-42.9	-29.6	0.1
SHD5-430m	286139	6415822	15	-31.3	-35.4	49.9	0.1
SHD5-85m	286139	6415822	3	17.1	15.1	18.5	0.1
W1102	300984	6416044	22	0.0	-2.2	4.2	0.5

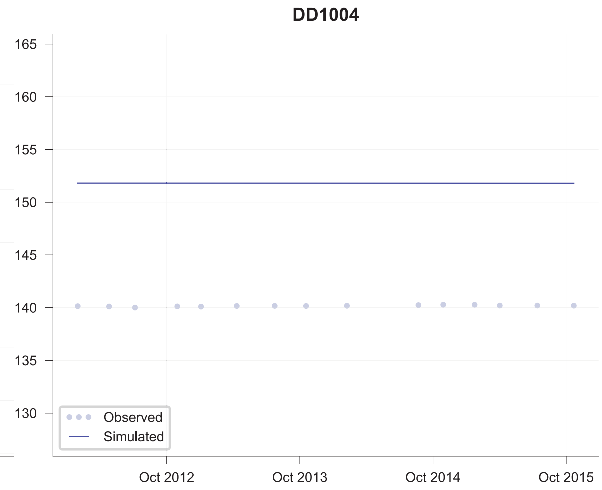
APPENDIX I

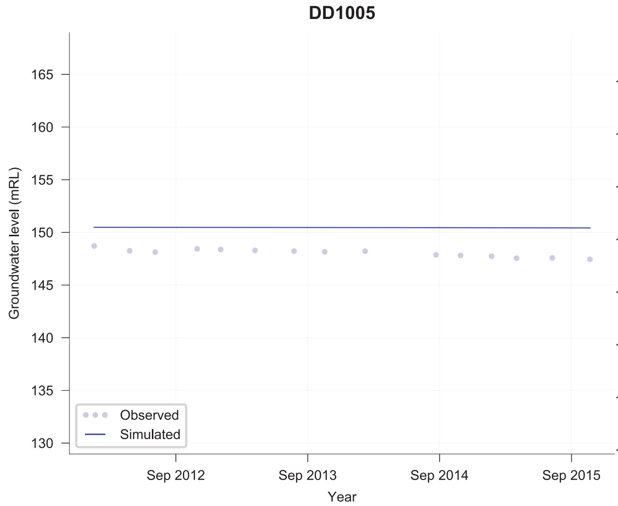
TRANSIENT CALIBRATION HYDROGRAPHS

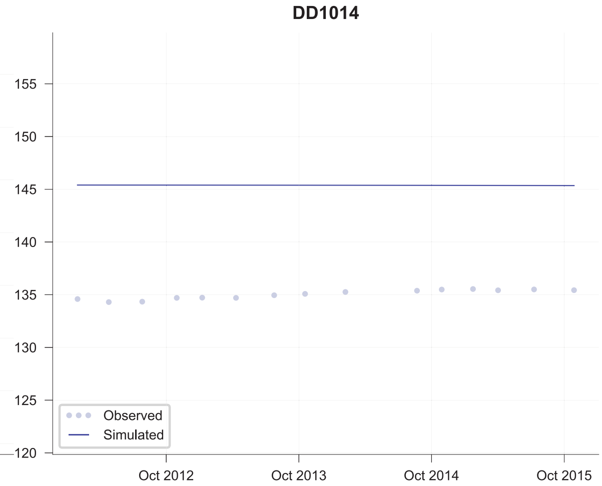
Observed and predicted water levels for the transient calibration.

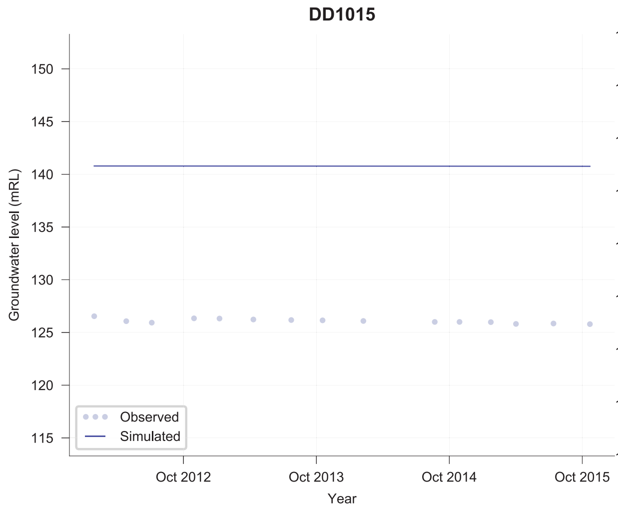

2051-PIEZO
BCGW05
BCGW10
BCGW11
BCGW15
BCGW18
BCGW19
BCGW22
Groundwater level (mRL)
Year
Observed
Simulated
Jan 2008
Jan 2009
Jan 2010
Jan 2011
Jan 2012
Jan 2013
Jan 2014
Jan 2015
Dec 2007
Dec 2008
Dec 2009
Dec 2010
Dec 2011
Dec 2012
Dec 2013

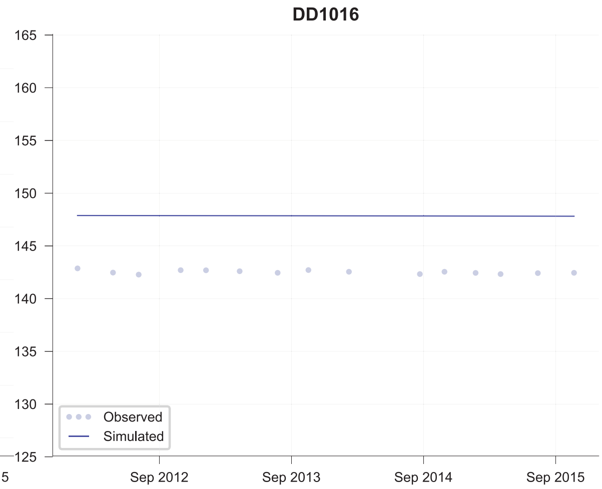

BCGW22_IW4026
Groundwater level (mRL)
155
150
145
140
135
130
125
120
Observed
Simulated
Apr 2016
Oct 2016
Apr 2017
Oct 2017
Apr 2018
Year

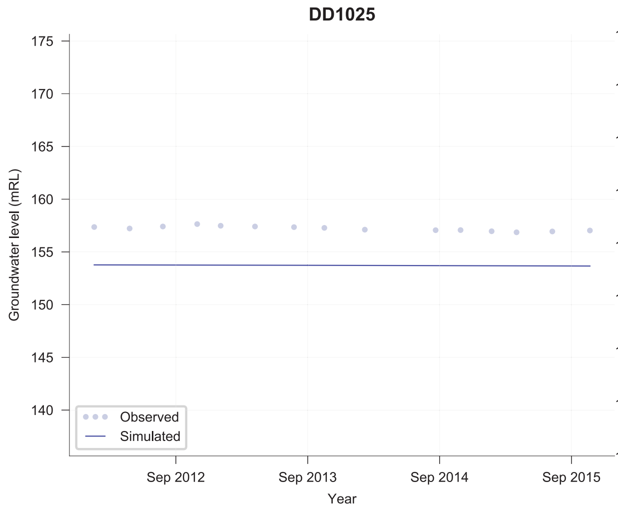

DD1004
165
160
155
150
145
140
135
130
Observed
Simulated
Oct 2012
Oct 2013
Oct 2014
Oct 2015

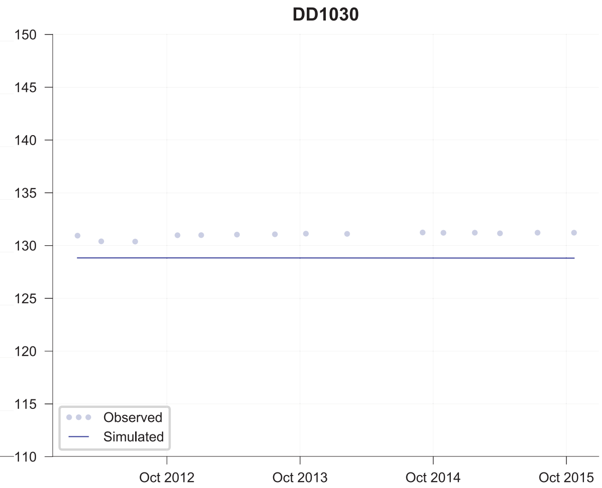

DD1005
Groundwater level (mRL)
165
160
155
150
145
140
135
130
Observed
Simulated
Sep 2012
Sep 2013
Sep 2014
Sep 2015
Year

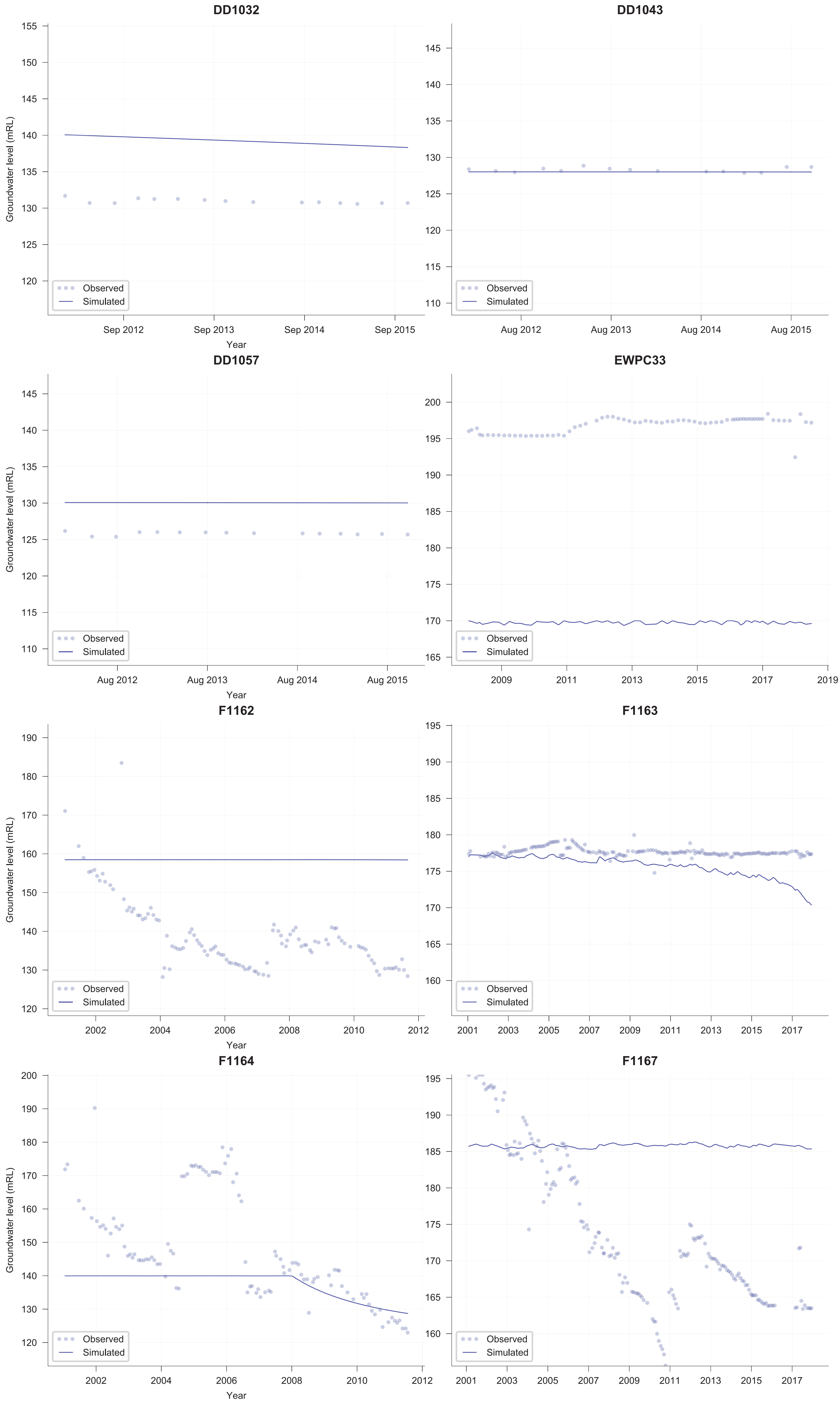

DD1014
155
150
145
140
135
130
125
120
Observed
Simulated
Oct 2012
Oct 2013
Oct 2014
Oct 2015

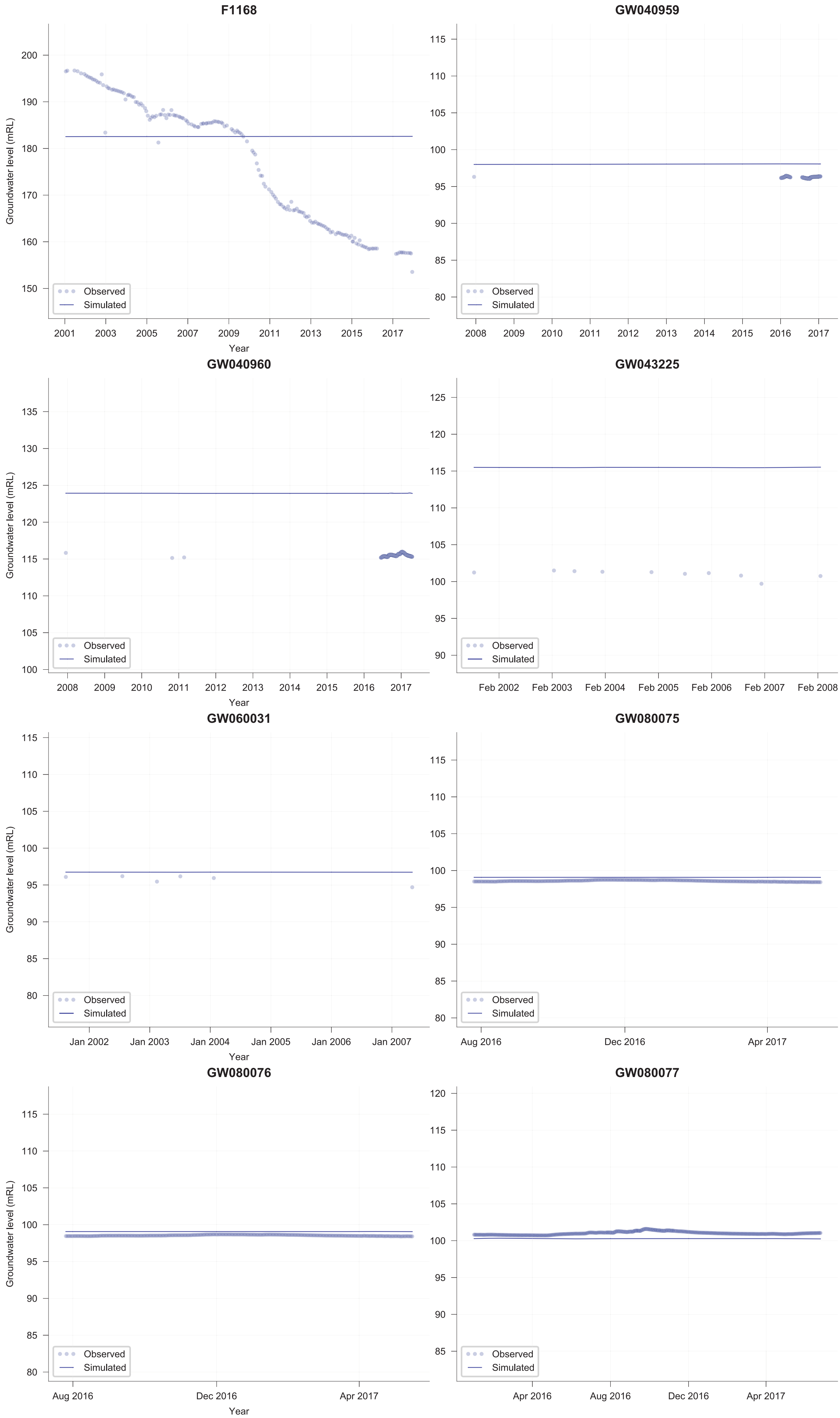

DD1015
Groundwater level (mRL)
150
145
140
135
130
125
120
115
Observed
Simulated
Oct 2012
Oct 2013
Oct 2014
Oct 2015
Year

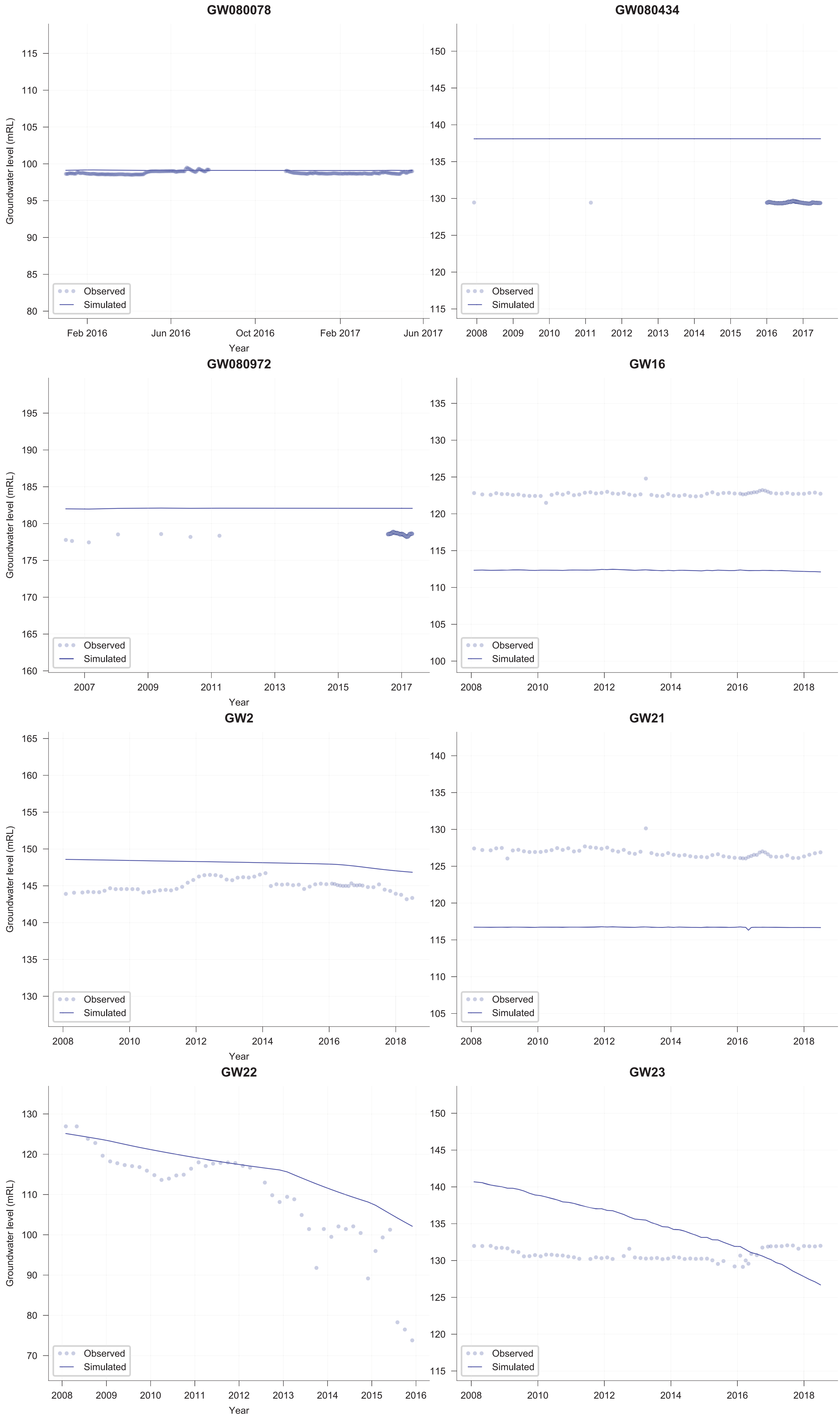

DD1016
165
160
155
150
145
140
135
130
125
Observed
Simulated
Sep 2012
Sep 2013
Sep 2014
Sep 2015

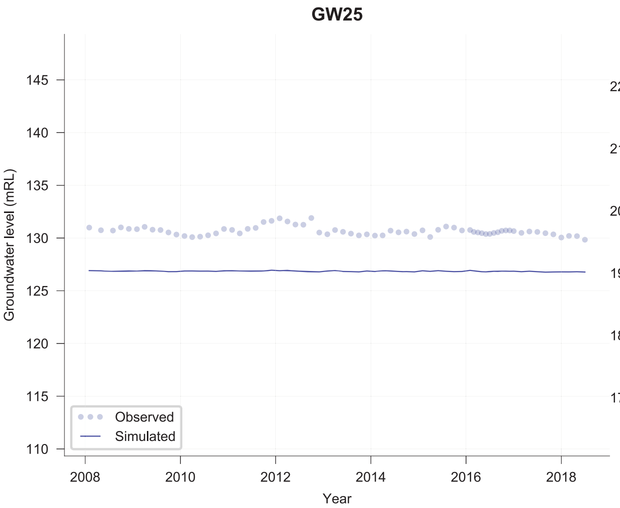

DD1025
Groundwater level (mRL)
175
170
165
160
155
150
145
140
Observed
Simulated
Sep 2012
Sep 2013
Sep 2014
Sep 2015
Year

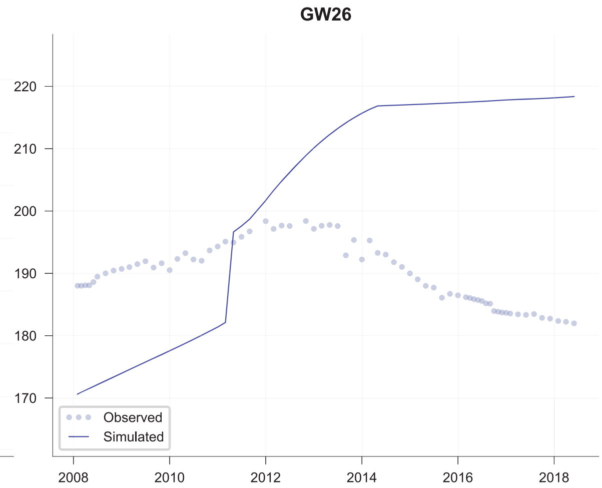

DD1030
150
145
140
135
130
125
120
115
110
Observed
Simulated
Oct 2012
Oct 2013
Oct 2014
Oct 2015

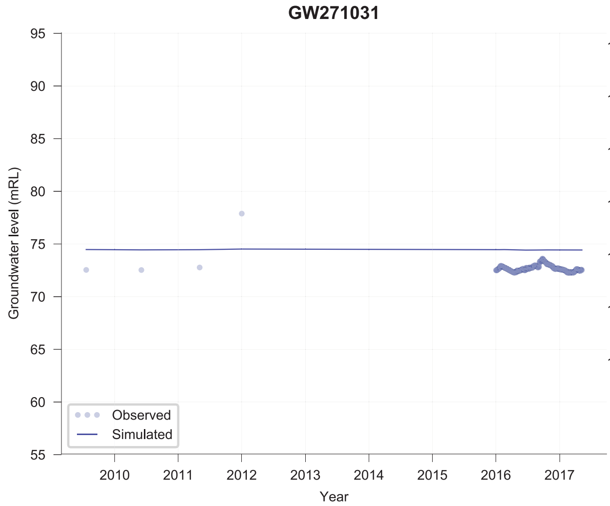

DD1032
DD1043
DD1057
EWPC33
F1162
F1163
F1164
F1167
Groundwater level (mRL)
Year
Observed
Simulated
Sep 2012
Sep 2013
Sep 2014
Sep 2015
Aug 2012
Aug 2013
Aug 2014
Aug 2015

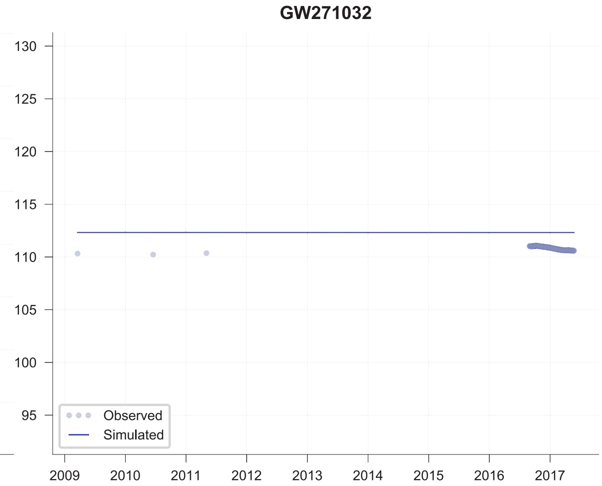

F1168
Groundwater level (mRL)
200
190
180
170
160
150
2001
2003
2005
2007
2009
2011
2013
2015
2017
Year
Observed
Simulated
GW040959
115
110
105
100
95
90
85
80
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Observed
Simulated
GW040960
Groundwater level (mRL)
135
130
125
120
115
110
105
100
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Year
Observed
Simulated
GW043225
125
120
115
110
105
100
95
90
Feb 2002
Feb 2003
Feb 2004
Feb 2005
Feb 2006
Feb 2007
Feb 2008
Observed
Simulated
GW060031
Groundwater level (mRL)
115
110
105
100
95
90
85
80
Jan 2002
Jan 2003
Jan 2004
Jan 2005
Jan 2006
Jan 2007
Year
Observed
Simulated
GW080075
115
110
105
100
95
90
85
80
Aug 2016
Dec 2016
Apr 2017
Observed
Simulated
GW080076
Groundwater level (mRL)
115
110
105
100
95
90
85
80
Aug 2016
Dec 2016
Apr 2017
Year
Observed
Simulated
GW080077
120
115
110
105
100
95
90
85
Apr 2016
Aug 2016
Dec 2016
Apr 2017
Observed
Simulated

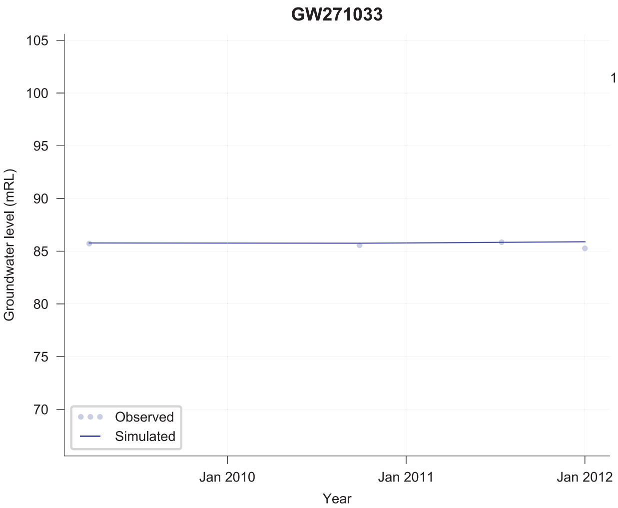

GW080078
Groundwater level (mRL)
Feb 2016
Jun 2016
Oct 2016
Feb 2017
Jun 2017
Year
Observed
Simulated
GW080434
GW080972
GW16
GW2
GW21
GW22
GW23

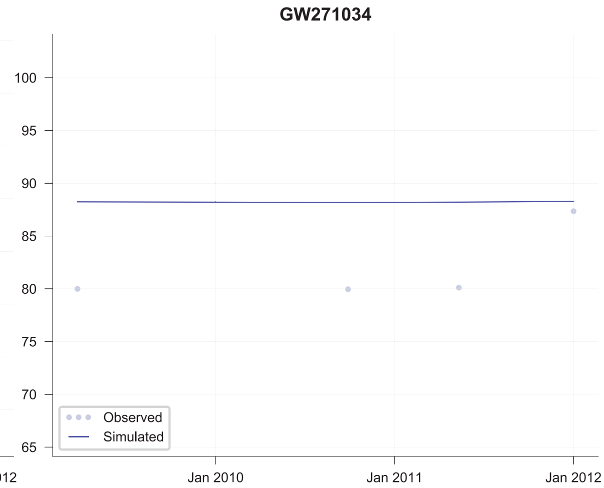

GW25
Groundwater level (mRL)
145
140
135
130
125
120
115
110
2008
2010
2012
2014
2016
2018
Year
Observed
Simulated

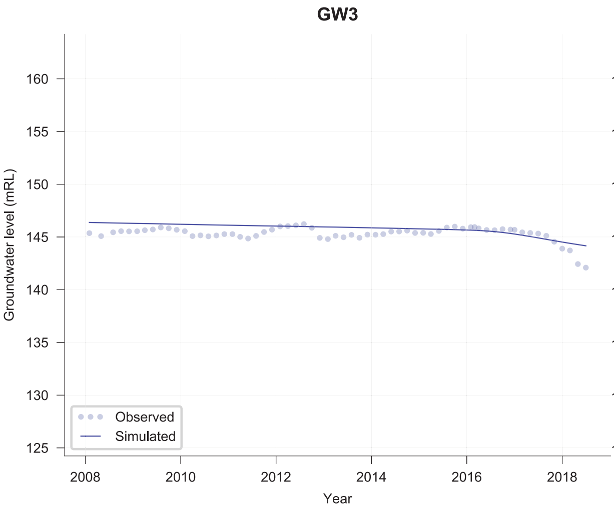

GW26
220
210
200
190
180
170
2008
2010
2012
2014
2016
2018
Observed
Simulated

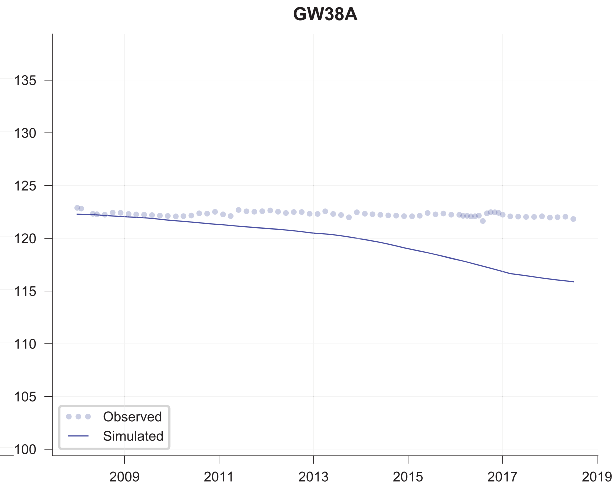

GW271031
Groundwater level (mRL)
95
90
85
80
75
70
65
60
55
2010
2011
2012
2013
2014
2015
2016
2017
Year
Observed
Simulated

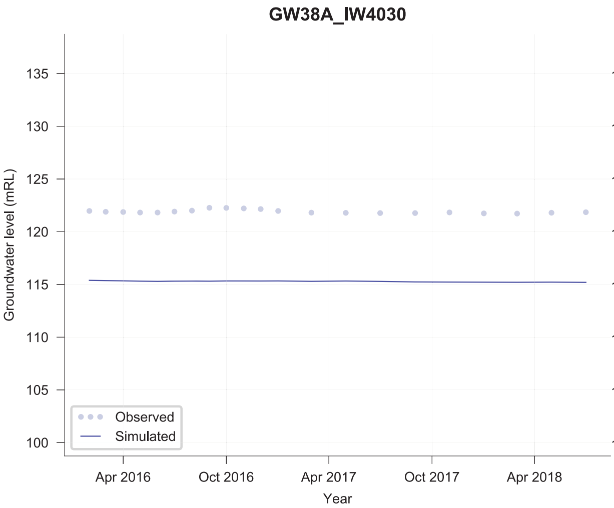

GW271032
130
125
120
115
110
105
100
95
2009
2010
2011
2012
2013
2014
2015
2016
2017
Observed
Simulated

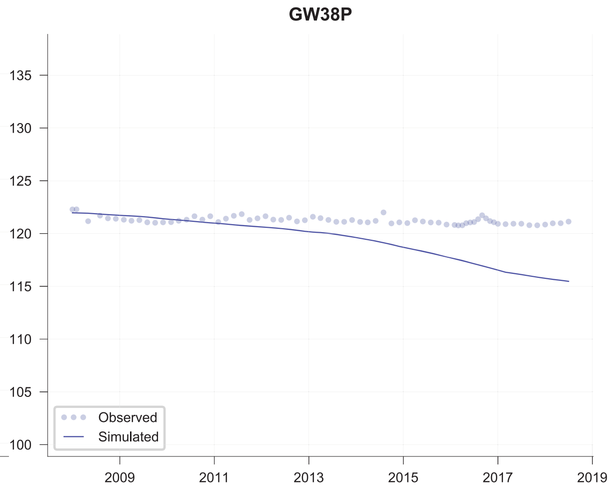

GW271033
Groundwater level (mRL)
105
100
95
90
85
80
75
70
Jan 2010
Jan 2011
Jan 2012
Year
Observed
Simulated

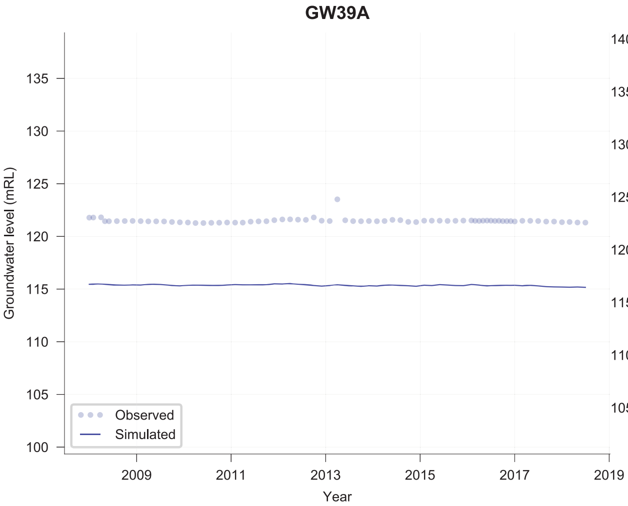

GW271034
100
95
90
85
80
75
70
65
Jan 2010
Jan 2011
Jan 2012
Observed
Simulated

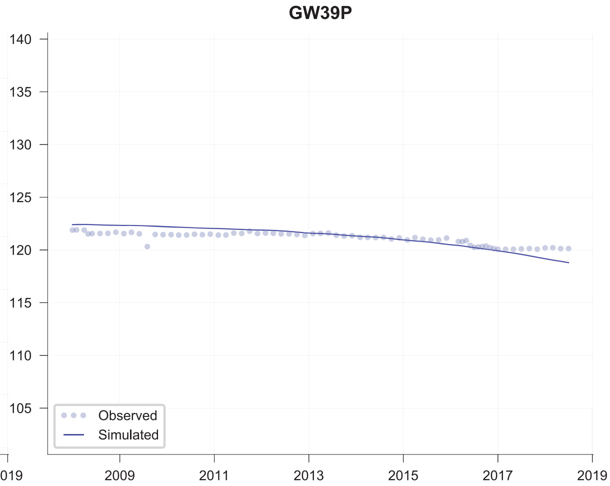

GW3
Groundwater level (mRL)
160
155
150
145
140
135
130
125
2008
2010
2012
2014
2016
2018
Year
Observed
Simulated

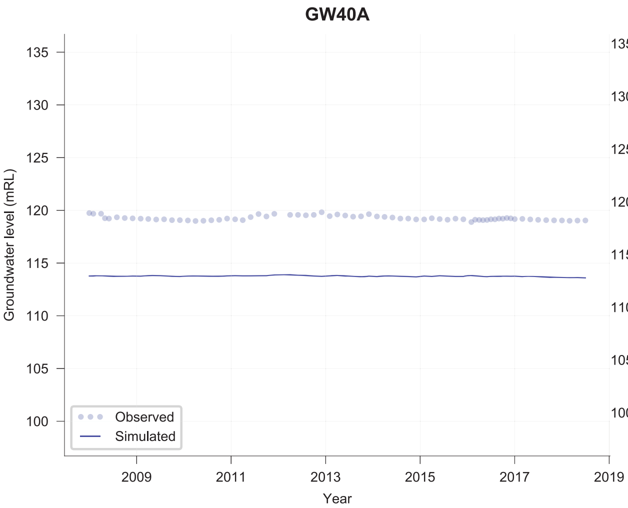

GW38A
135
130
125
120
115
110
105
100
2009
2011
2013
2015
2017
2019
Observed
Simulated

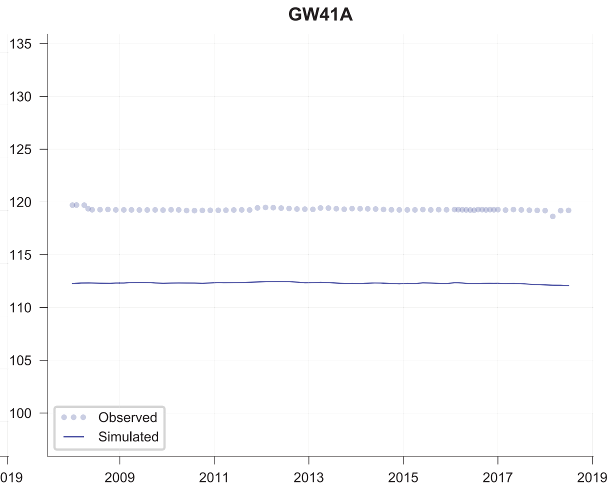

GW38A_IW4030
Groundwater level (mRL)
135
130
125
120
115
110
105
100
Observed
Simulated
Apr 2016
Oct 2016
Apr 2017
Oct 2017
Apr 2018
Year

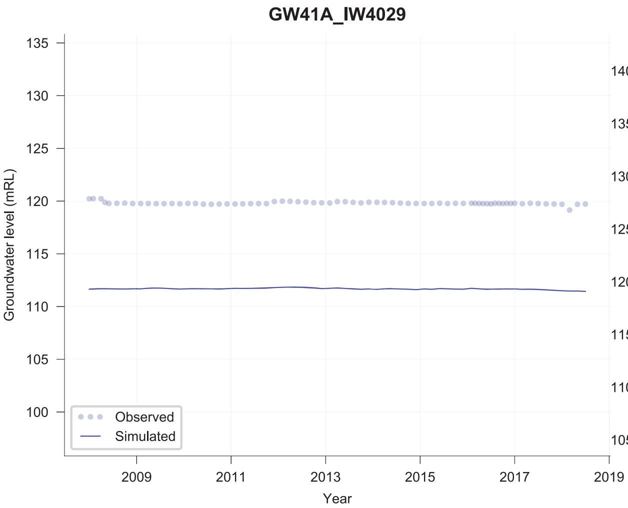

GW38P
135
130
125
120
115
110
105
100
Observed
Simulated
2009
2011
2013
2015
2017
2019

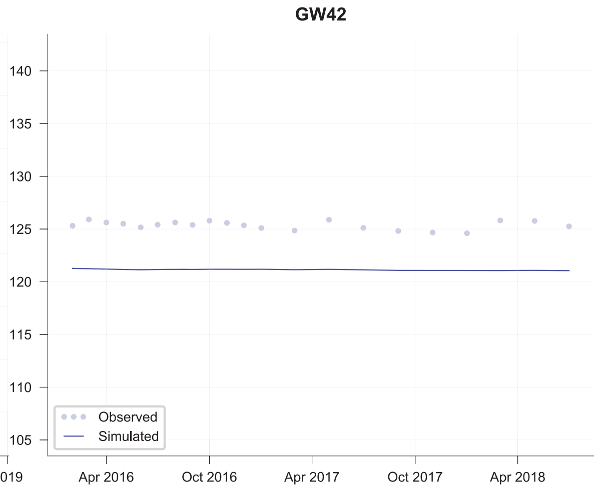

GW39A
Groundwater level (mRL)
135
130
125
120
115
110
105
100
Observed
Simulated
2009
2011
2013
2015
2017
2019
Year

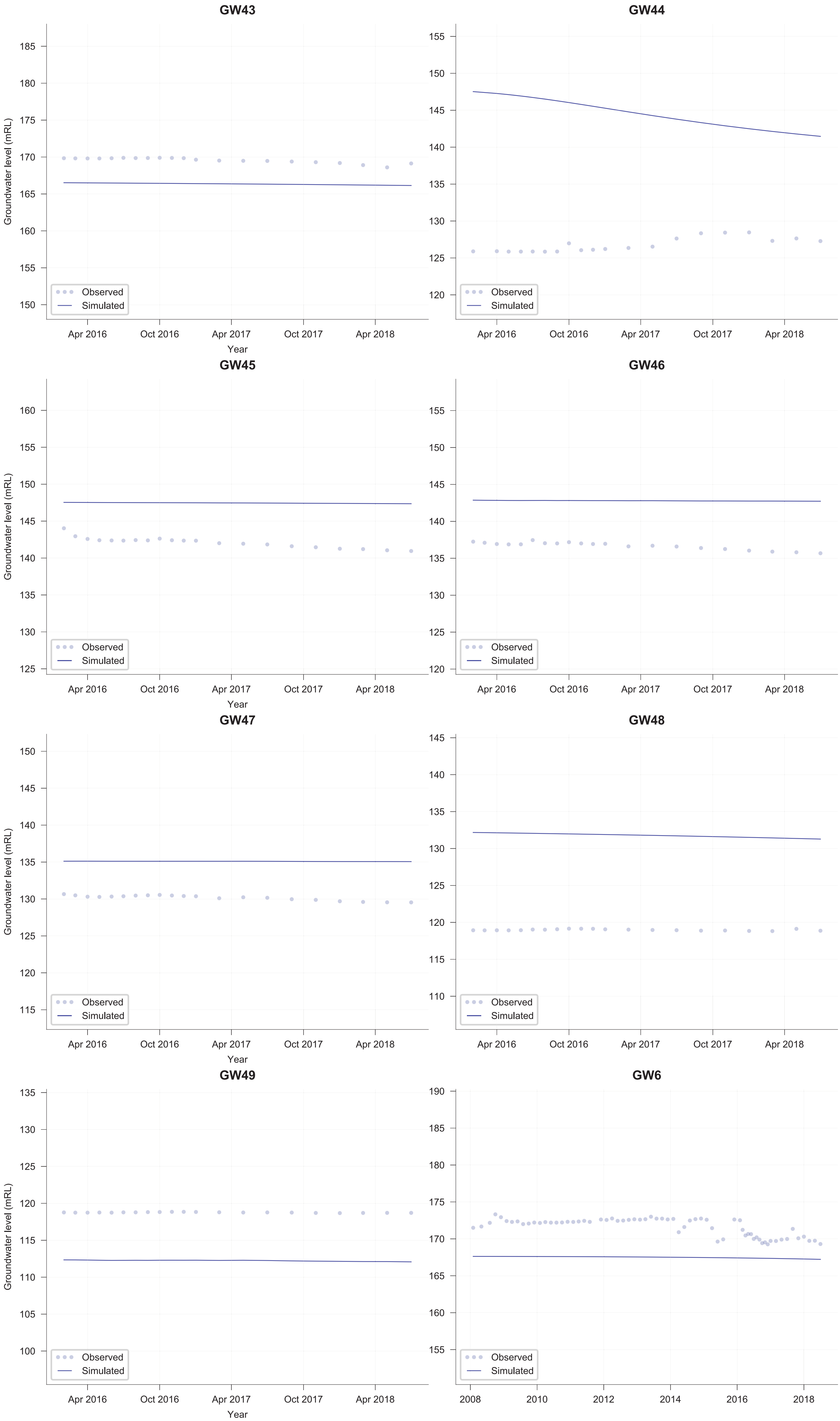

GW39P
140
135
130
125
120
115
110
105
Observed
Simulated
2009
2011
2013
2015
2017
2019

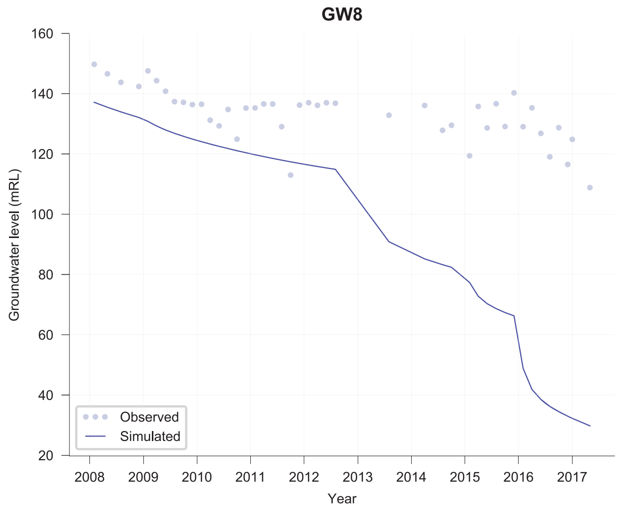

GW40A
Groundwater level (mRL)
135
130
125
120
115
110
105
100
Observed
Simulated
2009
2011
2013
2015
2017
2019
Year

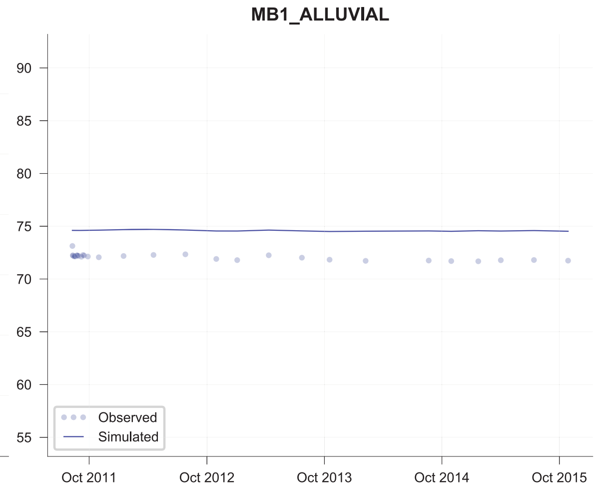

GW41A
135
130
125
120
115
110
105
100
Observed
Simulated
2009
2011
2013
2015
2017
2019

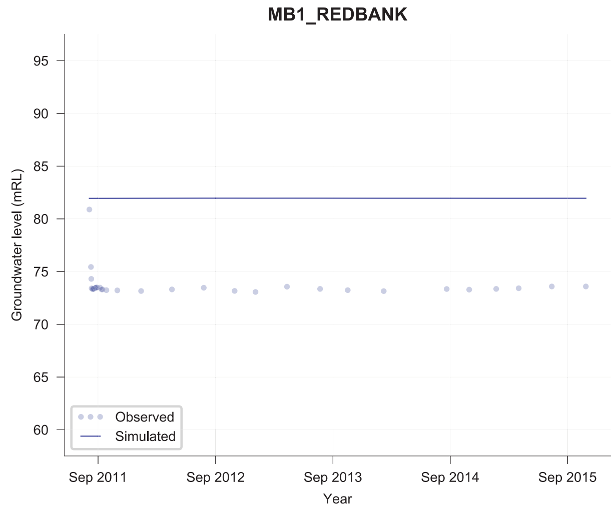

GW41A_IW4029
Groundwater level (mRL)
135
130
125
120
115
110
105
100
Observed
Simulated
2009
2011
2013
2015
2017
2019
Year

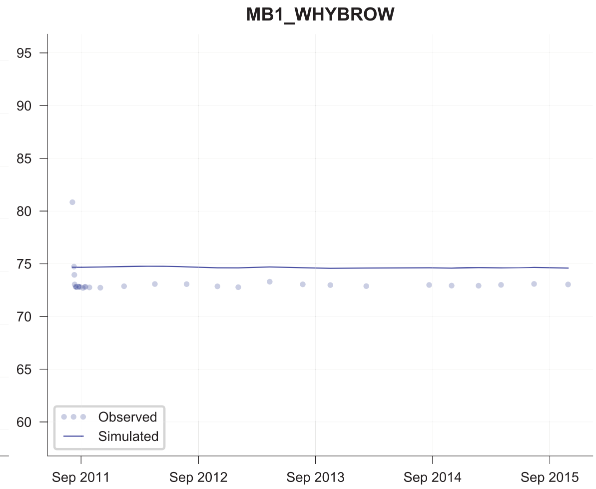

GW42
140
135
130
125
120
115
110
105
Observed
Simulated
Apr 2016
Oct 2016
Apr 2017
Oct 2017
Apr 2018

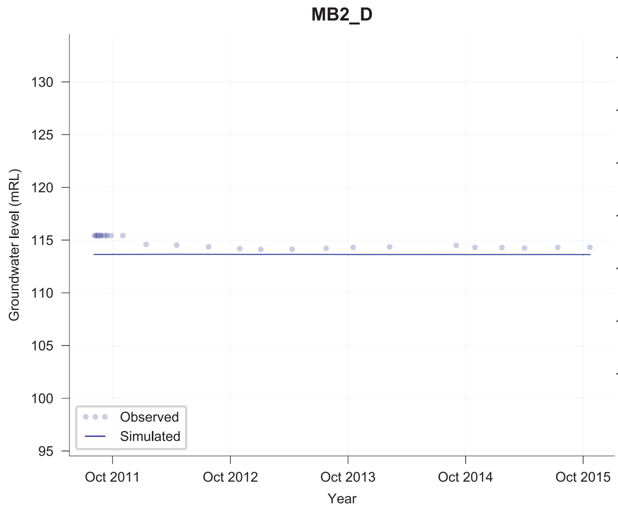

GW43
GW44
GW45
GW46
GW47
GW48
GW49
GW6
Groundwater level (mRL)
Year
Observed
Simulated
Apr 2016
Oct 2016
Apr 2017
Oct 2017
Apr 2018
2008
2010
2012
2014
2016
2018

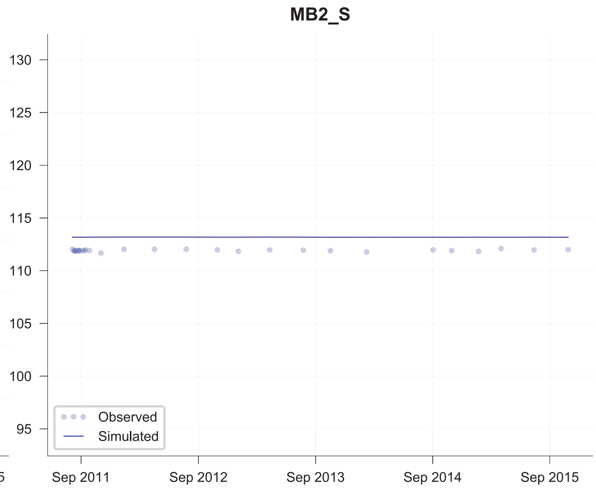

GW8
Groundwater level (mRL)
160
140
120
100
80
60
40
20
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Year
Observed
Simulated

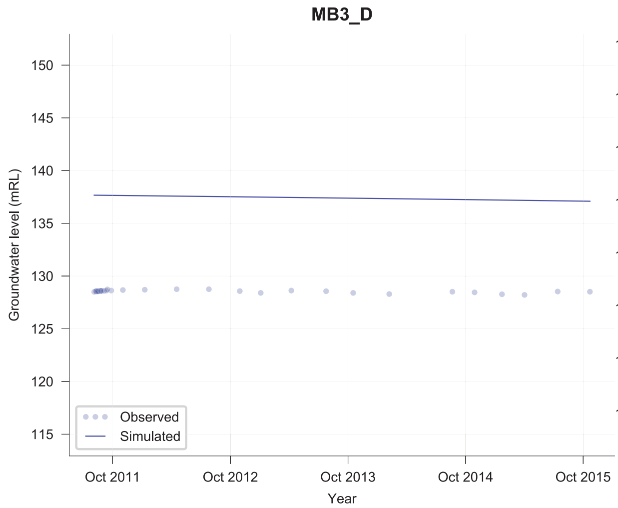

MB1_ALLUVIAL
90
85
80
75
70
65
60
55
Oct 2011
Oct 2012
Oct 2013
Oct 2014
Oct 2015
Observed
Simulated

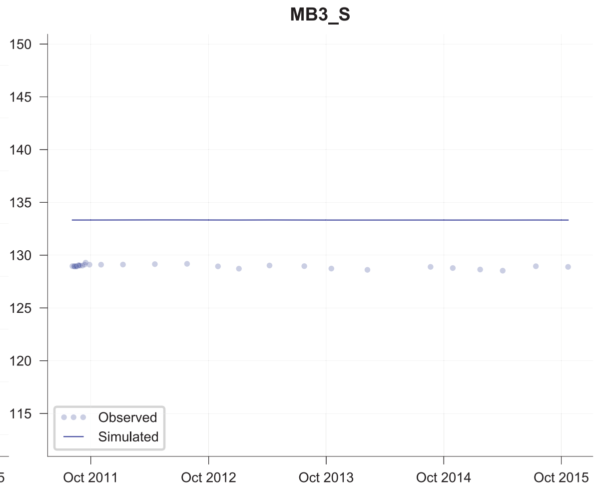

MB1_REDBANK
Groundwater level (mRL)
95
90
85
80
75
70
65
60
Sep 2011
Sep 2012
Sep 2013
Sep 2014
Sep 2015
Year
Observed
Simulated

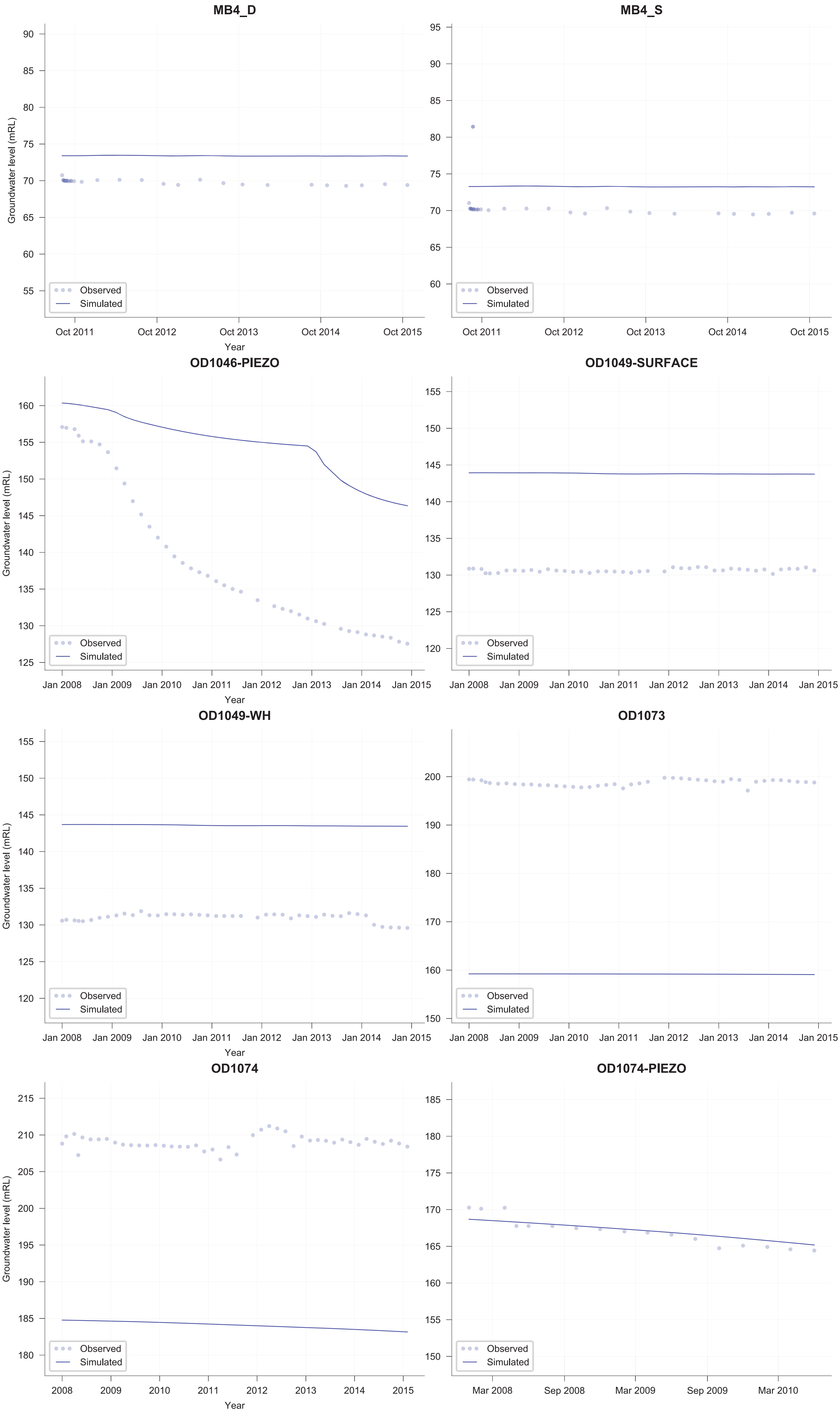

MB1_WHYBROW
95
90
85
80
75
70
65
60
Sep 2011
Sep 2012
Sep 2013
Sep 2014
Sep 2015
Observed
Simulated


MB2_D
Groundwater level (mRL)
130
125
120
115
110
105
100
95
Oct 2011
Oct 2012
Oct 2013
Oct 2014
Oct 2015
Year
Observed
Simulated


MB2_S
130
125
120
115
110
105
100
95
Sep 2011
Sep 2012
Sep 2013
Sep 2014
Sep 2015
Observed
Simulated


MB3_D
Groundwater level (mRL)
150
145
140
135
130
125
120
115
Oct 2011
Oct 2012
Oct 2013
Oct 2014
Oct 2015
Year
Observed
Simulated


MB3_S
150
145
140
135
130
125
120
115
Oct 2011
Oct 2012
Oct 2013
Oct 2014
Oct 2015
Observed
Simulated


MB4_D
MB4_S
OD1046-PIEZO
OD1049-SURFACE
OD1049-WH
OD1073
OD1074
OD1074-PIEZO
Groundwater level (mRL)
Year
Observed
Simulated
Oct 2011
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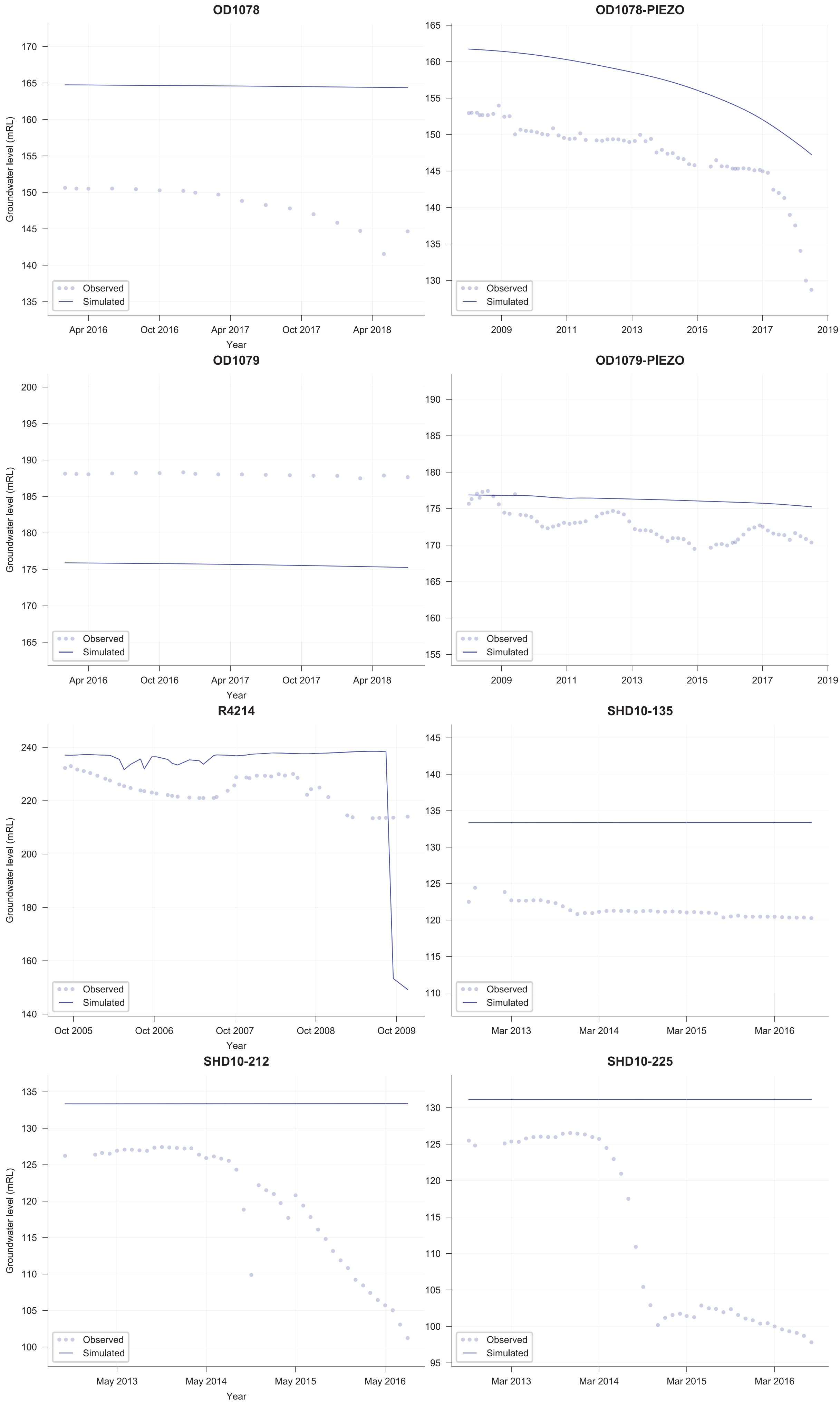
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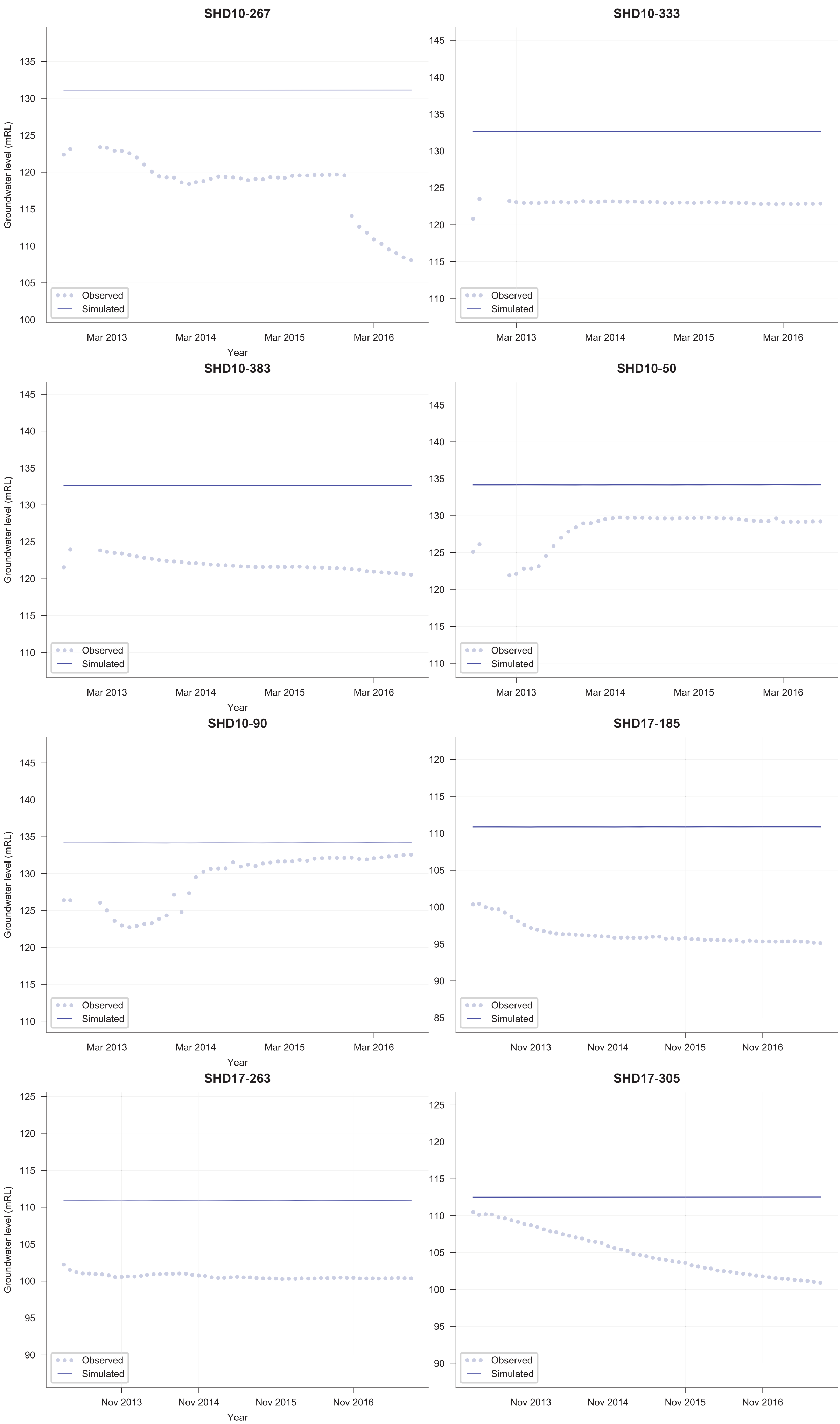
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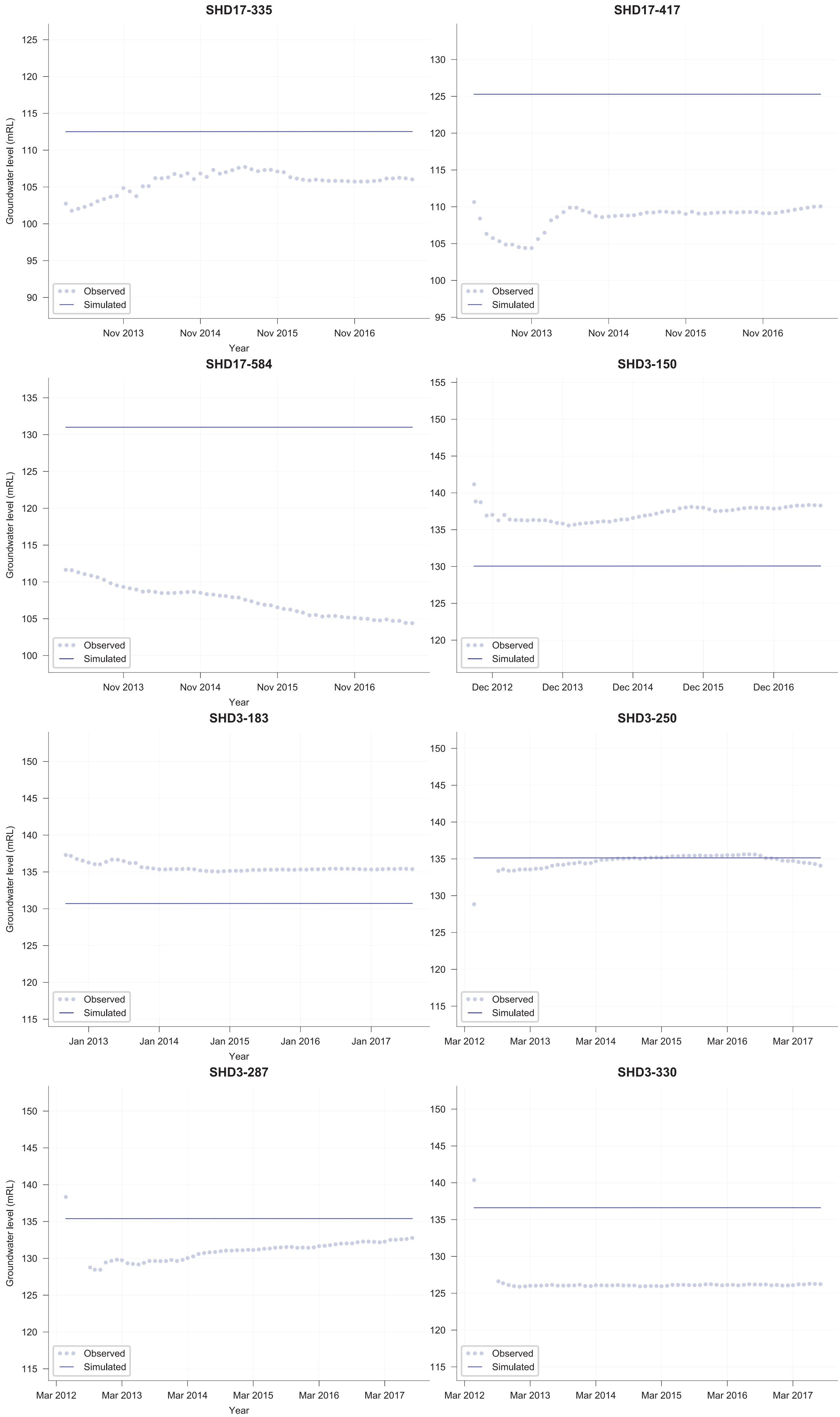
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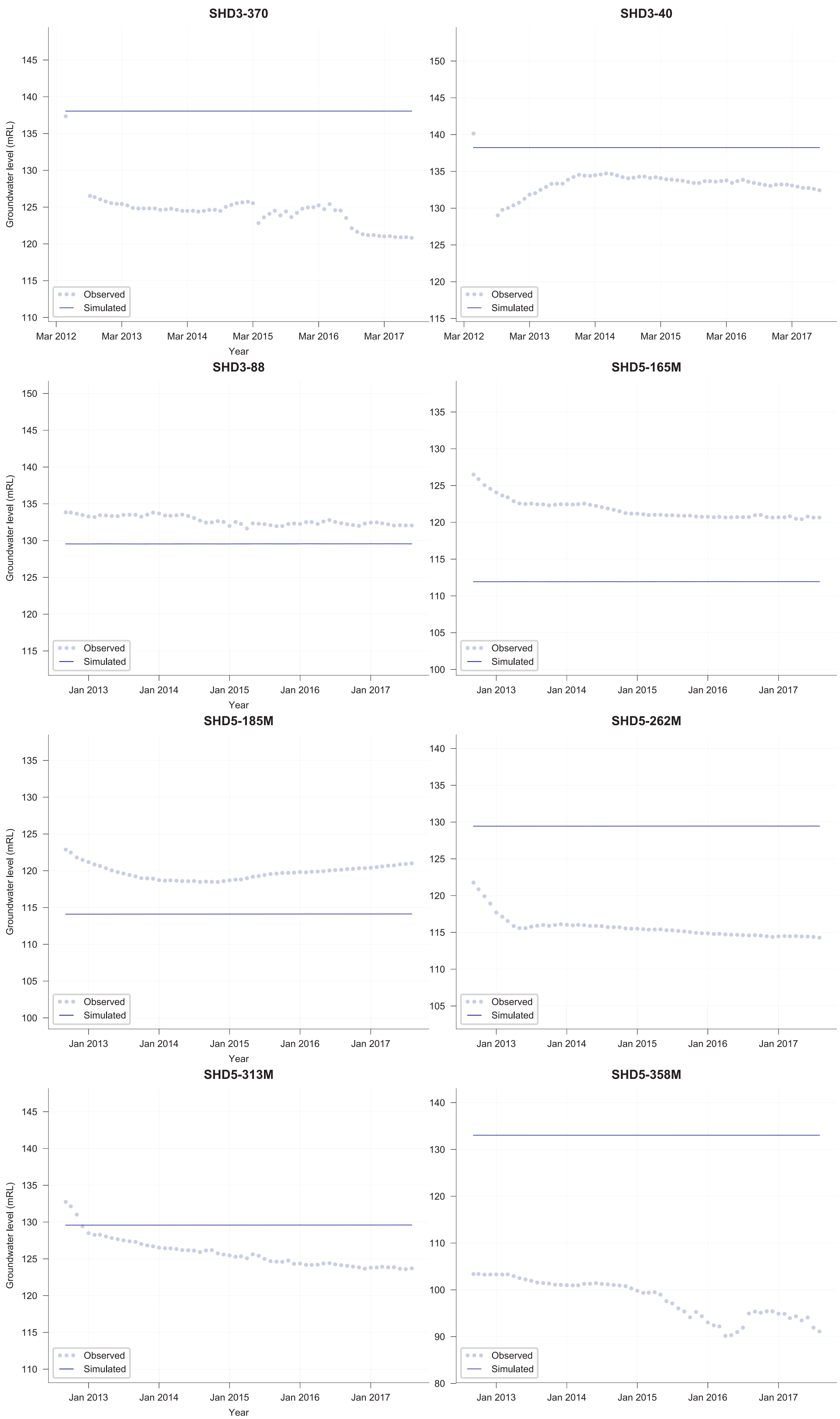
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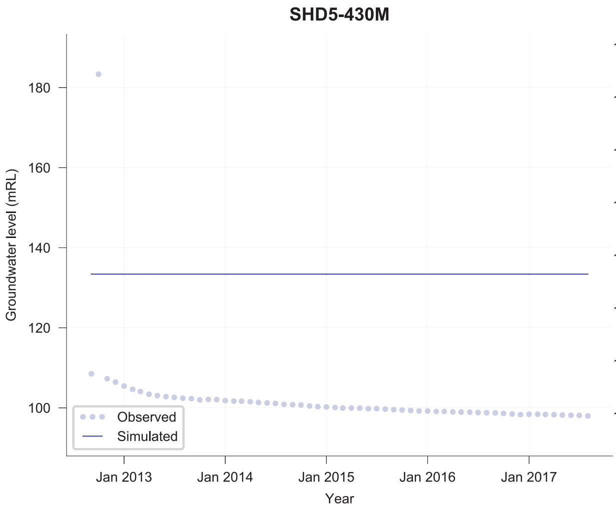
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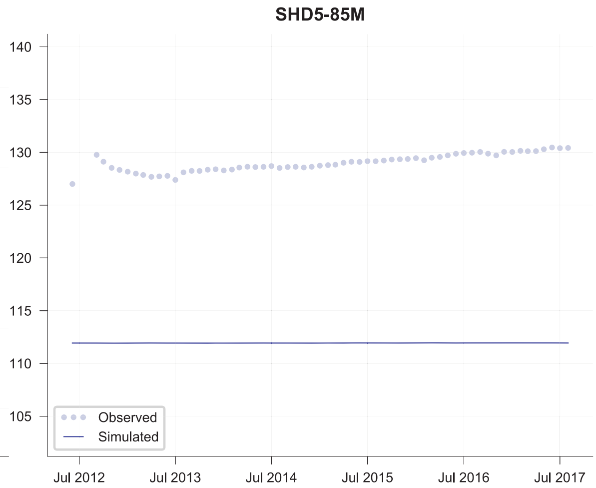
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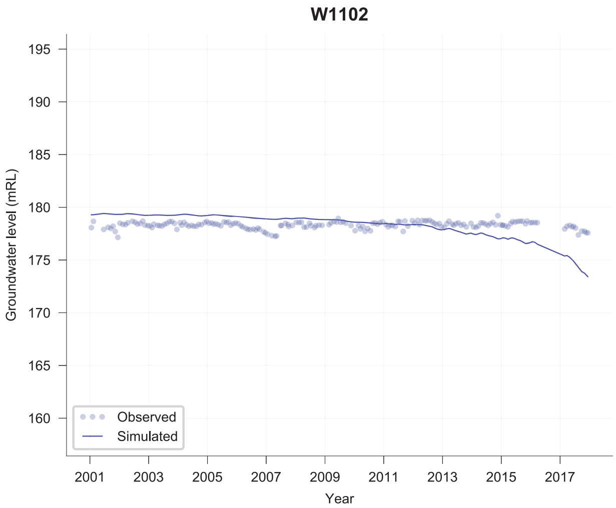
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APPENDIX J

HEIGHT OF FRACTURING ANALYSIS

Methodology adopted to determine the height of fracturing in groundwater model

APPENDIX J – HEIGHT OF FRACTURING ANALYSIS

1. INTRODUCTION

The purpose of this report is to outline the methodology adopted to determine the height of fracturing for the Maxwell Project Groundwater Assessment.

The estimates of height of fracturing have been informed by algorithms developed by Tammetta (Tammetta, 2013) and Ditton (Ditton and Merrick, 2014) as well as reviews of these models undertaken by Pells Sullivan Meynink (PSM) (Sullivan & Swarbrick, March 2017), Mackie (February 2017), Galvin (February 2017) and Galvin (June 2017).

The remainder of this report is structured as follows:

- **Section 2** – provides a conceptual overview of the impact of underground mining on overburden.
- **Section 3** – provides an overview of the existing height of fracturing models.
- **Section 4** – describes the methodology adopted to adjust the existing height of fracturing models to consider the effects of multi-seam mining.
- **Section 5** – details the calculations used to apply the multi-seam height of fracturing methodology to the Maxwell Project.
- **Section 6** – describes how the calculated height of fracturing was applied to the groundwater model using a series of drains aligned vertically (stacked) in the fractured zone above a mined model cell.
- **Section 7** – documents the references used in this report.

2. IMPACT OF UNDERGROUND MINING ON OVERBURDEN

The impact of mining on the hydraulic conductivity of overlying overburden has been based on monitoring experience and groundwater modelling conducted in similar mining environments, including research available on free draining heights. It is generally accepted that there would be a sequence of deformational zones produced by underground mining usually described as:

- Deformed floor strata (Z).
- Mined seam (O).
- The caved zone (AA).
- The fracture zone, consisting of:
    - a lower zone of connective-cracking (A); and
    - an upper zone of disconnected cracking (B).
- The constrained zone (C).
- The surface zone (D).

The rocks in the connective-cracking part of the fracture zone (A) would have a substantially higher vertical permeability than the undisturbed host rocks. This would encourage groundwater to move out of rock storage downwards towards the goaf. In the upper part of the fracture zone, where disconnected-cracking occurs, the vertical movement of groundwater should not be significantly greater than under natural conditions.

Depending on the width of the longwall panels, the depth of mining, and the presence of low permeability lithologies, there could be a constrained zone (C) in the overburden that acts as a bridge. Rock layers are likely to sag without breaking, and bedding planes are likely to open. As a result, some increase in horizontal permeability can be expected at least over the dimension of a longwall panel. A constrained zone (C) does not occur in areas where the connective-cracking zone (A) reaches the surface.

In the surface zone (D), near-surface cracking can occur due to horizontal tension at the edges of a subsidence trough. Cracking would be shallow (<15 m), often transitory, and any loss of water into the cracks would not continue downwards towards the goaf.

The strata movements and deformation that accompany subsidence would alter the hydraulic and storage characteristics of aquifers and aquitards. As there would be an overall increase in rock permeability, groundwater levels would be reduced either due to actual drainage of water into the goaf or by a flattening of the hydraulic gradient without drainage of water (in accordance with Darcy's Law). At the base of the fractured zone, groundwater pressures would reduce towards atmospheric pressure.

3. EXISTING SINGLE SEAM HEIGHT OF FRACTURING MODELS

Two existing single seam height of fracturing models were reviewed for the Maxwell Project:

- *A New Subsurface Fracture Height Prediction Model for Longwall Mines in the NSW Coalfields* (Ditton and Merrick, 2014) (referred to as the Ditton Model); and
- *Estimation of the height of complete groundwater drainage above mined longwall panels* (Tammetta, 2013) (referred to as the Tammetta Model).

The Ditton Model subdivides the deformed strata above mining panels into five zones, which are defined from ground surface downward in **Table 1**.

Tammetta (2013) put forward a similar conceptual model to that of Ditton and Merrick (2014). The Tammetta Model refers to a Collapsed Zone, taken to be fully desaturated (corresponding approximately to the AA and A Zones), and a saturated Disturbed Zone (corresponding conceptually to the B Zone). Both models have a continuous fracture zone that is arched in cross section.

Both authors have found a relation between the height of some representation of the "fracture zone" and three key attributes of the mining system:

- mining height (T [Ditton Model] or t [Tammetta Model]);
- cover depth (H [Ditton Model] or h [Tammetta Model]); and
- longwall panel width (W for both models).

Table 1 Sub-Surface Fracture Zone Summary

Zone Type	Zone	Fracture and Groundwater Response Description	Typical Vertical Strain (mm/m)
Surface Cracking Zone (un-constrained)	D	Vertical cracking due to horizontal strains extending to maximum depths of 10-15 m. Surface waters may be diverted below affected area and resurface downstream where interaction with B and C Zones occurs.	<3
Elastic Deformation Zone (dilated bedding & constrained)	C	Generally unaffected by strains with some bedding parting dilation. Horizontal strains constrained by overlying/underlying strata. Groundwater levels may be lowered temporarily due to new storage volume in voids between beds, but likely to recover at a rate dependent on recharge mechanisms. Elastic Deformation Zone may not be present if B or A Zones extend up to Surface Zone.	<3
Discontinuous Fracture Zone (dilated bedding & constrained)	B	Minor vertical cracking due to bending that does not extend through strata units. Increased bedding parting dilation and similar groundwater response to Zone C. Some groundwater leakage may occur to the A Zone; however, losses likely to be recharged by surface hydro-geological system.	<8
Continuous Fracture Zone (unconstrained)	A	Major vertical cracking due to bending that passes through strata units and allows a direct hydraulic connection to workings below. Full depressurisation of groundwater might occur in the A Zone but may recover in the long term once mining is completed.	>8
Caved (often included in the A Zone)	AA	Caved strata up to 3 to 5 x Mining Height above the workings. Collapsed roof bulks in volume to provide some support to overlying strata.	>80

In addition, the Ditton Model includes an effective spanning beam thickness [t'] as a surrogate for roof rock integrity in one of its two developed models. The second model that uses only mining geometry, with no geology term, is directly comparable to the Tammetta model.

The Ditton model formulas for fracture zone height (A) for single-seam mining (Ditton and Merrick, 2014) are:

- Geometry Model: $A = 2.215\, W'^{0.357} H^{0.271} T^{0.372}$ +/- [0.10 - 0.16] W' (metres).
- Geology Model: $A = 1.52\, W'^{0.4} H^{0.535} T^{0.464} t'^{-0.4}$ +/- [0.10 - 0.15] W' (metres).

  where W' is the minimum of the panel width (W) and the critical panel width (1.4H).

The 95th percentile (maximum) A-Zone heights are estimated by adding aW' to A, where a varies from 0.10 for supercritical panels to 0.16 (geometry model) or 0.15 (geology model) for subcritical panels.

The Ditton models have been validated to 34 measured Australian case-studies (including West Wallsend, Mandalong, Springvale, Abel, Ashton, Austar, Berrima, Metropolitan and Wollemi/North Wambo Mines) with a broad range of mining geometries and geological conditions included. The database also includes three cases in which connective cracking reached land surface (South Bulga, Homestead and Invincible Collieries).

Using the Ditton Model notation, the Tammetta formula for collapsed zone height (A) for single-seam mining is equivalent to:

- Geometry Model: $A = 1438 \ln[(4.315 \times 10^{-5}) H^{0.2} T^{1.4} W + 0.9818] + 26$ (metres).

The 95th percentile (maximum) A-height is estimated by adding 37 m.

The Tammetta model has been validated to Australian and international case-studies, using hydraulic head and ground movement (extensometer) data. An important assumption is that "H is taken as being equal to the top of the zone of large downward movement" (Tammetta, 2013). This level is said to correspond with zero groundwater pressure, according to the examined head database.

The effects of multi-seam subsidence on fracture height have been examined by Ditton but not by Tammetta. The methodology adopted to determine the height of fracturing for multi-seam mining is discussed in **Section 4**.

4. MULTI-SEAM HEIGHT OF FRACTURING METHODOLOGY

The effects of multi-seam subsidence on the fracture height calculations have been estimated for the Project in consultation with a geotechnical/subsidence expert (i.e. Ditton Geotechnical Services).

There are no published case studies relevant to above-seam fracturing for the multi-seam nature of the Project. However, Ditton (pers. comm.) considered multi-seam subsidence data from North Wambo, Liddell and Cumnock Collieries, and concluded that a multi-seam correction can be derived from the incremental subsidence due to mining of individual seams.

Best-case and worst-case estimates of fracture heights may be assessed by adopting the predictions for single seam outcomes (best-case) and cumulative outcomes based on multi-seam subsidence (worst-case). The additional subsidence is converted into an ‘effective’ mining height increase, ΔT1. The ΔT1 term can be estimated as:

- No additional subsidence (best-case).
- A summation of the effects of all underlying seams, calculated by adding ‘mining height increase’ components based on incremental subsidence for underlying seams.
- A summation of the effects of all underlying seams (worst-case), calculated by adding ‘mining height increase’ components based on conservative summing of the mining heights of underlying seams.

The combined mining height determined by summing the mining heights of the underlying seams is then conservatively applied at the depth of cover of the shallowest mined seam (i.e. the upper seam mining height T1 is increased to T1’ by ΔT1 and used to estimate the multi-seam A-Zone fracture height A1’).

This method provides a range of potential fracture height values, with the maxima representing the most conservative estimates, and 95%A being the value with a 95% degree of confidence (95% confidence that actual A predictions would be less than this value).

5. CALCULATION OF MULTI-SEAM HEIGHT OF FRACTURING FOR THE MAXWELL PROJECT

The Maxwell Project mine plans have been examined to identify where the mining panels in the target coal seams overlie each other. There are five different combinations of multi-seam mining and an area of single-seam mining (referred to as mining zones 1-6), as shown on **Figure 1**. The number of cells affected by fracturing (stacked drain cells) varies in both time and space, being controlled by mine progression over time across the mining zone in the different layers. Separate multi-seam corrections are required for each zone.

A conservative multi-seam correction was applied to the height of fracturing calculation by adjusting the effective thickness of the uppermost seam to be the sum of the stacked coal seam thicknesses (i.e. the 'worst-case' scenario identified in **Section 4**). This approach is considered conservative because the total subsidence cannot be greater than the sum of extracted seam thicknesses. Actual subsidence is more likely to be 70-90% of total combined seam thickness (based on multi-seam subsidence data from North Wambo, Liddell and Cumnock Collieries). The inherent conservatism in the 'worst-case' scenario is considered to outweigh concerns regarding the existing height of fracturing models raised by PSM (Sullivan & Swarbrick, March 2017), Mackie (February 2017) and Galvin (February 2017 and June 2017).

The height of fracturing for each multi-seam mining zone has been calculated based on the average mining height, cover depth and panel width within each multi-seam mining zone. The average parameters are summarised in **Table 2**.

Table 2 Height of Fracturing Parameters for each Mining Zone

Mining Zone	Extracted Seams	Average Upper Seam Cover Depth (Hzone [m])	Upper Seam Panel Width (Wzone' [m])	Average Total Thickness (Tzone' [m])	Adopted Height of Fracturing* (m above upper seam)
1	Woodlands Hill	191	268	2.7	154
2	Whynot Woodlands Hill	92	60	4.6	66
3	Woodlands Hill Arrowfield	278	300	5.6	258
4	Whynot Woodlands Hill Arrowfield	129	60	7.5	97
5	Woodlands Hill Arrowfield Bowfield	246	300	8.5	288
6	Whynot Woodlands Hill Arrowfield Bowfield	94	60	10.4	95

* Calculated by applying the following formula to the aggregated data:

$95\%\text{ile A Zone Height} = 1.52\ \text{Wzone}'^{0.4}\ \text{Hzone}^{0.535}\ \text{Tzone}'^{0.464}\ 15^{0.4} + 0.1\text{Wzone}'$

A comparison of the adopted height of fracturing with other contemporary methodologies is provided in **Table 3** for the empirical 33T formula, and the single-seam Ditton and Tammetta models, using the parameters of the uppermost mined seam in each zone.

Table 3 Comparison of Height of Fracturing Methodologies

Mining Zone	Extracted Seams	33T Model* (m)	Ditton Model^ (m)	Tammetta Model^ (m)	Adopted Height of Fracturing
1	Woodlands Hill	89	154	239	154
2	Whynot Woodlands Hill	63	46	59	66
3	Woodlands Hill Arrowfield	89	192	254	258
4	Whynot Woodlands Hill Arrowfield	63	54	61	97
5	Woodlands Hill Arrowfield Bowfield	89	182	249	288
6	Whynot Woodlands Hill Arrowfield Bowfield	63	47	60	95

* Source: Forster and Enever (1992) and Forster (1995).
^ Formulas for the Ditton and Tammetta Models are outlined in Section 3.

Table 3 confirms that the adopted height of fracturing for the Maxwell Project is more conservative than the three existing models for all but one of the mining zones. The adopted height of fracturing for Zone 1 is less than the height determined using the Tammetta Model. However, Zone 1 only represents a small part of the Maxwell Underground area, where single-seam longwall mining would occur in the Woodlands Hill seam. Accordingly, the approach adopted to determining the height of fracturing is considered conservative.

The adopted height of fracturing for each multi-seam mining zone was applied to the groundwater model to determine the uppermost layer that would be fractured (**Figure 2**). Areas where the adopted height of fracturing reaches Layer 1 (regolith) are representative of fracturing to the surface. Application of this conservative multi-seam fracturing approach indicates fracturing to the surface would occur across approximately half of the Maxwell Underground area.

It has been conservatively assumed that all interburden between mined seams would be fractured. This is supported by calculations of fracture height above each deeper individual seam.

6. APPLICATION OF HEIGHT OF FRACTURING TO THE GROUNDWATER MODEL

In this application, a set of stacked drains is used to represent the fracture network. Each drain cell requires a specified conductance value which is an approximation for the connectivity between the host strata and the fracture network. The MODFLOW-USG manual (Panday *et al.* 2013) defines the conductance of a Drain (the COND parameter) as "the hydraulic conductance of the interface between the groundwater system and the drain", where conductance is based on the size of the drain, the distance across the interface, and the hydraulic conductivity of the interface.

Drain elevations are set to the base of each cell within the fracture zone, with the relevant drain conductance (related to the height above the longwall panel) applied and remaining active for the duration of mining activity. Enhanced equivalent porous medium hydraulic conductivities representing the collapsed strata are applied at the end of mining prior to the simulation of recovery.

Drains are not applied to layer 1, as this can cause interference with RCH and EVT boundary conditions. Where fracturing to surface occurs, or superficial cracking is represented, layer 1 is given increased hydraulic conductivities, as indicated in **Table 4**.

Drain conductance values adopted for the Maxwell Project were as follows:

- Mined seams: COND set to 0.1 m^2/day – an order of magnitude greater than in the fracture zone.
- Interburden fracture zones between deeper seams: COND set to 0.01 m^2/day.
- Overburden above the Whynot Seam (Layer 5): COND set to 0.01 m^2/day in Layer 4 and 0.001 m^2/day for higher layers where fractured.
- It is noted that the Whynot Seam is bord and pillar mining, so fracturing would not necessarily be fully transmitted, despite being treated as such in multi-seam calculations.

The applied conductance values have been guided by calibration to reported inflows at Mt Arthur underground roadways.

The layer definition within the groundwater model has allowed each mined coal seam to be represented individually. Interburden separates each target coal seam in the model. Because the target coal seams begin in model layer 5, there is flexibility in the model to simulate the fracture zone to various heights (i.e. different deformation properties can be applied to Layers 1, 3 and 4 as shown in **Table 4**). This ensures that the impact of progressive caving and fracturing associated with the mining is adequately represented.

Table 4 shows layer properties defined by fracturing above mined cells. Average layer heights [top] in the mine affected area are shown also in **Table 4**.

The number of cells affected by fracturing (stacked drain cells) varies in both time and space, being controlled by mine progression over time across the mining zone in the different layers. To manage this complexity, a series of six zones was developed to represent groups of cells subject to fracturing to differing heights above different respective mine levels (**Section 5**), for which the drains could be turned on or off at the appropriate time in the model. The six zones are consistent with the mining zones shown on **Figure 1**. While **Figure 1** does not show the detail of individual model cells, it accurately represents the zones and shows the complexity of the procedure.

Table 4 Layer (L) Properties Defined by Fracturing in the Mined Areas

L	Top (Ave. m)	Description	Deformation Category	Drain
				COND (m^2/day)
1	0	Alluvium		
1	2	Regolith	A/D	Kz increased
2	27	Maxwell Infrastructure		
3	82	Whybrow overburden	A/B/C	0.001
4	83.9	Whynot overburden	A	0.01
5	249.9	Whynot Seam	O	0.1
6	252.6	Blakefield overburden	A	0.01
7	300.6	Blakefield Seam	A	0.01
8	303.5	Glen Munro overburden	A	0.01
9	333.5	Glen Munro Seam	A	0.01
10	336.4	Woodlands Hill overburden	AA	0.01
11	370.7	Woodlands Hill Seam	O	0.1
12	374.4	Arrowfield overburden	AA/A	0.01
13	622.4	Arrowfield Seam	O	0.1
14		Bowfield overburden	AA/A	0.01
15		Bowfield Seam	O	0.1
16		Piercefield overburden	Z	
17		Piercefield Seam		
18		Edderton overburden		
19		Edderton Seam		
20		Ramrod Creek overburden		
21		Ramrod Creek Seam		

Note: Z = Deformed floor strata; O = Mined seam
AA = Caved zone; A = Connective cracking zone
B = Disconnected cracking zone; C = Constrained zone
D = surface zone
Refer to Section 4.7.4.1 for definitions of each of these deformational zones.

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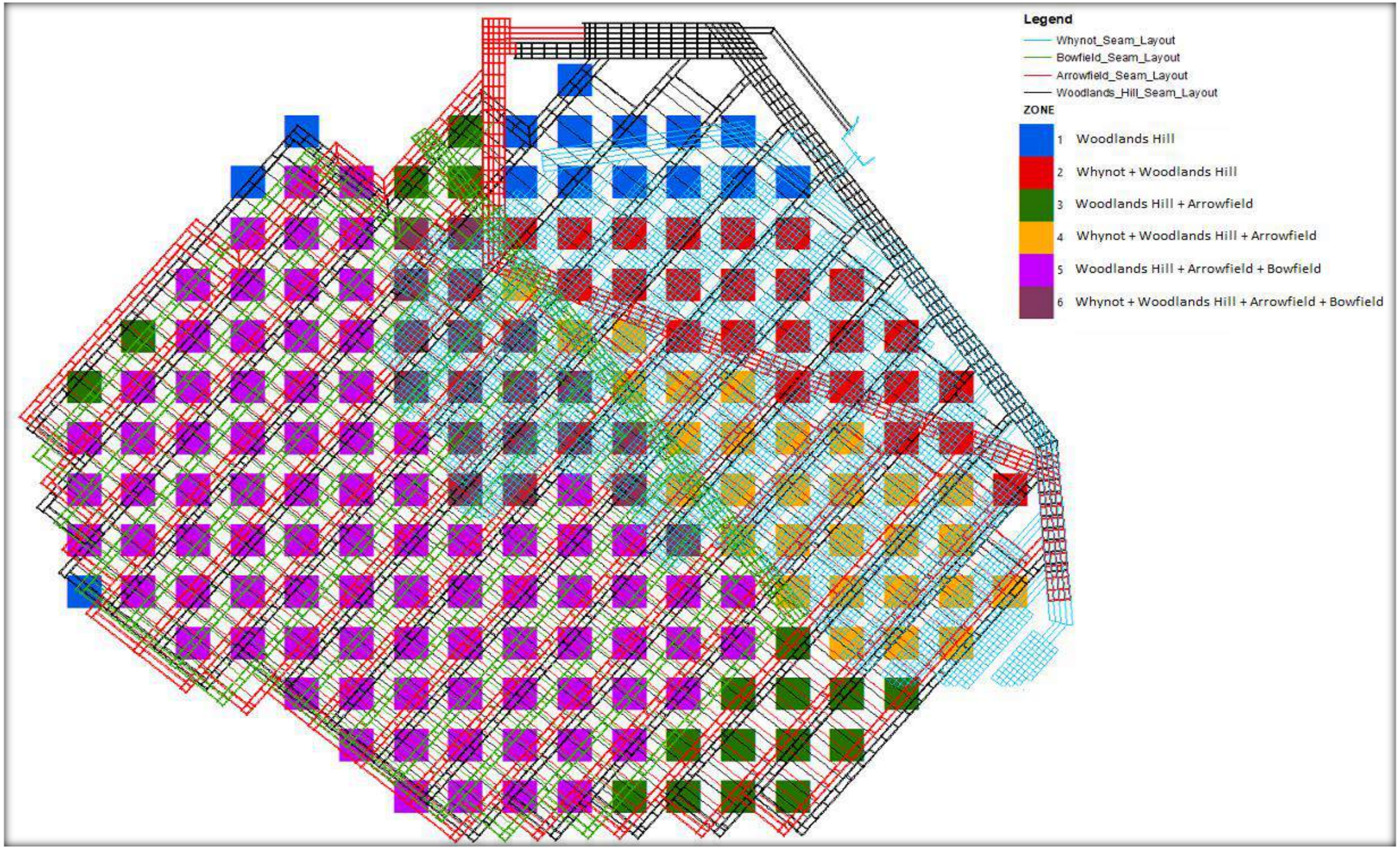

Figure 1 Mining Zones

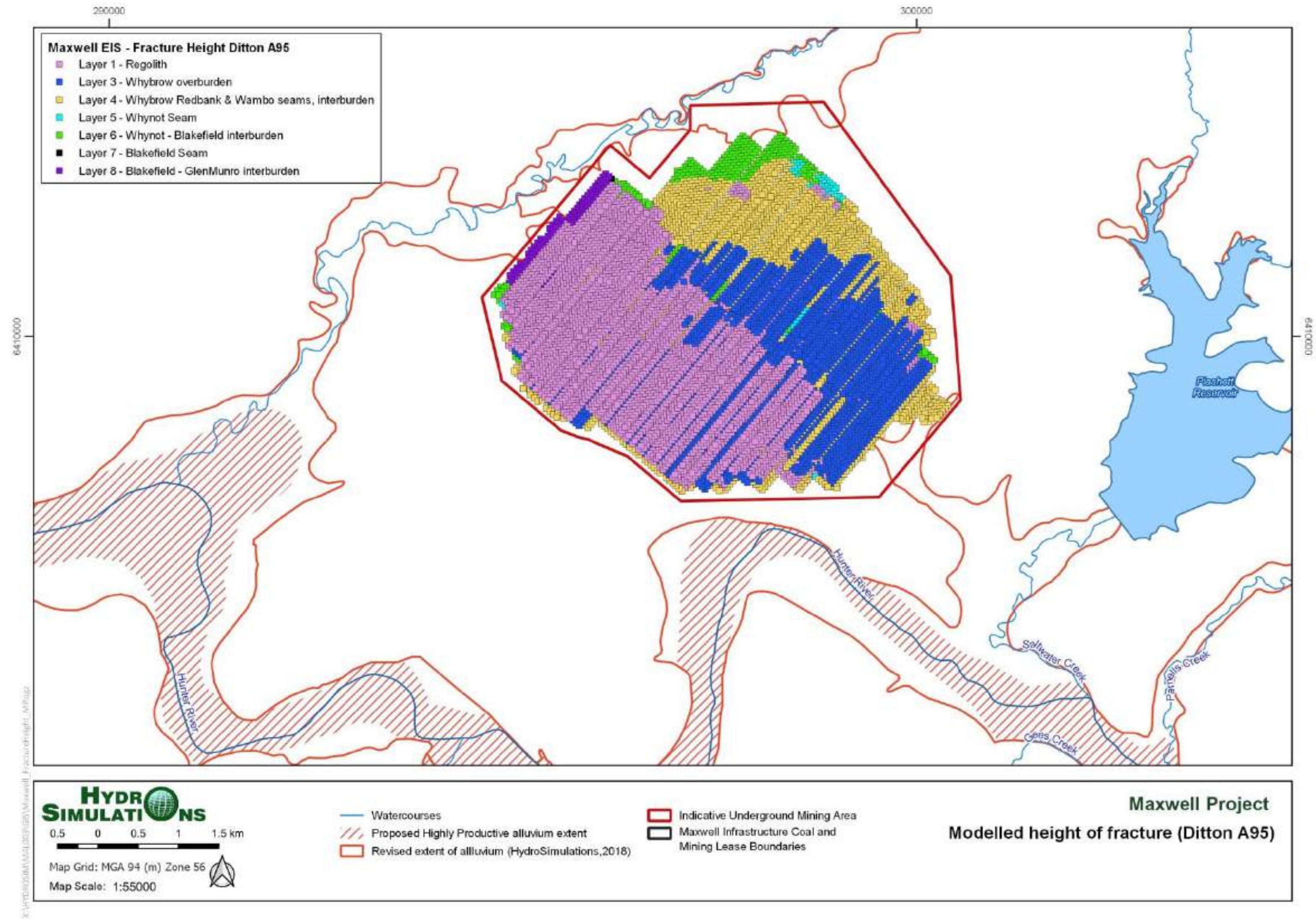

Figure 2 Uppermost Model Layer for the Adopted Height of Fracture

[Note: Layer 2 is pinched out in the mining area]

ATTACHMENT A

MBGS STRUCTURE REPORT

STRUCTURE REPORT

Maxwell Project

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August 2018

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EXECUTIVE SUMMARY

The Maxwell Underground Project is located within EL5460 in the Hunter Coalfield.

Exploration of the Wittingham Coal Measures has been undertaken since the 1970's. While the exploration since 1998 had a primary focus on the potential open cut coal resources, a considerable effort was made to explore the relatively shallow underground coal resources in the Woodlands Hill, Arrowfield, Bowfield and Warkworth Seams which are at depths of less than 450 m dipping gently to the south over an area of about 20 km^2. In addition to drilling of both cored and non-cored drill holes the exploration included both ground and airborne magnetic surveys and 2D and 3D seismic surveys. Coal seams were sampled and subjected to a comprehensive suite of analyses that provide data relevant to both coking and thermal coal products.

When Malabar Coal acquired the Drayton Mine and EL5460 in February 2018, a vast amount of exploration data became available, and this has been reviewed and the 3D geological model has been recently revised. The Minex 3D geological model is the basis for mine planning of the Maxwell Underground Project.

The geology review, completed in October 2017 for Malabar Coal involved an appraisal of potential working sections in the Whybrow Seam, Whynot Seam, Woodlands Hill Seam, Arrowfield Seam, Bowfield Seam and Warkworth Seam. The preferred underground working section that was derived for those seams was used for the mine planning that followed.

In the Maxwell Project area there are a number of faults that have been interpreted to exist, either from the seismic surveys or from structure contour plans, and at 18 locations a line of drill holes was completed to confirm the existence of the fault, and to indicate the position and throw on that structure in that location. Also, igneous dykes have been delineated by the magnetic surveys and some have been confirmed by trenching. Twenty drill holes have evidence of a fault or have intersected an igneous dyke or have localised silling into a coal seam that indicates that it is very close to a dyke. The faults and dykes that have been identified in the Maxwell Project area are shown on Figure 1, including possible extensions of known structures. There are three structures that have evidence of an igneous dyke being coincident with a fault (DF9, DF15 and DF16) and they all trend northeast to southwest for at least several km of their strike length and are all downthrown to the southeast. It may be prudent to expect that other faults such as F3 and F8, in a similar orientation, may also be associated with an igneous dyke. The faults are all normal faults. There are also faults that trend northwest to southeast (F4, F5, F6 and F9) and these are also normal faults; some are downthrown to the west and others to the east.

There are 2 main igneous dykes (D1 and D2) which trend north to south, and there may be some faulting along these dykes, as indicated by the seismic surveys. While D1 and D2 have been located by surface trenching, the existence of D3 and several other possible dykes are based on interpretation of magnetic data. The igneous material is described as "dolerite" in the lithology logs and is generally a hard and strong rock.

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APPENDICES

1 INTRODUCTION

The Maxwell Underground Project is located within EL5460, an area south of the Mt Arthur and Drayton open cut mine areas. The target coal seams are in the Jerry's Plains Subgroup of the Wittingham Coal Measures, and include the Whynot Seam, Woodlands Hill Seam, Arrowfield Seam, Bowfield Seam and Warkworth Seam. Upper seams in the sequence, including the Whybrow, Redbank Creek, Whynot and Blakefield Seams were explored for open-cut potential firstly by Mt Arthur South Coal in the period 1978 to 1982 and then by Saddlers Creek Coal Pty Ltd (Shell Coal) from 1998 to 2011 in EL 5460. Malabar Coal acquired Drayton Coal Pty Ltd in February 2018.

Since acquiring EL5460 Malabar Coal has been reviewing the potential for underground mining in the Edderton Block, located in the central and eastern parts of the EL. MBGS has undertaken a review of the geology, with particular focus on those coal seams that are amenable to underground mining. Five target seams have been identified (Whynot, Woodlands Hill, Arrowfield, Bowfield and Warkworth Seams) all of which have working sections in the range of 1.8 m to 4.2 m thick and are under depths of cover ranging from 50 m to 450 m. The geology review by MBGS, completed in October 2017, examined the working sections of each seam in all of the drill holes to ensure that the selected intervals were the most appropriate for an underground mining operation, considering the coal quality (raw ash), and the nature of the roof and floor of the selected working section. The structure interpretation was checked and the location, extent and throw of known faults was incorporated into a 3D geological model that was developed using Minex software.

In July 2018 Gary Fallon completed a review of the geophysical data available for EL5460. The seismic surveys and magnetic surveys were reviewed by Gary Fallon. This review assisted with the delineation of potential faults and dykes within the Edderton Block and this information has been used in this report to enhance the previous interpretation and has enabled a more complete understanding of known and possible geological structures that need to be taken into account in the mine planning.

3D seismic surveys were undertaken, as shown on Figure 2, in 2003, 2004, 2005 and 2006. The ground magnetic survey was carried out in 1998 and the airborne magnetic survey was carried out in 2002 and both covered the entire Edderton Block.

This report provides some detail on the faults and igneous intrusions in EL5460 and makes reference to drill holes that assisted in the fault delineation, and in which either igneous sill or dyke material was recorded.

2 STRUCTURAL INTERPRETATION EL5460

There have been several drilling programmes involving non-core “RD” series drill holes, that were specifically targeting faults that had been interpreted from the seismic surveys and/or from structure contours generated using existing drill hole data. A total of 18 fault drill lines (Figure 1) are apparent where closely spaced (20 m to 100 m apart) drill holes are oriented at right angles to the direction of a structural feature. A total of 92 RD holes were drilled along these lines, and together with any pre-existing drill holes have enabled the predicted faults to be either confirmed or deleted from the structural interpretation. Many of those RD drill holes extended down to the Warkworth Seam to provide data on seam thickness as well as structure to the depth of the lowest potentially mineable coal seam.

As part of the geology review, completed for Malabar Coal in October 2017 by MBGS, the drill holes on each of these drill lines were used to draw detailed cross sections, and from that exercise the location and throw of the significant faults was determined, and then these were incorporated into the 3D faulted model, built using Minex software. The geological model has now been used to prepare V/H = 1 cross sections along each of the 18 drill lines and these are included as Figures A1 to A18 in Appendix A of this report with a brief discussion provided on each section figure.

The 3D seismic has resulted in the interpretation of faults that have not been able to be proven by drilling. Of the 18 fault drill lines, 7 did not delineate a fault. On Line 16 it is possible that the fault lies to the west of the drill line (west of RD1161). The fault drill holes show that the throw of the faults is generally consistent from the upper seam (Whynot) down to the lower seam (Warkworth). The 3D seismic has more accurately delineated the faults with a displacement of 3 m or more, but is less reliable at predicting faults with less than 2 m displacement.

Figure 1 shows the faults (F), dykes (D) and fault/dyke (DF) structures that constitute geological structures interpreted from seismic surveys and drill hole data. A series of cross sections (A1- A18) along lines of holes crossing these structures are also presented in Appendix A of this report and the location is showed in Figure 1. The main resource area is the Edderton Block limited in the east by the steeper dipping zone where all the strata dip at more than 10 degrees to the west. The western limit is the East Graben fault (F4) which has a downthrow of up to 20 m to the west into the graben which it forms with the sub-parallel Randwick Park Fault which has a throw of up to 50 m on its eastern side.

Figure 2 shows the different 3D seismic survey campaigns, extent and main features interpreted. The seismic surveys extend down to about 6,409,000N, about 1 km north of the southern boundary of EL5460. About 75% of the Edderton Block has been covered by the 3D seismic surveys, and they were carried out specifically to provide additional structural data on the shallow underground coal seams, down to the Warkworth Seam.

A total of 12 faults, 3 of which include an igneous dyke, 6 dykes and 3 volcanic plugs have been interpreted. There is a high degree of certainty on the interpreted faults, however the features shown as possible faults on Figure 1 cannot be confirmed at this stage. Two dykes (D1 and D2) have been confirmed by trenching while the others require further investigation as they are only interpreted from magnetic surveys. The level of certainty and data used for the interpretation of these geological features are described below, in order of confidence (from high to low).

2.1 Fault F3

This NE-SW structure shows up on the structure contour plans at all seam levels and has a throw of about 10 m up to the southeast. Drill hole RD1032 is very close to this structure and at 52 m is intersected by a normal fault with a throw of at least 8 m. This fault defines the limit of proposed mining in the southeast.

2.2 Dyke D1

This igneous dyke tends N-S near to 299,000E and is known from the Bayswater #3 Open Cut, to the north of EL5460, where it was 1 m wide intruding the Blakefield Seam. In 1998 the weathered dyke was exposed by trenching, but the exact location is not known. The dyke was 1.8 m wide in the trench. Along the extent of this dyke there are several drill holes which either encountered a subvertical igneous dolerite dyke or have localised silling in coal seams. These are RD1157, EMAS107, and EMAS 119. The 3D seismic surveys suggest that the D1 dyke lineament may coincide with minor faulting.

2.3 Dyke D2

About 1 km to the west of D1 is a second N-S dyke that was trenched at 2 locations in 1998. The weathered dolerite was a total of 1.8 m in width, spread over a 5 m wide zone. Drill holes with evidence of an igneous dyke or silling are EMAS 26 and EMAS 51. A 2D seismic line crossed this feature at about 6,409,800N and indicates that a fault exists with a throw of about 7 m up to the west at the level of the Woodlands Hill Seam. A line of closely spaced drill holes along the seismic line did not confirm a fault with a 7 m throw, but a lesser displacement is possible.

2.4 Dyke D3

This feature is interpreted from the magnetic surveys and at its southern extent it intersects the DF9 feature, and it is likely that the curved DF9 is made up of a NE-SW component and a NNE-SSW component (D3), along which there is also faulting with displacements of up to 6 m. A line of drill holes at A14 shows a normal fault with a throw of 4 m at the level of the Woodlands Hill Seam. Igneous material in drill hole BBH5S could be attributed to localised silling from D3 dyke.

2.5 Dyke/Fault DF9

This feature has evidence of faulting at Line A14 and in drill hole EMAS118, and also a dyke in drill hole RD1004. The normal fault throw is down to the southeast.

2.6 Dyke/Fault DF15

Sub-parallel to DF9 is a similar feature which has evidence of both faulting and of a dyke being present along at least part of the strike length. Closely spaced drill holes along Line A2 show a normal fault with a throw of about 4 m, while in DD1074 and DD1016 there is evidence of localised silling related to a dyke that exists along DF15.

2.7 Dyke/Fault DF16

In the northern part of EL5460 another NE-SW fault /dyke extends from the Mt Arthur Mine, where it is mapped as a dyke (D16). Along Line A6, closely spaced drill holes show a normal fault with a throw of about 5 m, down to the southeast. North of EL5460, drill hole EMA50 intersected a fault, which is likely to be associated with this structure. Evidence of an igneous dyke exists in drill holes DD1045R, RD1082 and RD1095 along DF16.

2.8 Fault F5

This normal fault is parallel to the East Graben Fault, but the throw of about 3 m is down to the east on both Lines A4 and A5. In the report by Gary Fallon the faults 5a and 5b are indicated by the seismic data, but the closely spaced holes on LineA3 did not indicate any significant fault here, but a very minor structure with a throw of about 1 m is possible along F5a.

2.9 Fault F6

This NW-SE structure has a throw of about 2 m along Line A11, with east side down like F5. At Line A17 the fault throw is of the order of 1 m only.

2.10 Fault F7

This NW-SE structure has a throw of about 2 m at Lines A9 and A13, down to the west. The seismic indicates that this fault might continue further to the southeast as Fault F7S, and that there may also be an F7E structure, shown on Figure 1 as a possible fault.

2.11 Fault F8

This normal fault has a throw of about 4m on Line A12, down to the north, and is sub-parallel to F3, DF9, DF15 and DF16.

2.12 Fault F9

This structure is similar to F7 in orientation and throw, and structure contours indicate a throw of about 4 m.

2.13 Faults F11, F12 and F13

These are possible faults, interpreted from the seismic surveys, and are not able to be confirmed by drill hole data, and are not indicated by structure contour trends. They are not in the same alignment as the main NE-SW features, but for completeness are shown on Figure 1 and should be considered as possible faults.

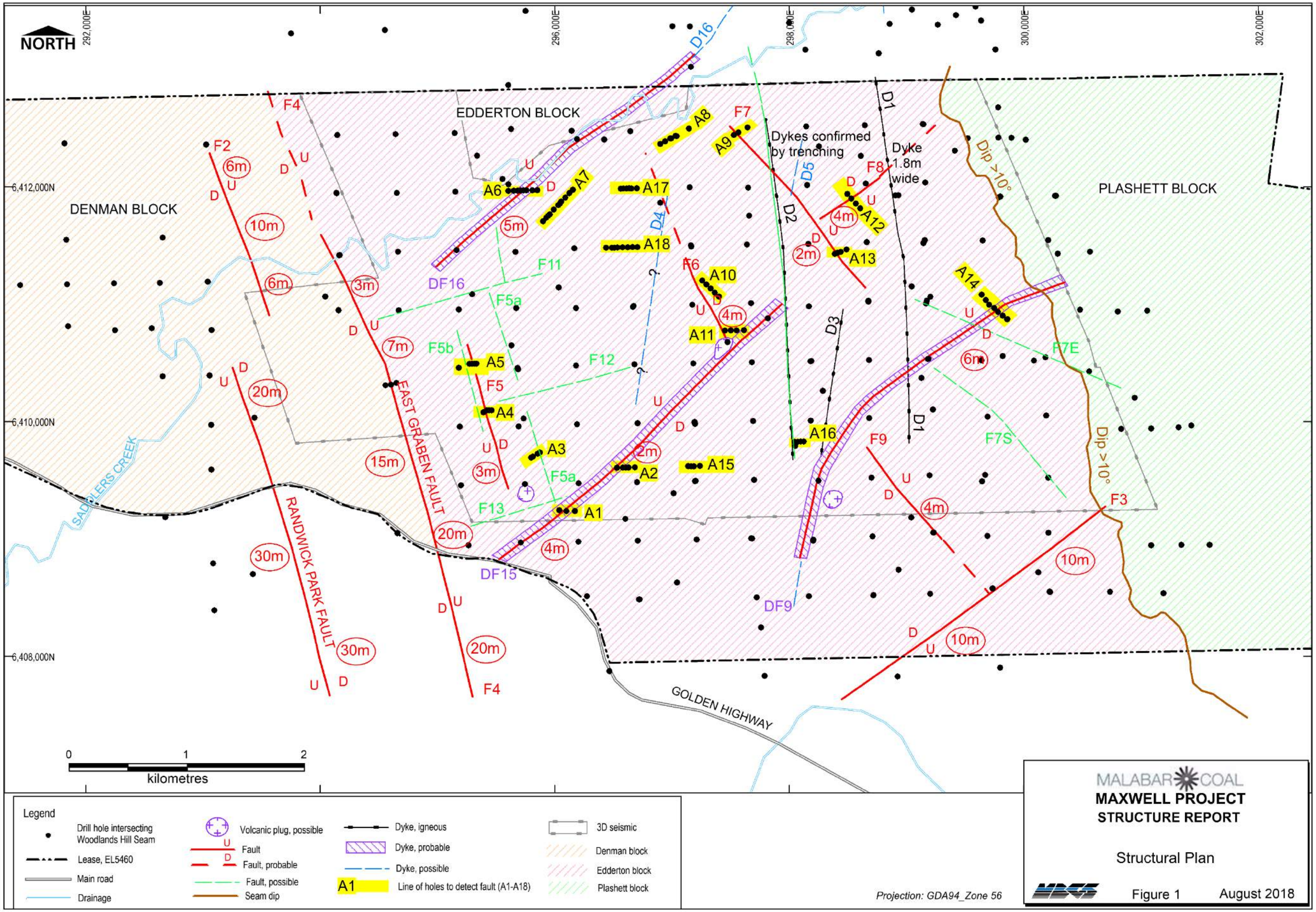
2.14 Dykes D4 and D5

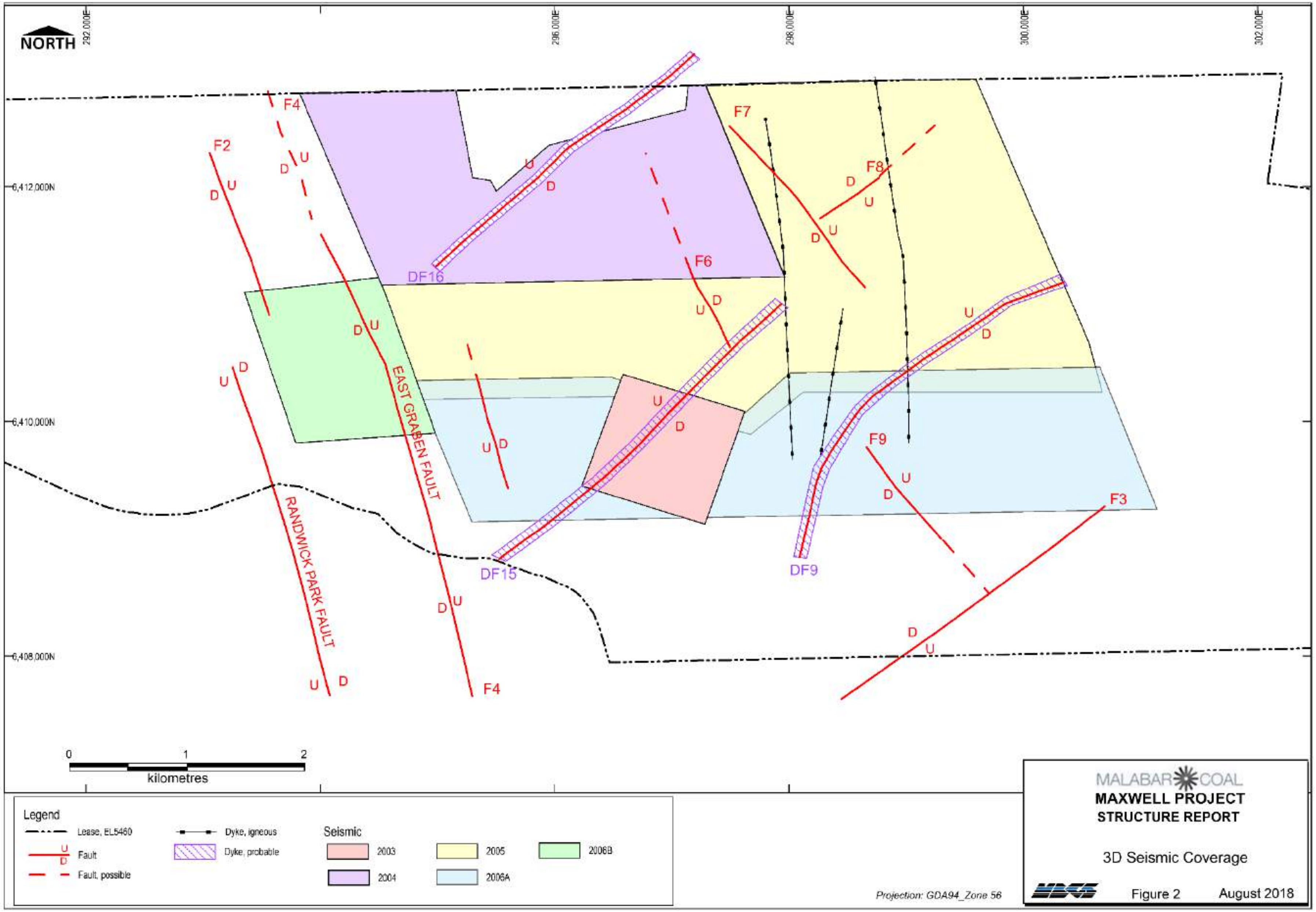
These are sub-parallel to D3 and are interpreted from the magnetic survey data. They should be considered potential geological structures, like D9 which is an extension of the DF9 feature to the southwest, and in an orientation that is common for dykes in this region. The igneous rocks that were intersected at depth in cored drill holes are described as hard fresh grey/brown dolerite, have resulted in cindered or coked coal and/or indurated sediments where there has been silling into a coal seam, or where the drill hole has cored part of the sub-vertical dyke.

2.15 Volcanic Plugs

From the magnetic data there are three locations where volcanic plugs are interpreted, as shown on Figure 1. One of these is on DF15 structure near line A11, another is near the southern end of Fault F5, and the third is close to the southern end of DF9.

The possible plug near DF15 was drilled by RD1067 and no volcanic breccia was found in that drill hole. The other possible plug was drilled by RD1066 and like RD1067 encountered sediments and coal down to the level of the Whynot Seam.


NORTH
EDDERTON BLOCK
DENMAN BLOCK
PLASHETT BLOCK
Dykes confirmed by trenching
Dyke 1.8m wide
Dip >10°
RANDWICK PARK FAULT
EAST GRABEN FAULT
SADDLERS CREEK
GOLDEN HIGHWAY
kilometres
Legend
Drill hole intersecting Woodlands Hill Seam
Lease, EL5460
Main road
Drainage
Volcanic plug, possible
Fault
Fault, probable
Fault, possible
Seam dip
Dyke, igneous
Dyke, probable
Dyke, possible
Line of holes to detect fault (A1-A18)
3D seismic
Denman block
Edderton block
Plashett block
Projection: GDA94_Zone 56
MALABAR COAL
MAXWELL PROJECT
STRUCTURE REPORT
Structural Plan
Figure 1
August 2018


NORTH
292,000E
296,000E
298,000E
300,000E
302,000E
6,412,000N
6,410,000N
6,408,000N
F2
F3
F4
F6
F7
F8
F9
DF15
DF16
DF9
EAST GRABEN FAULT
RANDWICK PARK FAULT
0
1
2
kilometres
Legend
Lease, EL5460
Fault
Fault, possible
Dyke, igneous
Dyke, probable
Seismic
2003
2004
2005
2006A
2006B
Projection: GDA94_Zone 56
MALABAR COAL
MAXWELL PROJECT
STRUCTURE REPORT
3D Seismic Coverage
Figure 2
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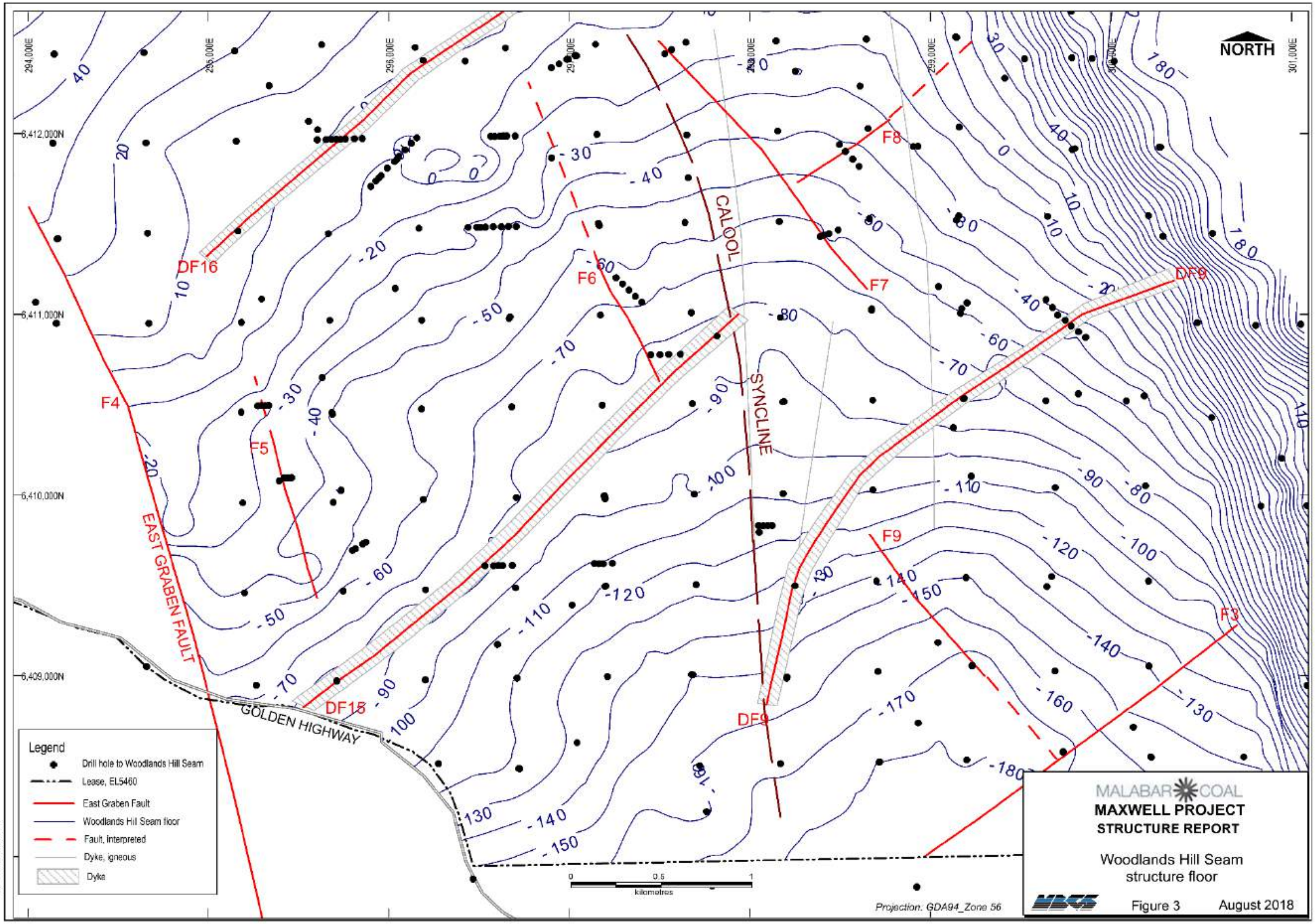
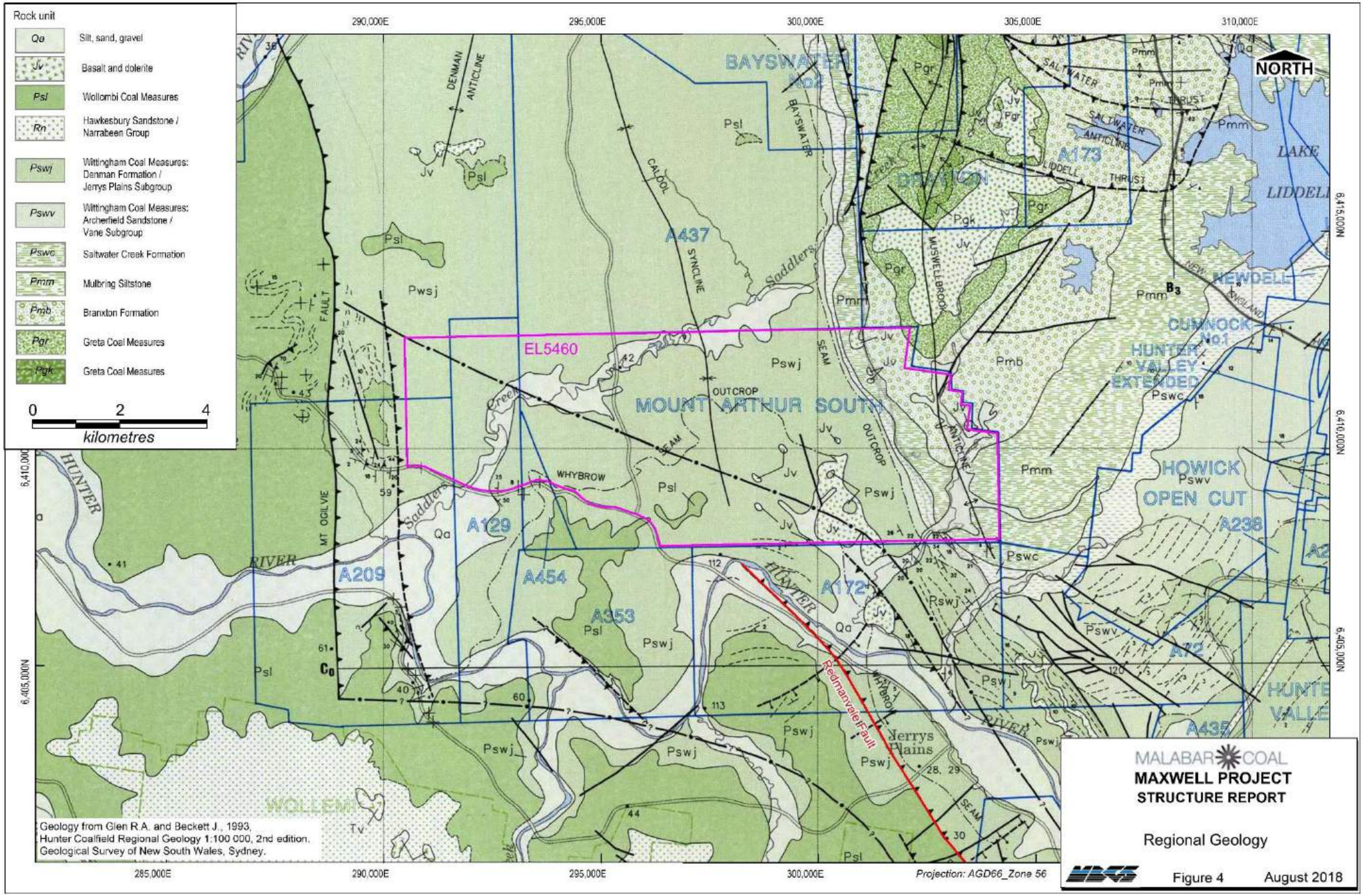
3 REGIONAL STRUCTURE

The Edderton Block is located within the Calool Syncline, which plunges gently to the south. The axis of the syncline (Figure 3) is sub-parallel to the East Graben Fault, and strata on both limbs dip at between 2º and 5º in a southerly direction. To the east of EL5460 the Muswellbrook Anticline is a prominent regional feature along which the marine sediments of the Maitland Group and the Greta Coal Measures crop out. Figure 4 shows the regional geology as depicted on the 1:100,000 Hunter Coalfield Map. The known structure in the Maxwell Project Area that is shown on Figure 1, differs from that on the 1:100,000 map in that there are faults on that earlier map that are trending northwest into the Edderton Block, which are now known not to exist. In particular, the Redmanvale Fault is shown trending to the northwest from Jerry's Plains and crossing the Hunter River up into EL5460, but within the EL there is no evidence of a fault with that orientation in that location. A much more likely trend for the Redmanvale Fault is to swing to the north, in a direction that is more or less parallel to the axis of the Muswellbrook Anticline which is also the strike direction of the more steeply dipping strata of the Plashett Block, in the eastern part of EL5460.

In the eastern part of EL5460 the coal sequence dips more steeply, at up to 30 degrees to the west in the Plashett Block. The eastern limit of the Edderton Block is where the strata dip at more than 10 degrees to the southwest. The seam structure and continuity within the Edderton Block is defined by a total of 954 drill holes, and at the level of the Whybrow Seam the drill hole spacing is about 250 m, while at the level of the Whynot Seam and the Woodlands Hill Seam the drill hole spacing is about 500 m. The geological database for the Maxwell Project is based on the drill hole data, supported by the geophysical surveys carried out as part of the exploration conducted between 1998 and 2011.


NORTH
Legend
Drill hole to Woodlands Hill Seam
Lease, EL5460
East Graben Fault
Woodlands Hill Seam floor
Fault, interpreted
Dyke, igneous
Dyke
EAST GRABEN FAULT
CALOOL
SYNCLINE
GOLDEN HIGHWAY
F4
F5
F6
F7
F8
F9
F3
DF16
DF15
DF9
MALABAR COAL
MAXWELL PROJECT
STRUCTURE REPORT
Woodlands Hill Seam structure floor
Figure 3
August 2018
Projection: GDA94_Zone 56
kilometres
6,412,000N
6,411,000N
6,410,000N
6,409,000N

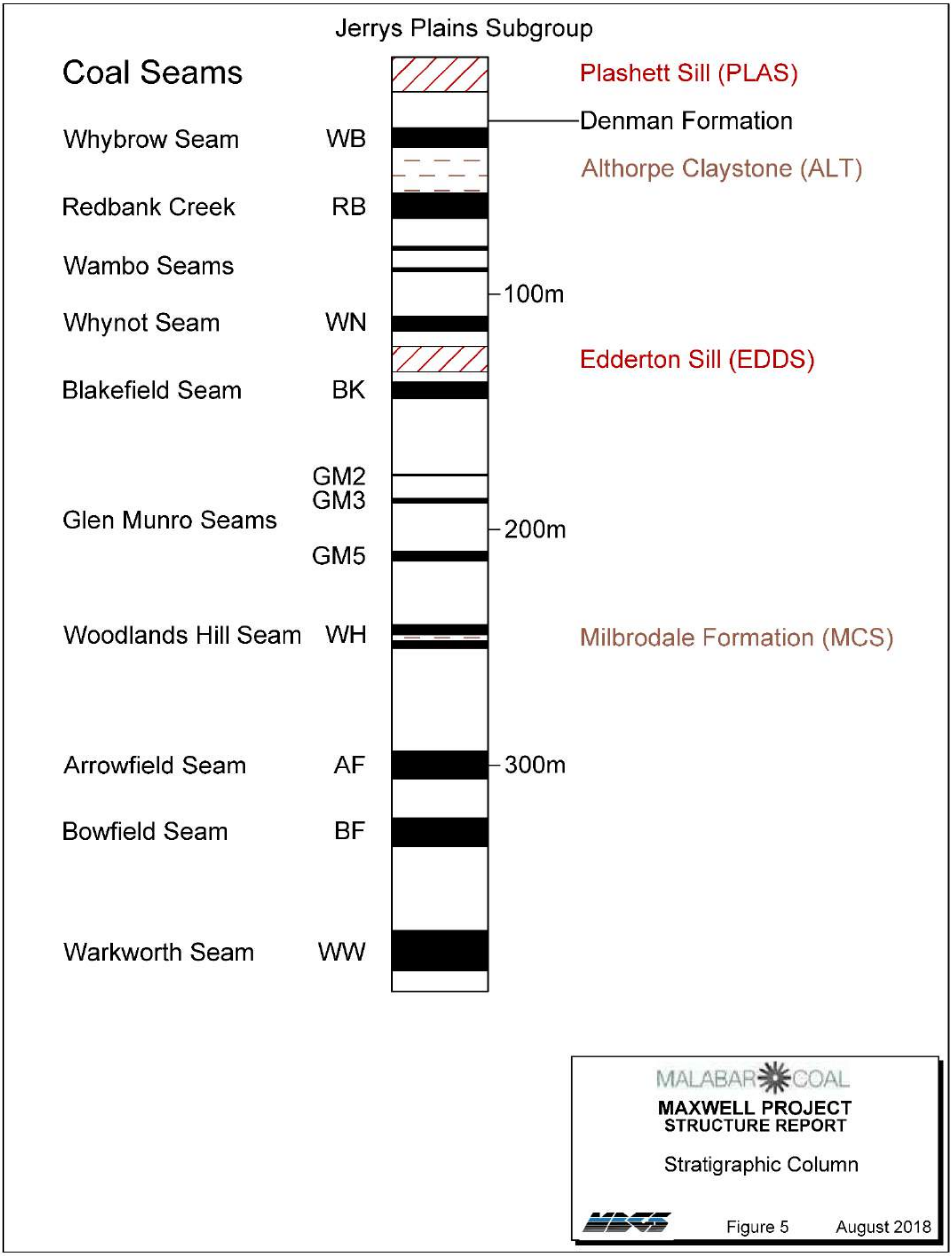

Rock unit
Qa Silt, sand, gravel
Jv Basalt and dolerite
Psl Wollombi Coal Measures
Rn Hawkesbury Sandstone / Narrabeen Group
Pswj Wittingham Coal Measures: Denman Formation / Jerrys Plains Subgroup
Pswv Wittingham Coal Measures: Archerfield Sandstone / Vane Subgroup
Pswc Saltwater Creek Formation
Pmm Mulbring Siltstone
Pmb Branxton Formation
Pgr Greta Coal Measures
Pgk Greta Coal Measures
0 2 4
kilometres
NORTH
EL5460
MOUNT ARTHUR SOUTH
BAYSWATER No2
DRAYTON
HOWICK OPEN CUT
HUNTER VALLEY EXTENDED
CUMNOCK No1
NEWDELL
LAKE LIDDELL
Redmanvale Fault
Jerrys Plains
WOLLEMI
Geology from Glen R.A. and Beckett J., 1993, Hunter Coalfield Regional Geology 1:100 000, 2nd edition, Geological Survey of New South Wales, Sydney.
Projection: AGD66_Zone 56
285,000E
290,000E
295,000E
300,000E
305,000E
310,000E
6,405,000N
6,410,000N
6,415,000N
MALABAR COAL
MAXWELL PROJECT
STRUCTURE REPORT
Regional Geology
Figure 4
August 2018

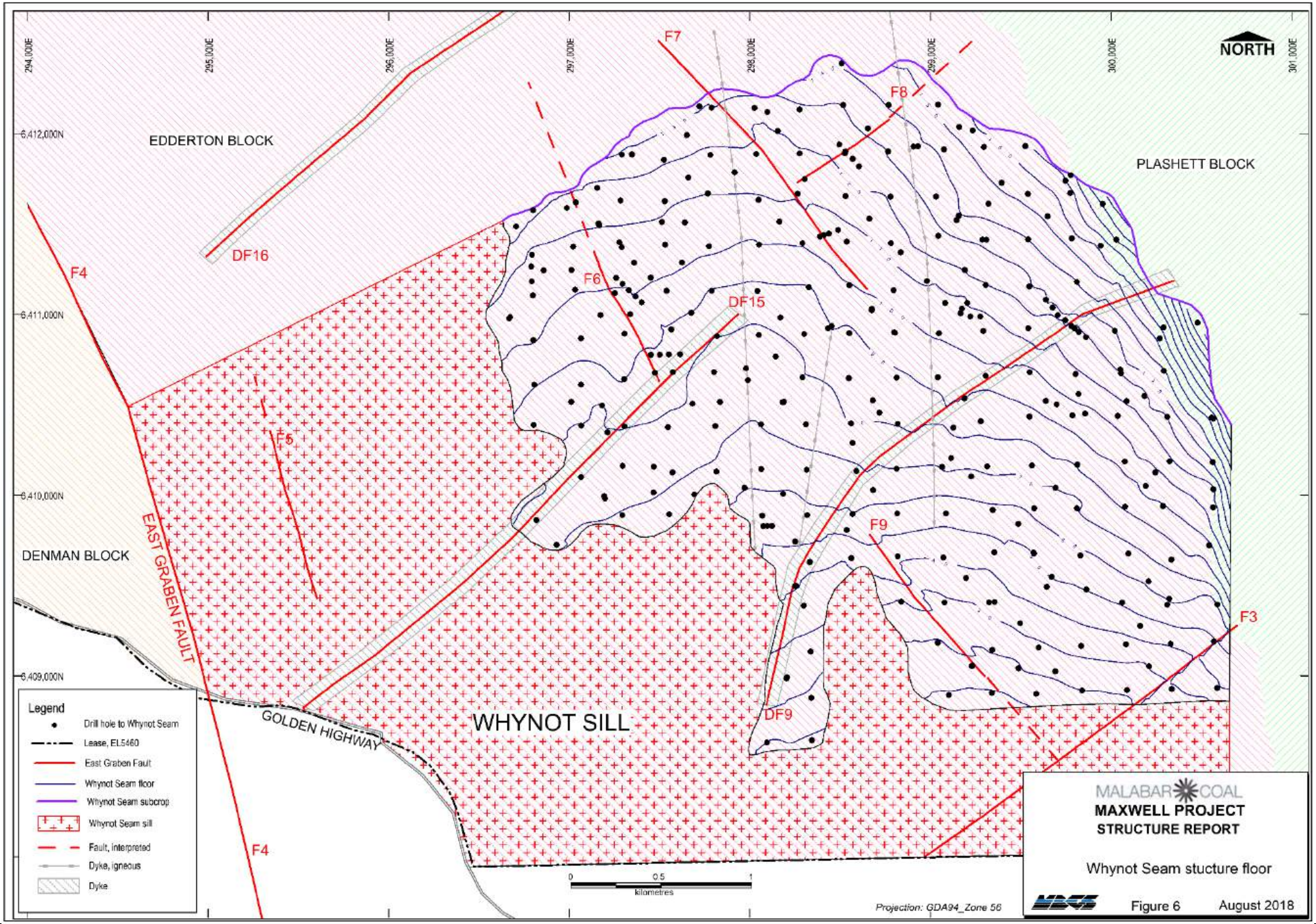
4 IGNEOUS SILLS

There are several igneous sills that affect coal seams in the Edderton Block (Figure 5). These are mainly dolerites and a Middle Triassic age has been determined for some of these, while others may be of Jurassic age. In the southeast part of the Edderton Block resource area the Plashett Sill outcrops over an area of about 2 km^2 and is up to 60 m thick. This sill is shown on the published 1:100,000 geology map (Jv)and has been intersected in 22 drill holes. The sill is evident on the magnetic survey plans. To the northeast of EL5460, the Savoy Sill (Jv) crops out over a significant area, where it intrudes the Greta Coal Measures.

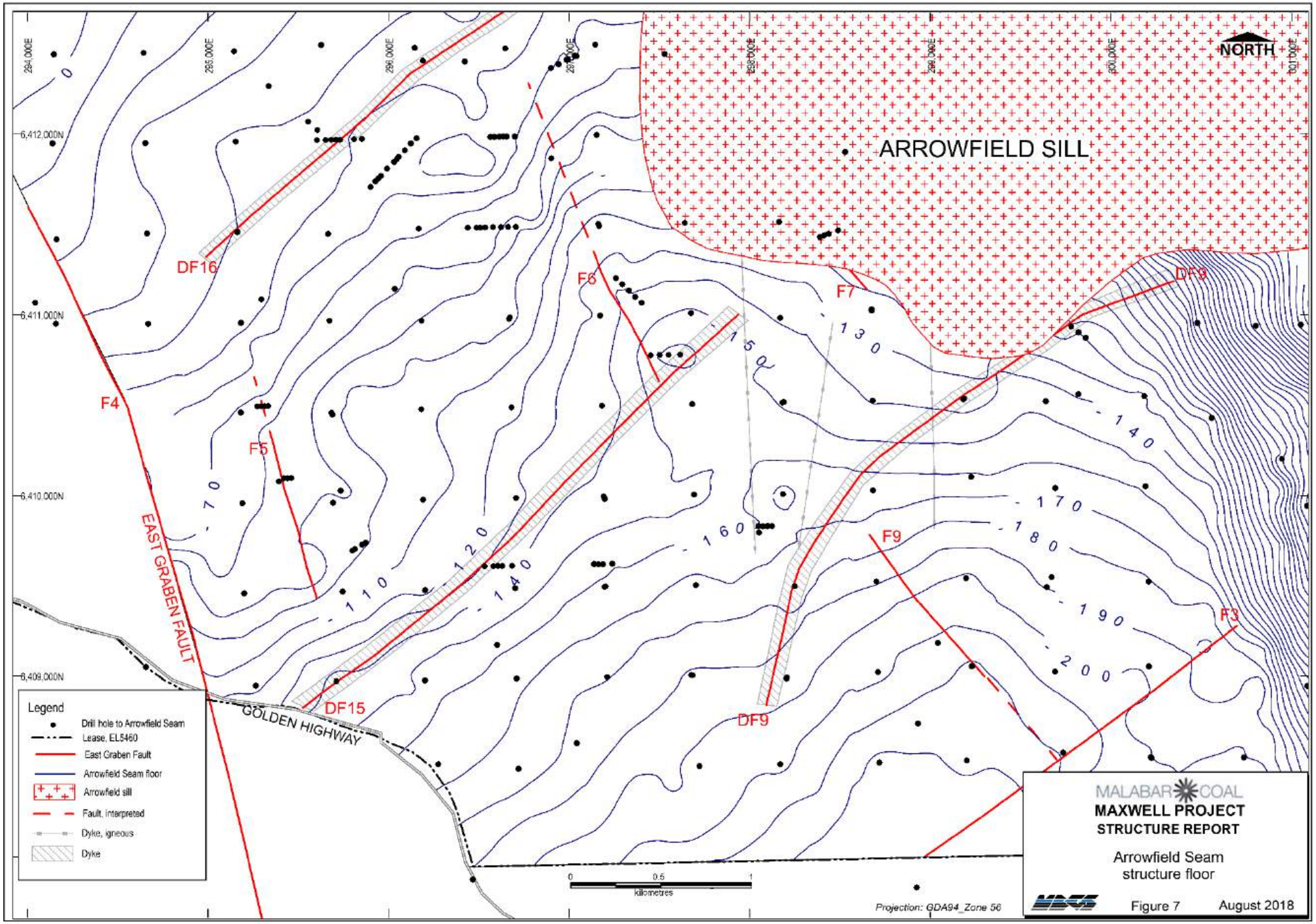
Over a considerable part of the Edderton Block, in the south and west, the Whynot Seam is intruded by dolerite, which has at least partly replaced the coal and/or coked or cindered the coal, rendering that seam unmineable where the sill exists (Figure 6). The igneous material is from 1 m to 10 m thick. Below the Whynot Seam and above the Blakefield Seam a dolerite sill exists over a large part of the Edderton Block and it is about 20 m thick for much of its extent. This has been named the "Edderton Sill" and it has been incorporated into the geological model as it is a significant geological unit that in the east has affected the Blakefield Seam to the extent that it is not a mining target, due to the heating of the coal or replacement of at least part of the seam. The dolerite from the Edderton Sill has recently been tested and has a reasonably high magnetic susceptibility. Two samples are being subjected to a petrological examination to determine the nature of the igneous material, which is very strong with measured UCS of up to 186 MPa.

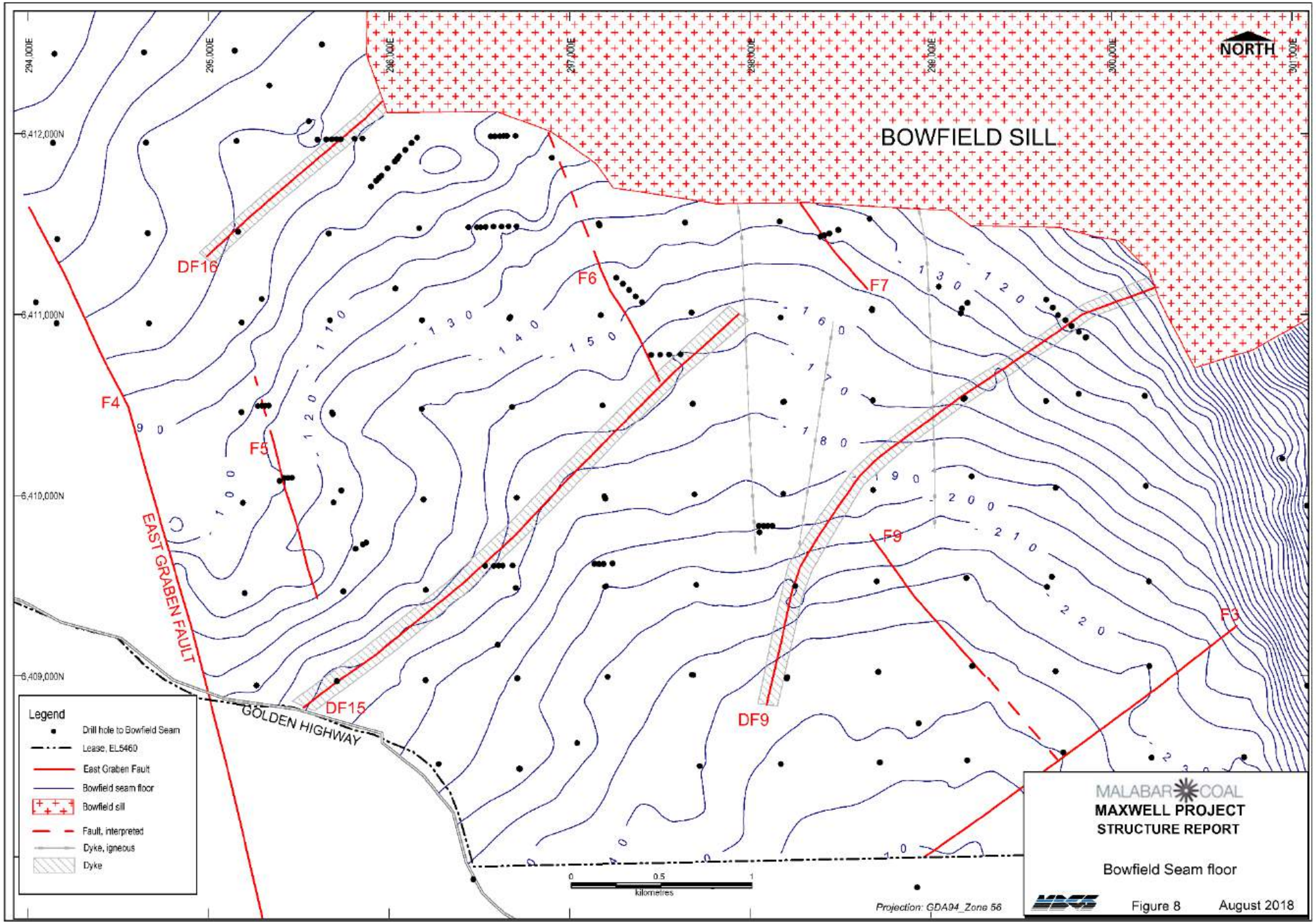
In the Edderton Block the Woodlands Hill Seam is unaffected by any igneous sill at the seam level, but both the Arrowfield and Bowfield Seams are intruded and/or heat affected over significant areas in the northeast (Figures 6 and 7). The extent of the silling is taken to be at the halfway point between a drill hole with sill and a drill hole without a sill. The Warkworth Seam, like the Woodlands Hill Seam, is not affected by any widespread sill intrusion and is potentially mineable over a large part of the Edderton Block.


Jerrys Plains Subgroup
Coal Seams
Whybrow Seam WB
Redbank Creek RB
Wambo Seams
Whynot Seam WN
Blakefield Seam BK
Glen Munro Seams GM2 GM3 GM5
Woodlands Hill Seam WH
Arrowfield Seam AF
Bowfield Seam BF
Warkworth Seam WW
100m
200m
300m
Plashett Sill (PLAS)
Denman Formation
Althorpe Claystone (ALT)
Edderton Sill (EDDS)
Milbrodale Formation (MCS)
MALABAR COAL
MAXWELL PROJECT
STRUCTURE REPORT
Stratigraphic Column
Figure 5
August 2018



294,000E
295,000E
296,000E
297,000E
298,000E
299,000E
300,000E
301,000E
NORTH
6,412,000N
6,411,000N
6,410,000N
6,409,000N
EDDERTON BLOCK
PLASHETT BLOCK
DENMAN BLOCK
WHYNOT SILL
EAST GRABEN FAULT
GOLDEN HIGHWAY
F3
F4
F5
F6
F7
F8
F9
DF9
DF15
DF16
Legend
Drill hole to Whynot Seam
Lease, EL5460
East Graben Fault
Whynot Seam floor
Whynot Seam subcrop
Whynot Seam sill
Fault, interpreted
Dyke, igneous
Dyke
0
0.5
1
kilometres
Projection: GDA94_Zone 56
MALABAR COAL
MAXWELL PROJECT
STRUCTURE REPORT
Whynot Seam stucture floor
Figure 6
August 2018


NORTH
ARROWFIELD SILL
DF16
F6
F7
DF9
F4
F5
EAST GRABEN FAULT
F9
F3
DF15
DF9
GOLDEN HIGHWAY
Legend
Drill hole to Arrowfield Seam
Lease, EL5460
East Graben Fault
Arrowfield Seam floor
Arrowfield sill
Fault, interpreted
Dyke, igneous
Dyke
MALABAR COAL
MAXWELL PROJECT
STRUCTURE REPORT
Arrowfield Seam
structure floor
Figure 7
August 2018
Projection: GDA94_Zone 56
kilometres


NORTH
BOWFIELD SILL
6,412,000N
6,411,000N
6,410,000N
6,409,000N
DF16
DF15
DF9
F4
F5
F6
F7
F9
F3
EAST GRABEN FAULT
GOLDEN HIGHWAY
Legend
Drill hole to Bowfield Seam
Lease, EL5460
East Graben Fault
Bowfield seam floor
Bowfield sill
Fault, interpreted
Dyke, igneous
Dyke
0
0.5
1
kilometres
Projection: GDA94_Zone 56
MALABAR COAL
MAXWELL PROJECT
STRUCTURE REPORT
Bowfield Seam floor
Figure 8
August 2018

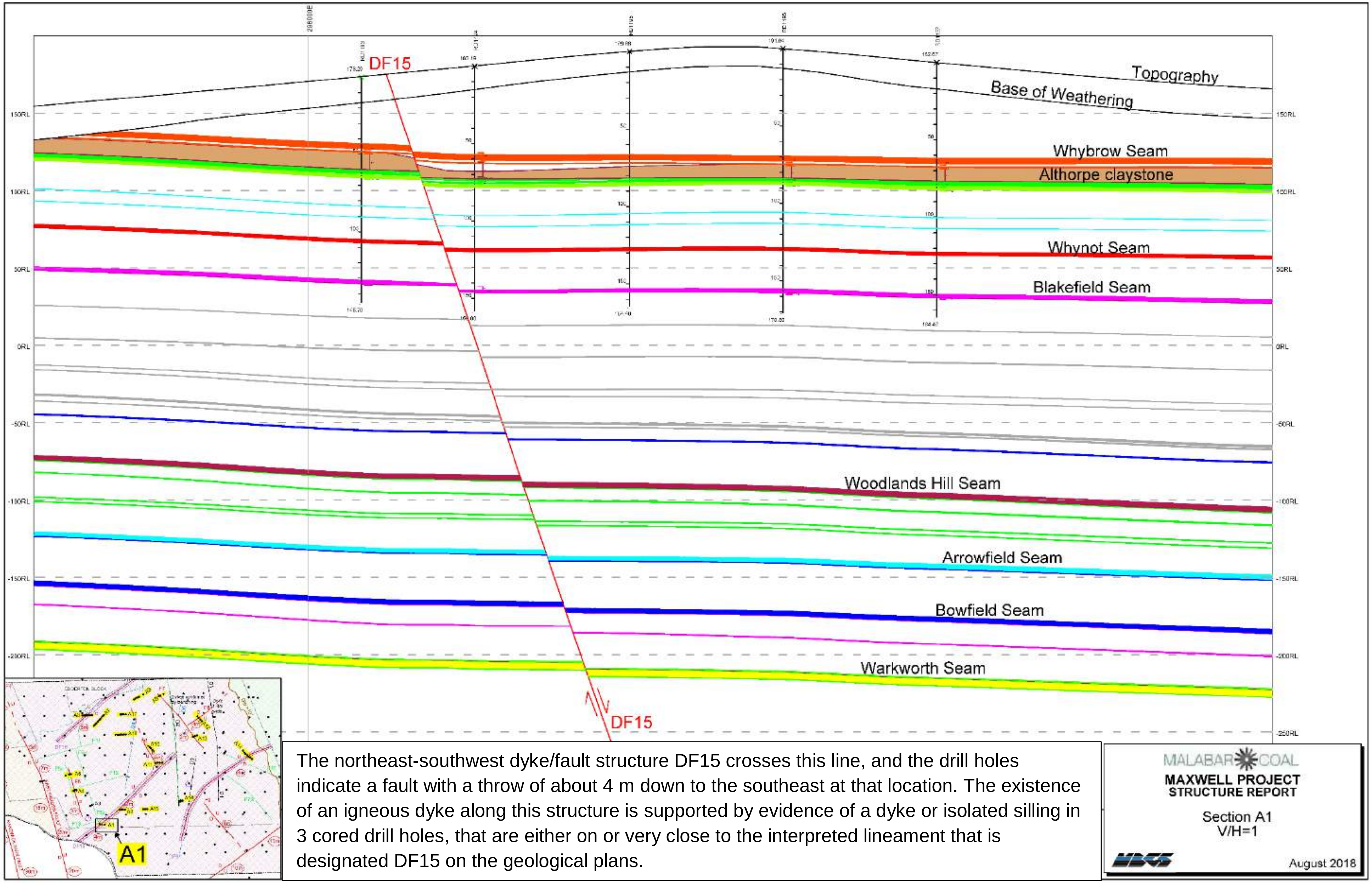
5 OVERVIEW OF THE STRUCTURE IN EL5460

Malabar has acquired a very comprehensive set of geological and geophysical data in relation to the Maxwell Project, which provides a sound basis for mine planning of the underground coal resources in EL5460. While there are known faults and igneous dykes, as outlined in this report, that disrupt the continuity of the mineable coal seams, this enables the mine planning to accommodate for these geological features in advance.

The number and extent of the faults and dykes is not unusual in this geological domain, and the precise nature of each feature will become better defined as mining of the Whynot and Woodlands Hill Seams progresses. Most of the structural features are predicted to extend down to the level of the Warkworth Seam. Progressive mining of the seams down the sequence will mean that information gathered when mining the Woodlands Hill Seam will provide additional data on each structure with respect to the seam below, the Arrowfield Seam. In turn, mining of the Arrowfield Seam will improve the understanding of each structure below in the Bowfield Seam, and then on to the Warkworth Seam.

Appendix A Sections A1 to A18

Cross Sections A1 to A18, included in this appendix are derived from the Minex Geological Model. Each cross section is located along a line of drill holes that were targeting a fault that was predicted either from the seismic surveys or indicated by the structure contour plans. The location of the section lines is shown on Figure 1 and on each section figure.



The northeast-southwest dyke/fault structure DF15 crosses this line, and the drill holes indicate a fault with a throw of about 4 m down to the southeast at that location. The existence of an igneous dyke along this structure is supported by evidence of a dyke or isolated silling in 3 cored drill holes, that are either on or very close to the interpreted lineament that is designated DF15 on the geological plans.

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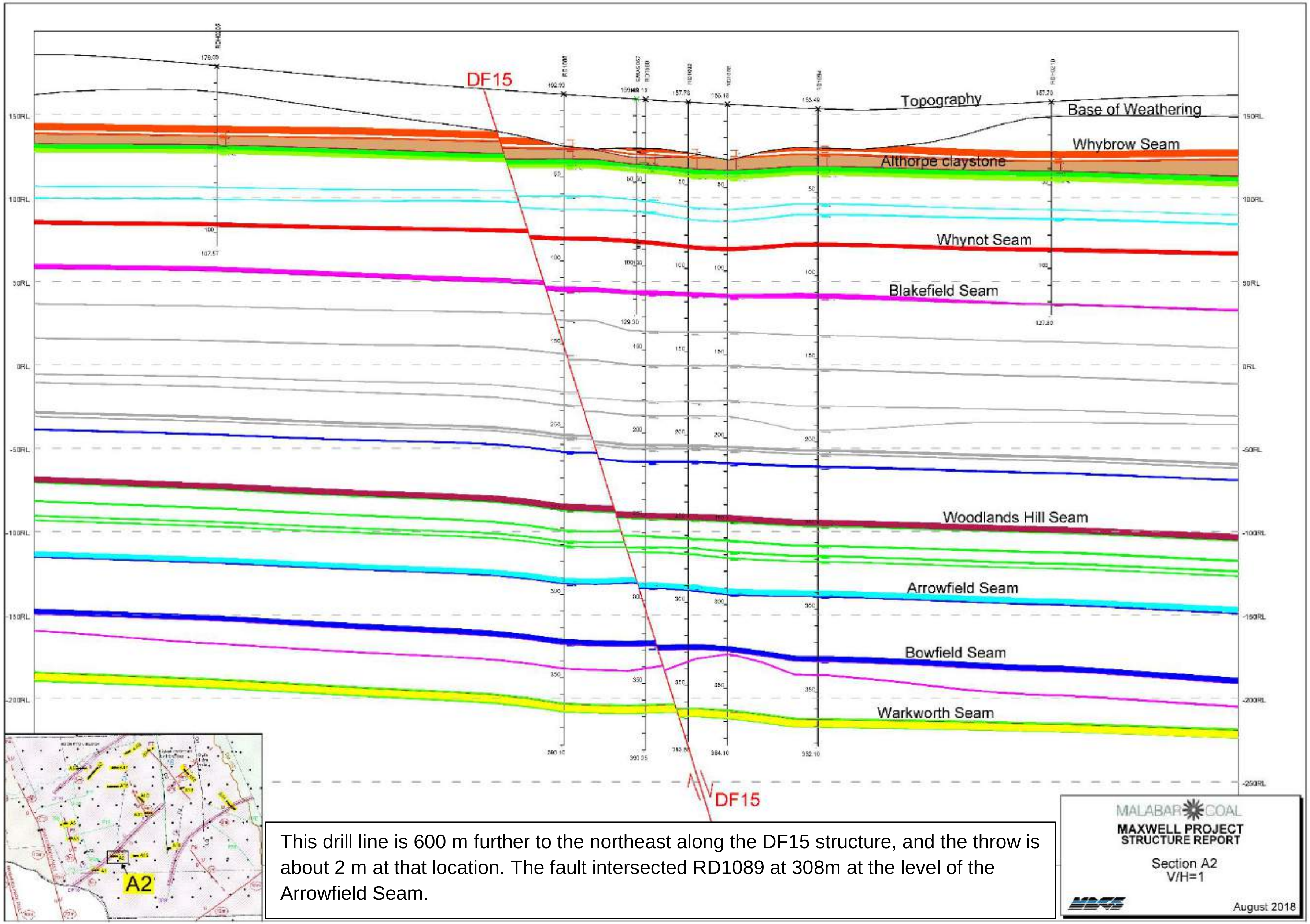
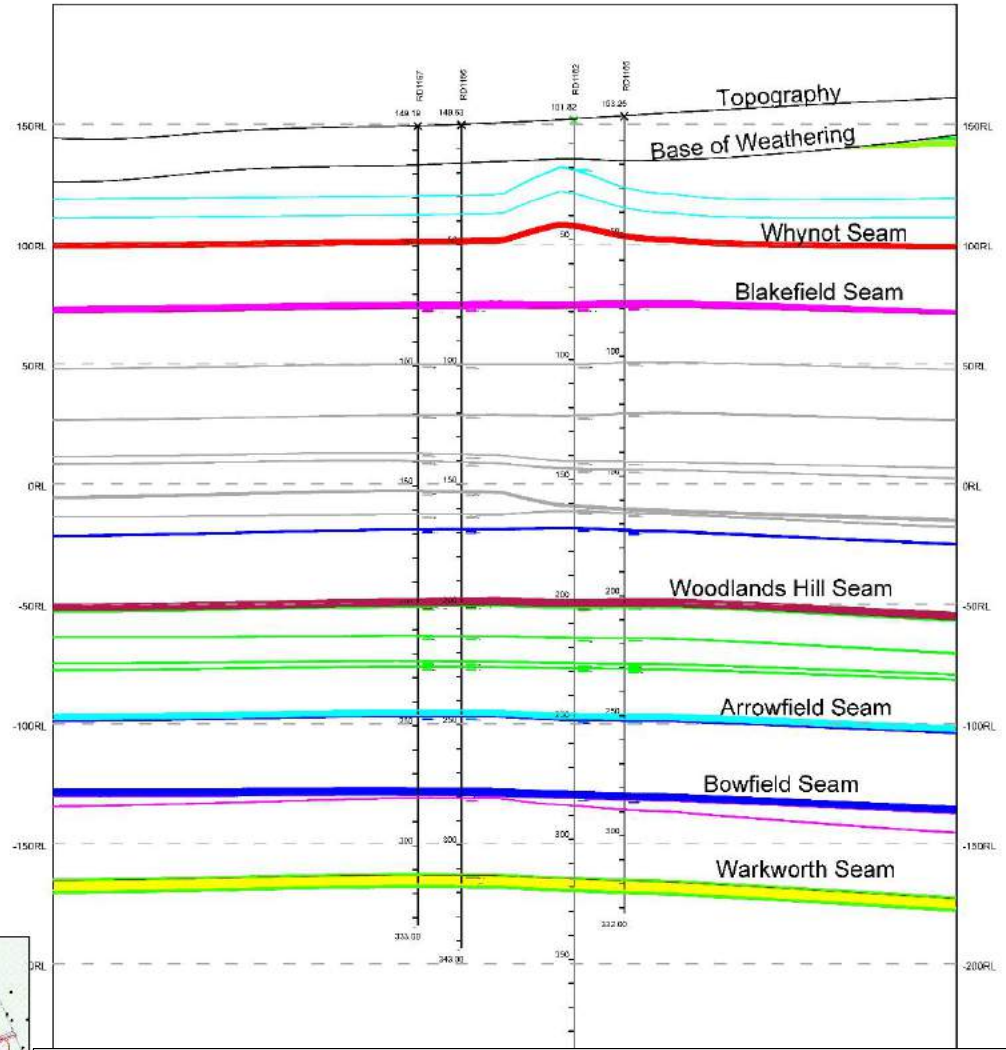
MAXWELL PROJECT
STRUCTURE REPORT

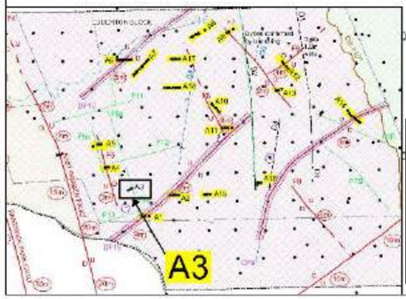
Section A1
V/H=1

August 2018



This drill line is 600 m further to the northeast along the DF15 structure, and the throw is about 2 m at that location. The fault intersected RD1089 at 308m at the level of the Arrowfield Seam.





This drill line has targeted an interpreted structure that is east of Fault F5, but a fault is not confirmed by the drilling. A seam roll at the level of the Whynot Seam is indicated to exist but is not relevant as the Whynot Seam is intruded here and not considered a resource target.

MALABAR COAL
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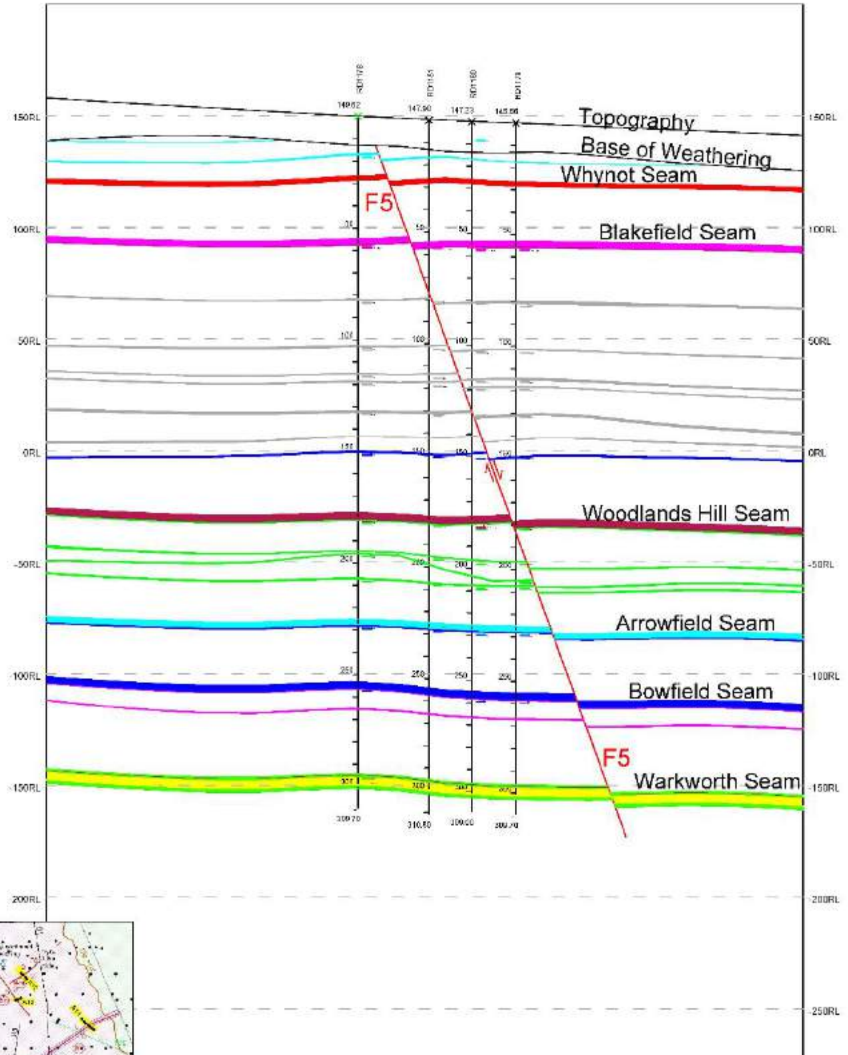
STRUCTURE REPORT

Section A3
V/H=1

August 2018

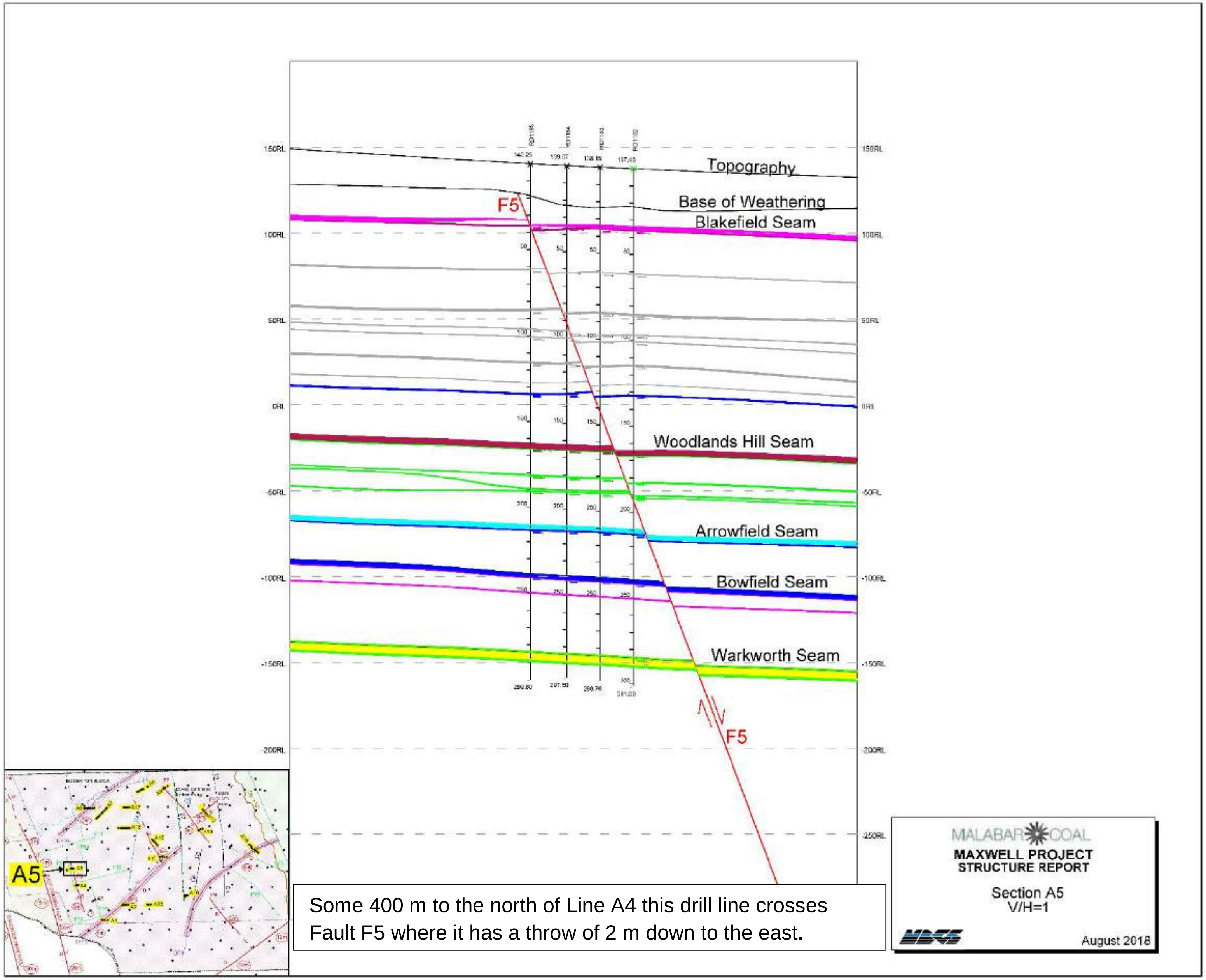


This drill line crosses Fault F5, and at this location the throw is about 3 m down to the east.

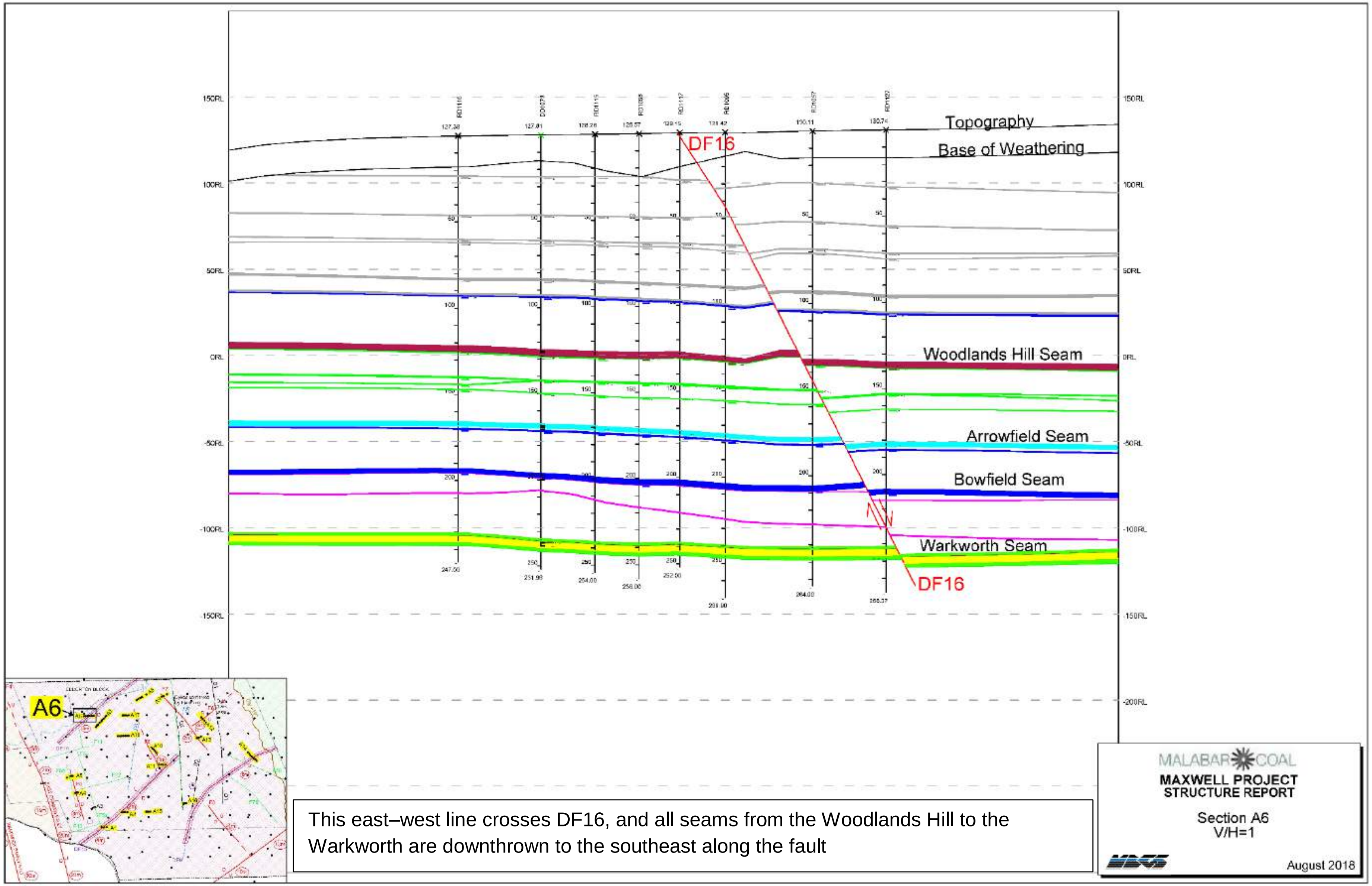
MALABAR COAL
MAXWELL PROJECT
STRUCTURE REPORT

Section A4
V/H=1

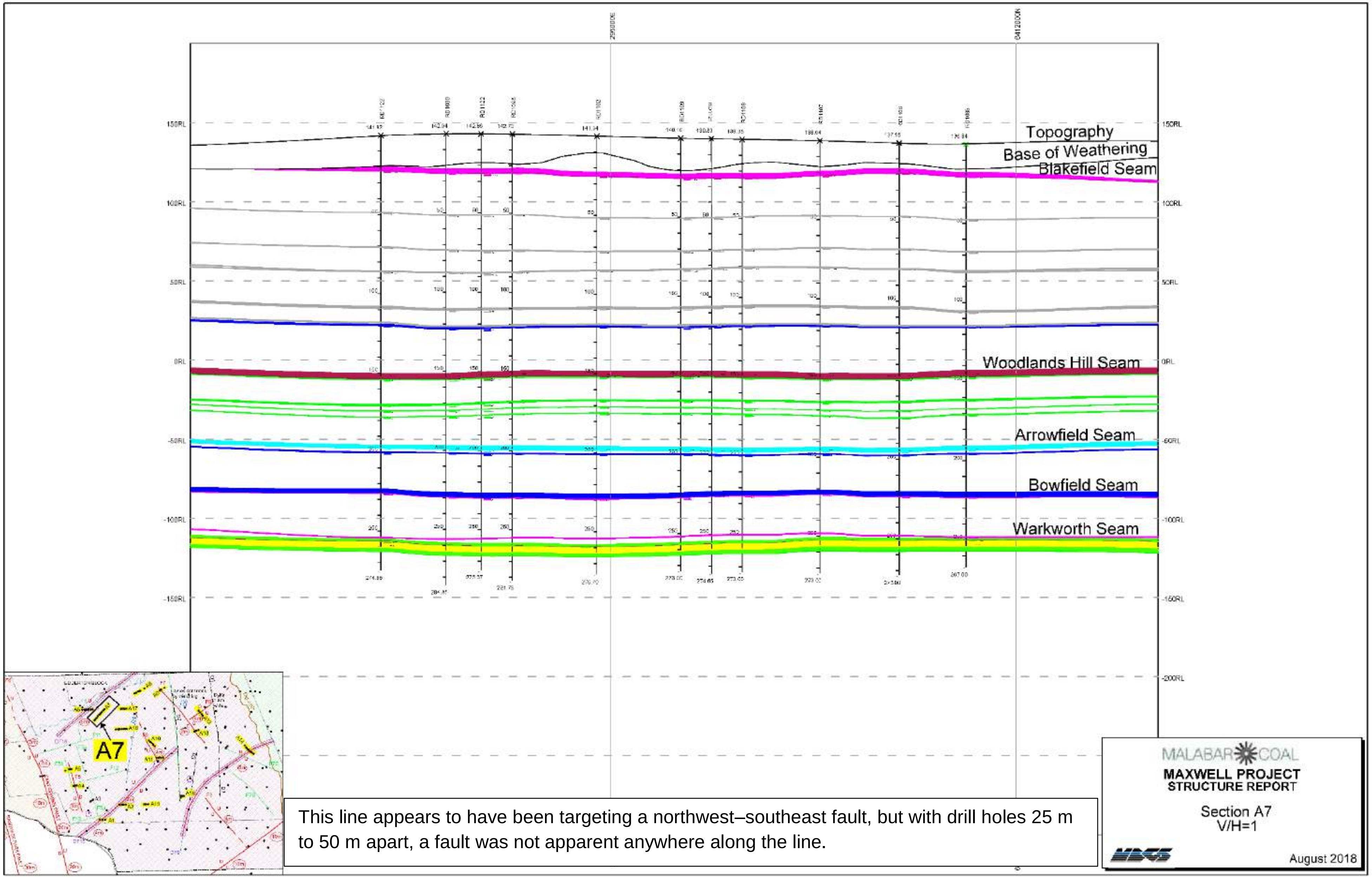
August 2018



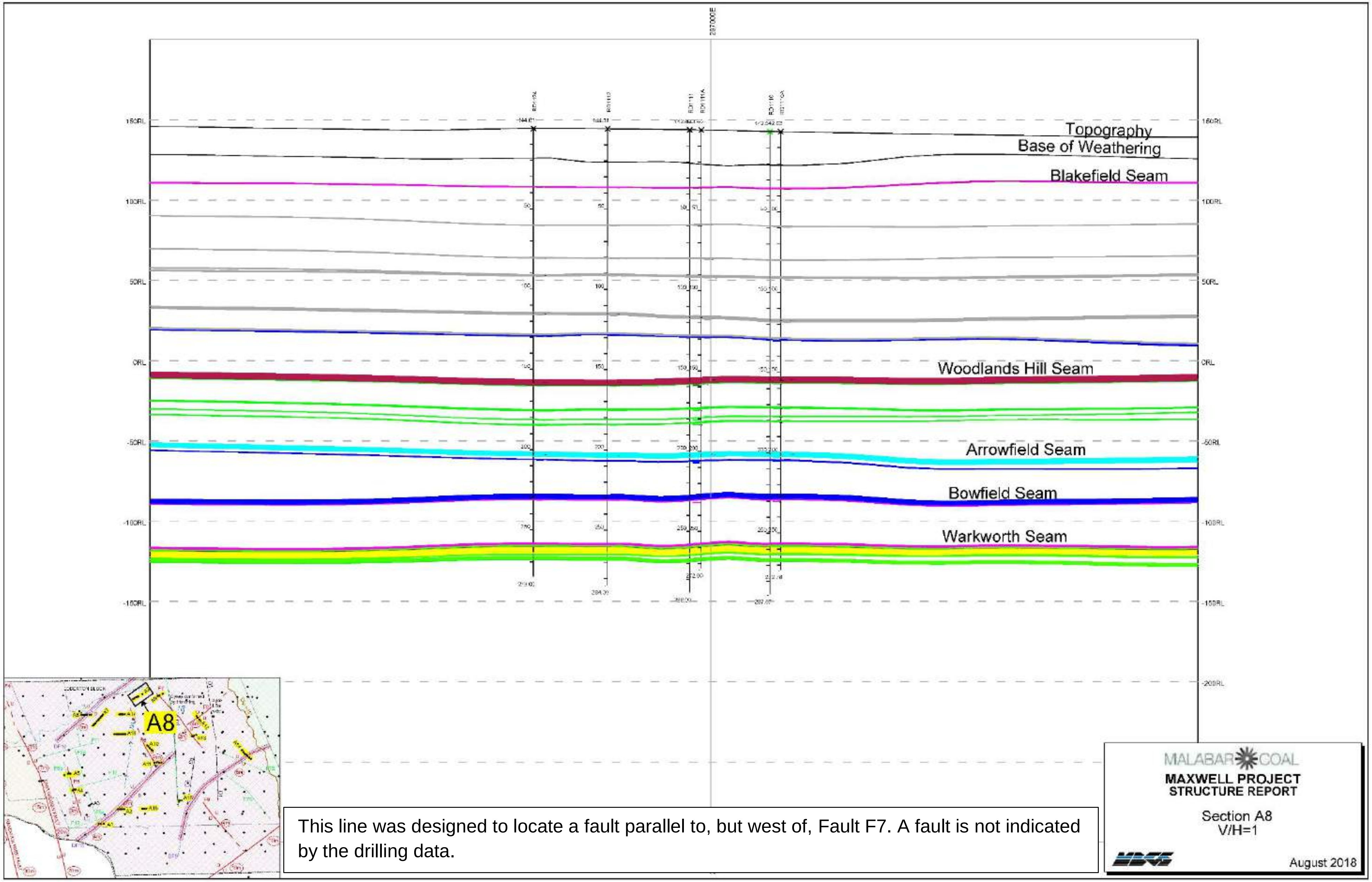
Some 400 m to the north of Line A4 this drill line crosses Fault F5 where it has a throw of 2 m down to the east.



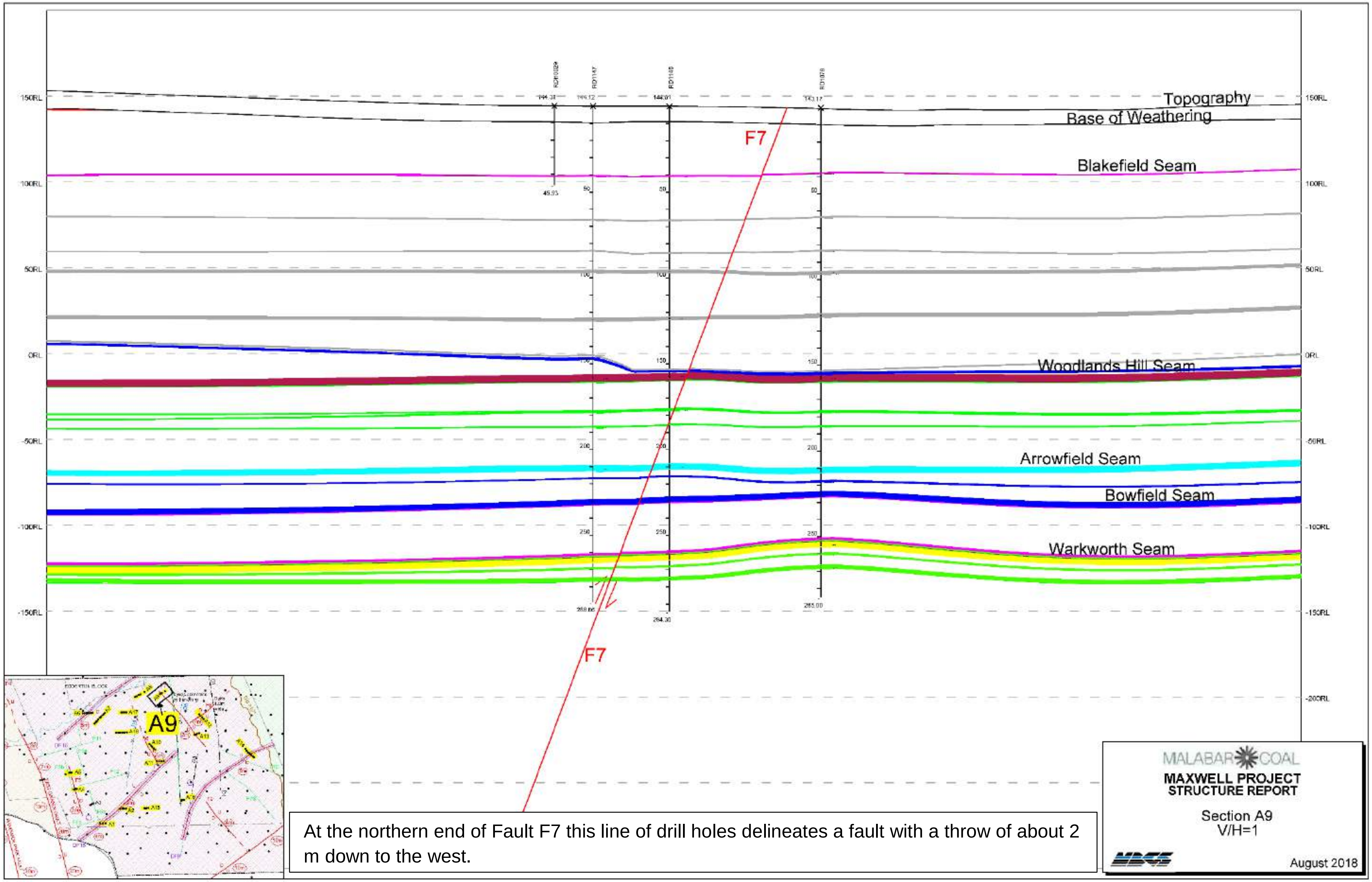
This east–west line crosses DF16, and all seams from the Woodlands Hill to the Warkworth are downthrown to the southeast along the fault



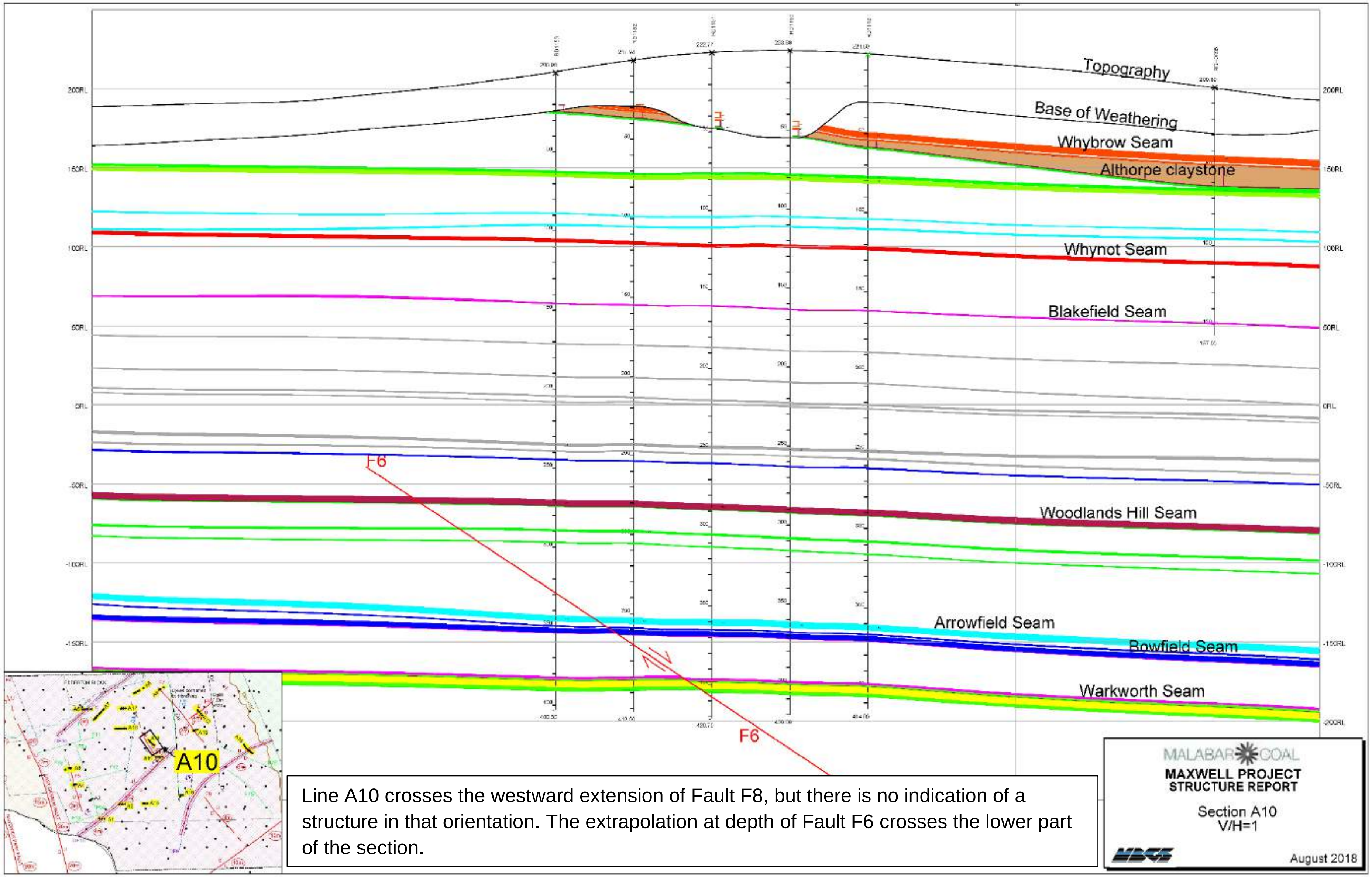
This line appears to have been targeting a northwest–southeast fault, but with drill holes 25 m to 50 m apart, a fault was not apparent anywhere along the line.



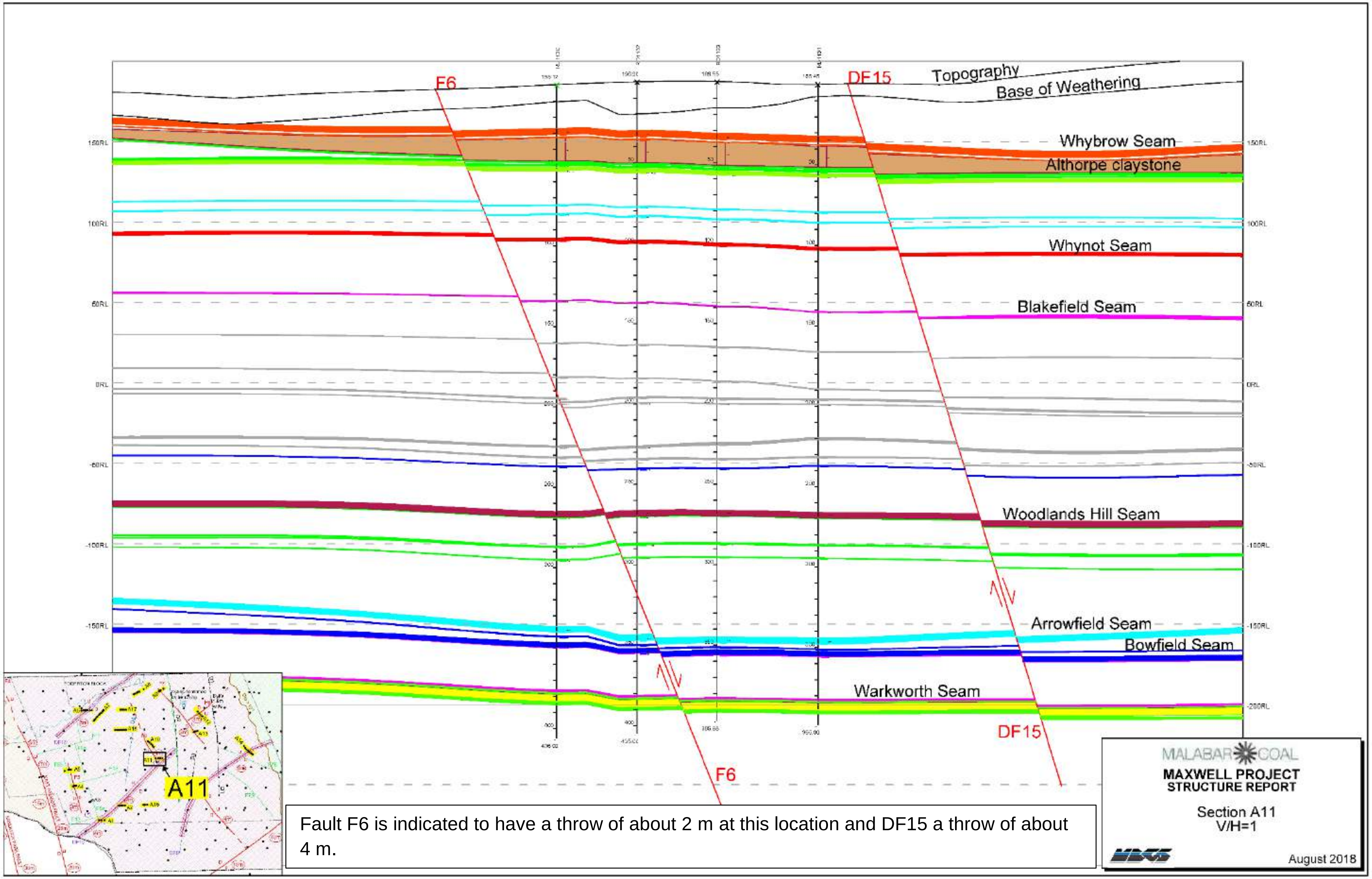
This line was designed to locate a fault parallel to, but west of, Fault F7. A fault is not indicated by the drilling data.



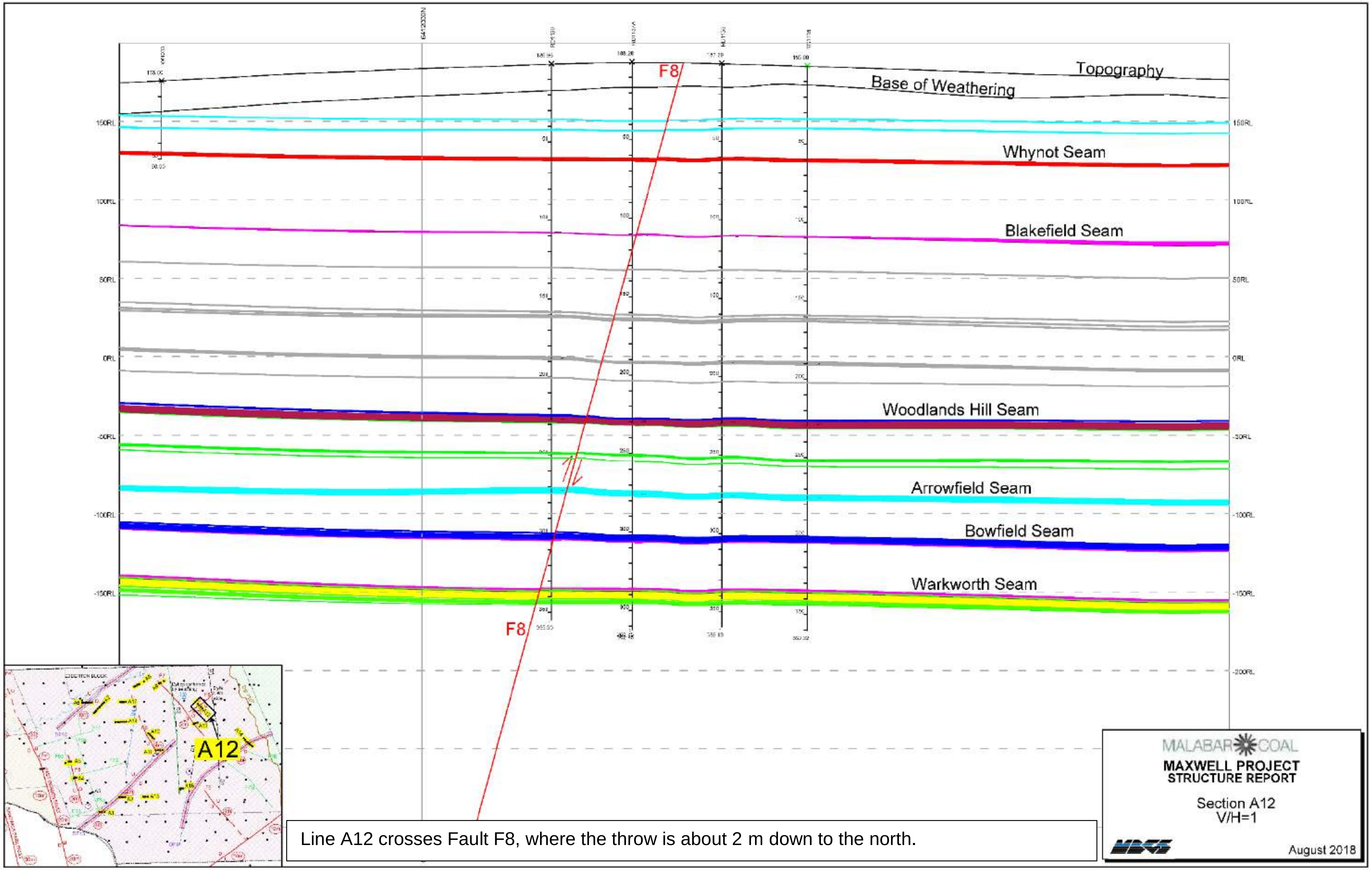
At the northern end of Fault F7 this line of drill holes delineates a fault with a throw of about 2 m down to the west.



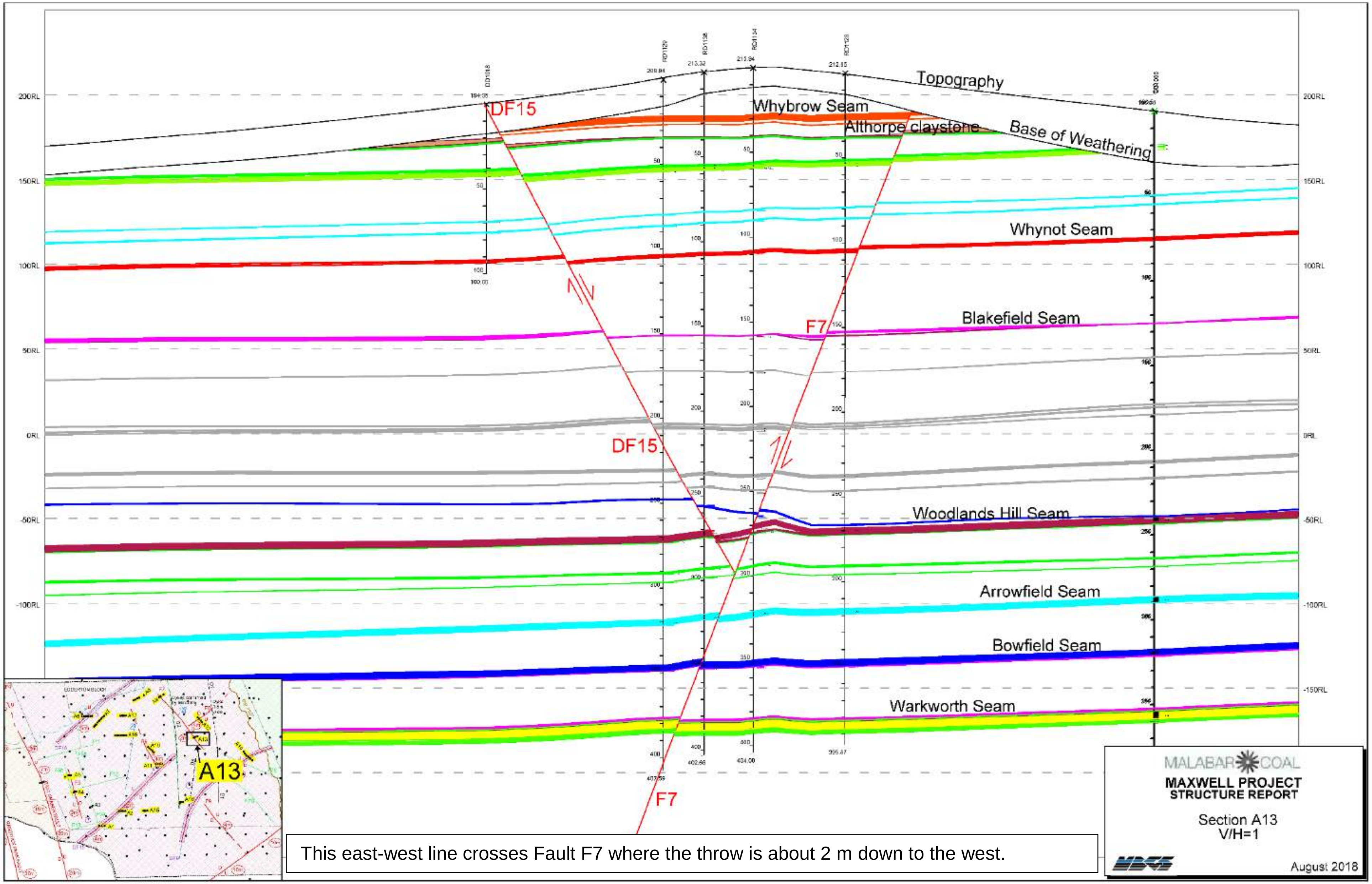
Line A10 crosses the westward extension of Fault F8, but there is no indication of a structure in that orientation. The extrapolation at depth of Fault F6 crosses the lower part of the section.



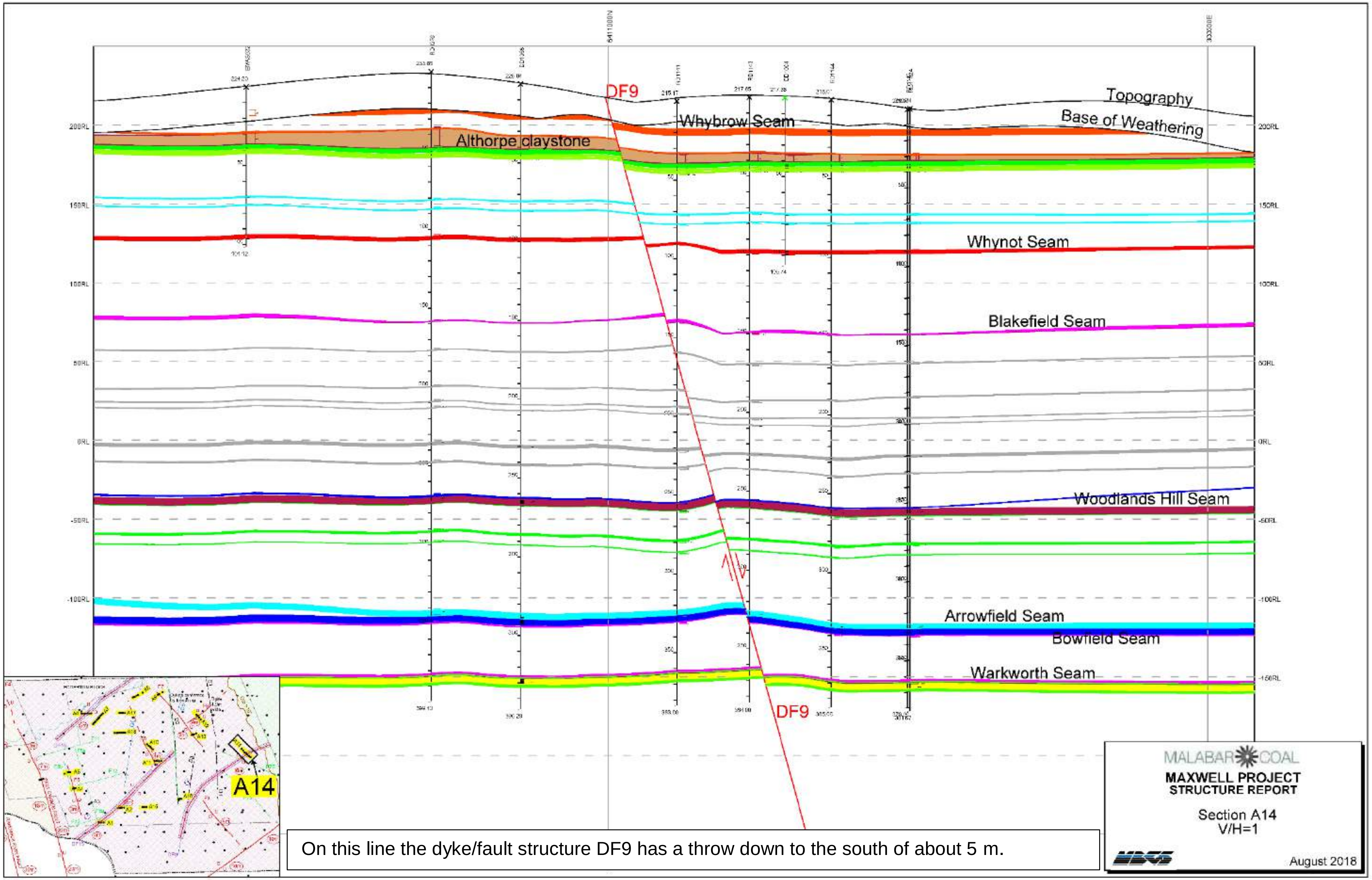
Fault F6 is indicated to have a throw of about 2 m at this location and DF15 a throw of about 4 m.



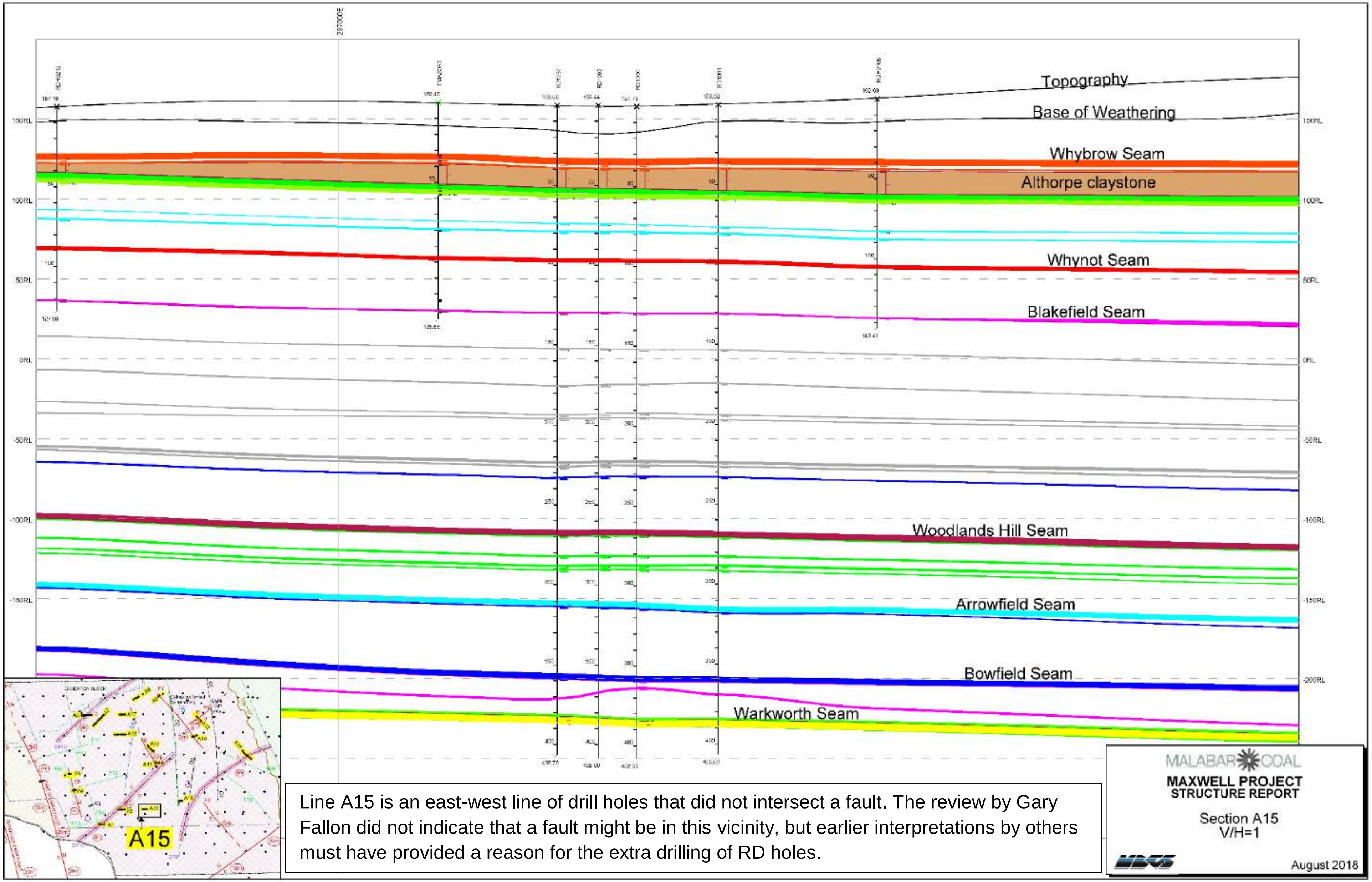
Line A12 crosses Fault F8, where the throw is about 2 m down to the north.



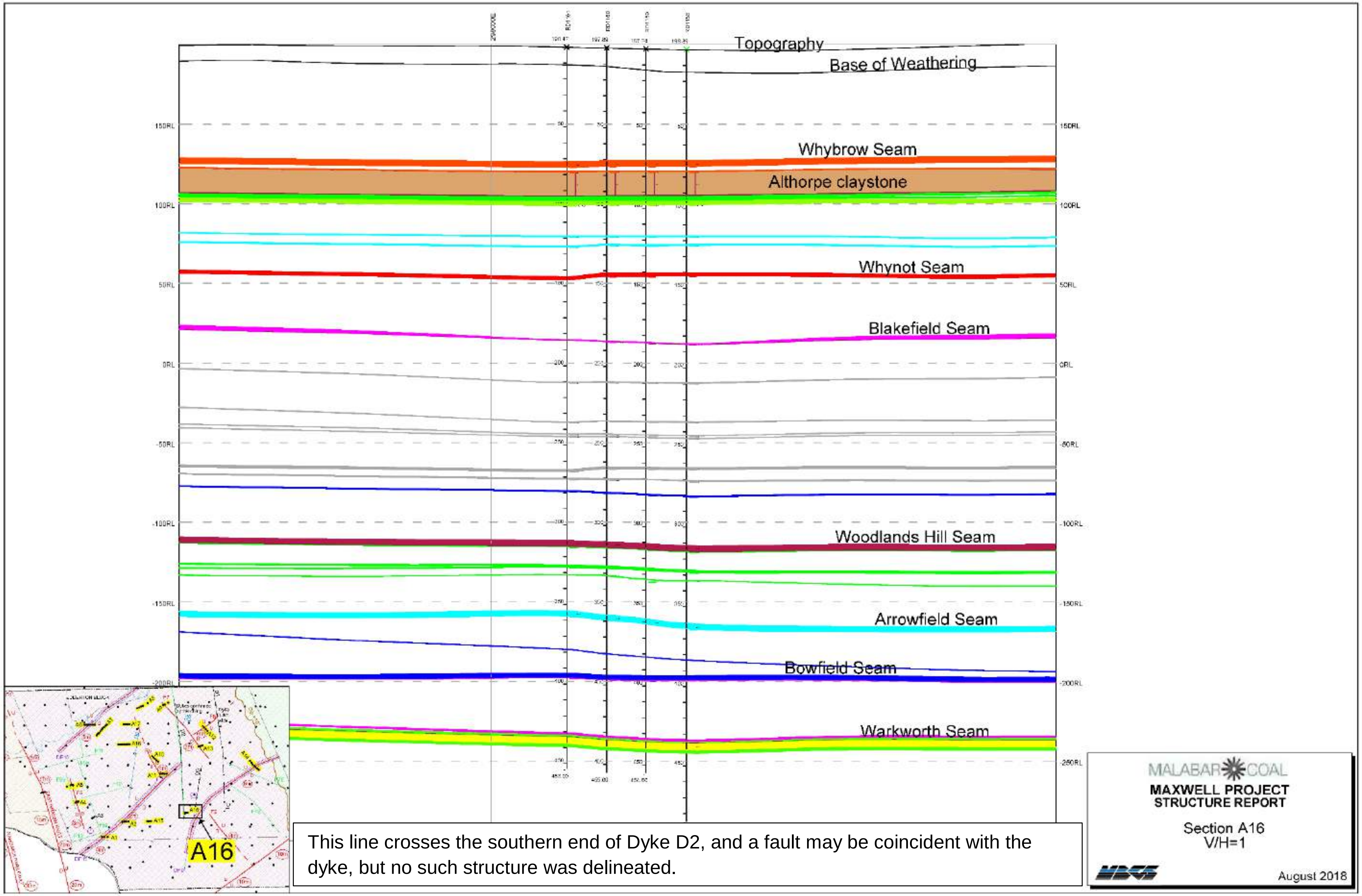
This east-west line crosses Fault F7 where the throw is about 2 m down to the west.



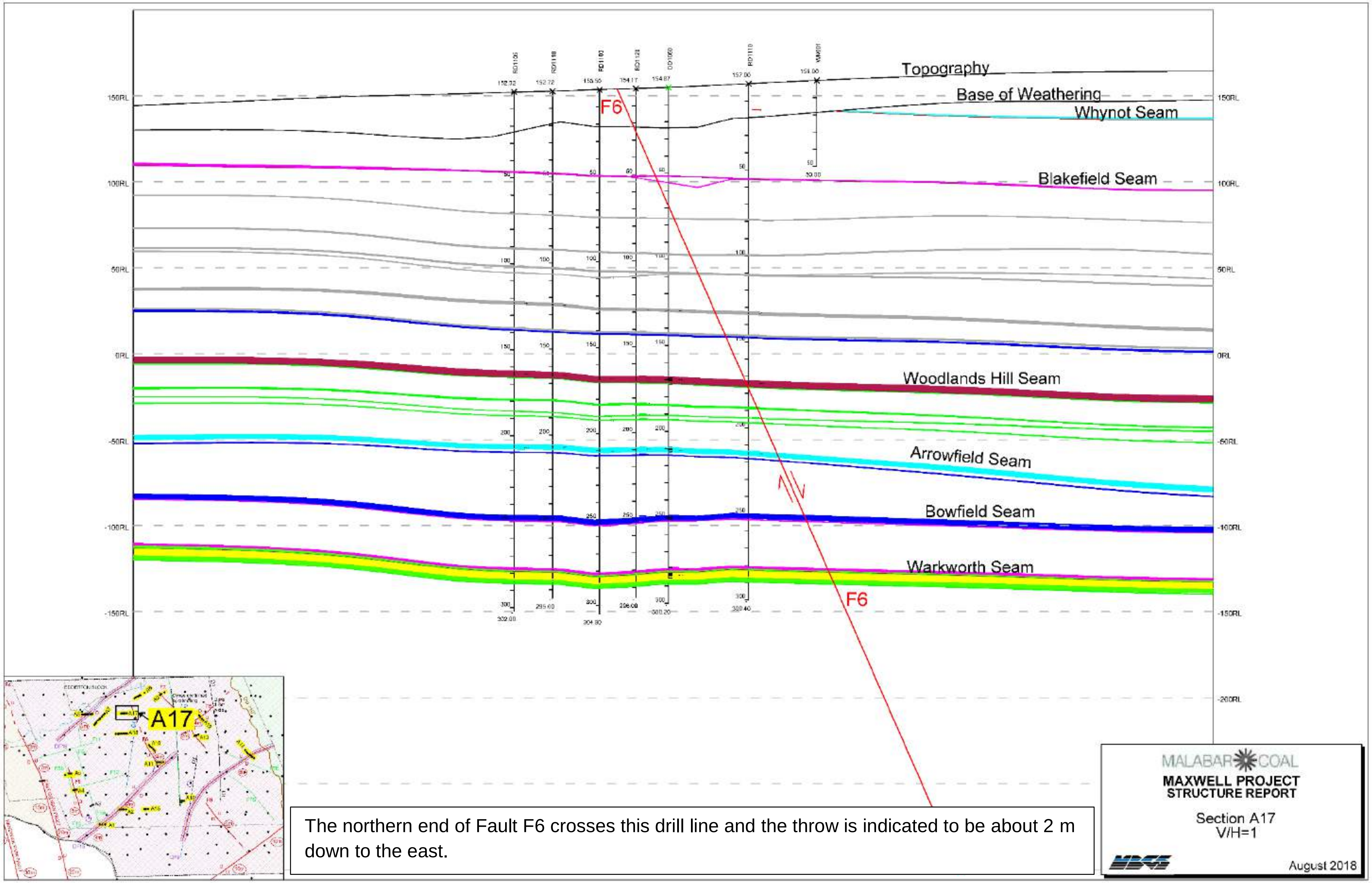
On this line the dyke/fault structure DF9 has a throw down to the south of about 5 m.



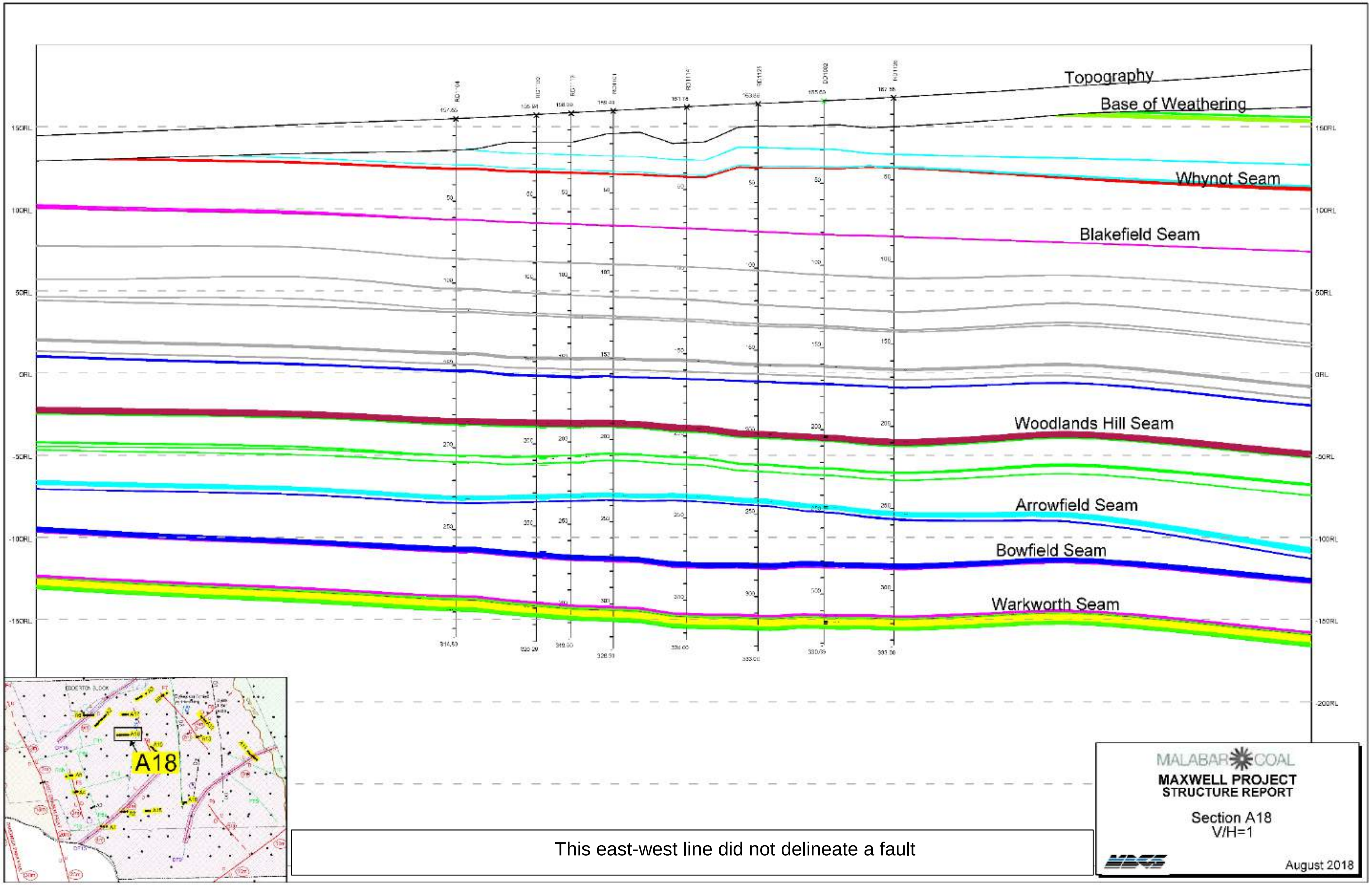
Line A15 is an east-west line of drill holes that did not intersect a fault. The review by Gary Fallon did not indicate that a fault might be in this vicinity, but earlier interpretations by others must have provided a reason for the extra drilling of RD holes.



This line crosses the southern end of Dyke D2, and a fault may be coincident with the dyke, but no such structure was delineated.



The northern end of Fault F6 crosses this drill line and the throw is indicated to be about 2 m down to the east.



This east-west line did not delineate a fault

ATTACHMENT B

TEM SURVEY REPORT

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AgTEM survey investigating groundwater on Maxwell Underground Coal Mine prospect, near Muswellbrook, NSW

May 2018
For: Malabar Coal as arranged by Resource Strategies P/L.

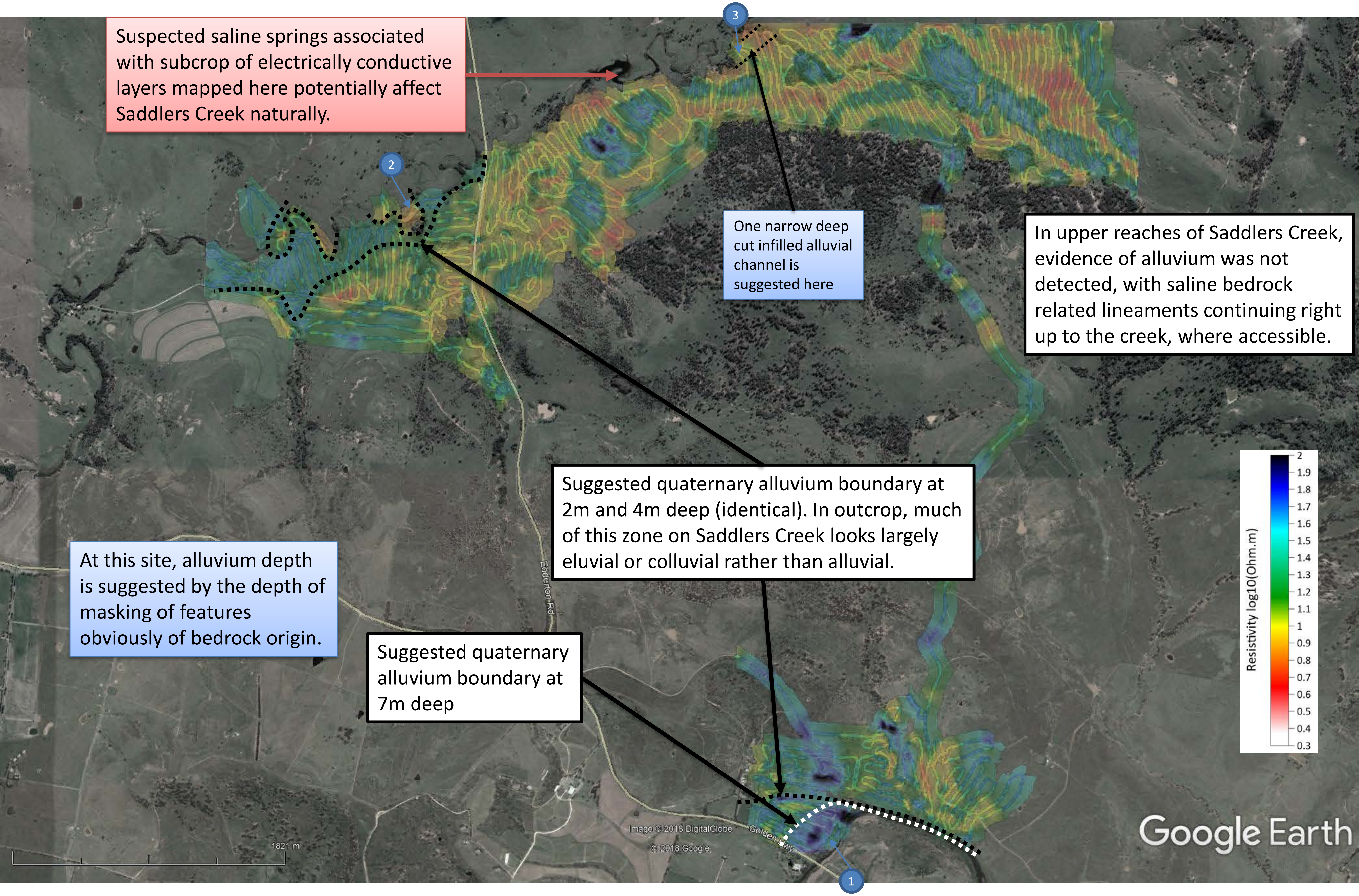
By Dr David Allen.
David@GroundwaterImaging.com.au 0418964097

GROUNDWATER IMAGING

Main points

- The area in the vicinity of the Maxwell Project has scant alluvium overlying coal measures with igneous intrusions.
- Electrical Resistivity Tomographic Imaging using AgTEM has revealed bedrock features clearly even though the soil profile and terrain reveal little to no evidence of these features. Weathering processes have hidden subcrop that AgTEM clearly reveals.
- Alluvial thickness must be less than the depth at which bedrock features are indicated in AgTEM data (with the exception of upward saline groundwater flow into alluvium).
- Apart from near the Hunter River at the river flats, there is little indication of unconsolidated alluvium.
- An ambiguous zone exists above the depth that weathered rock features are indicated – in this zone sediment may be either weathered rock (eluvium and colluvium) or alluvium. Predominantly, weathered rock features are indicated within the 0.3m deep data.
- True unconsolidated alluvium will contain meandering point bar sand features. Features possibly of this geometry are only evident in close proximity to the Hunter River under the alluvial flats. Features in the distal part of those flats even indicate very shallow bedrock features.
- Resistivities detected at the site range from high for a conglomerate, boulder conglomerate, angular jointed sandstone and fossil log layer (rock type changes along strike) to extremely low for some subcrops believed to be hypersaline.
- Resistivities were so low for some subcrops that a warning about potential extreme salinity is given. With strata dipping up out of the hillsides such that they may collect recharge rather than shedding recharge along Saddlers Creek south side, underground mining may considerably reduce salt load into Saddlers Creek. A dyke is known along some of the creek and may be related to the high salinity as could saline ash or claystone layers within the coal measures and an extensive sill within the Whynot working section. Hydrothermal salt sources could have followed the dyke and sill paths yet the mapped dyke and sill locations are not precisely where saline features exist. The response received is perhaps so strong in places that it could even represent metallic sulphide mineralization along the dyke (i.e. iron, zinc and lead sulphide minerals that weather to form acid sulphate soil and groundwater). No record of such mineralization is known in the area.
- West of Edderton Road, the monitoring bore indicates artesian conditions and widespread high electrical conductivity exists within gradually dipping to horizontal layers. Positive groundwater pressure appears to have naturally brought salinity extensively into the soil here, diluted within more permeable alluvium such that a thin veneer of lower salinity exists within the lower Saddlers Creek alluvium.
- Two particularly saline features are inferred. The first subcropping with strike passing under a shallow discoloured dam pond on the middle of Saddlers Creek (locked off). This feature seems to be subcrop of the Saxonville Claystone. The second is deep under upper reaches of the creek just west of Edderton Road where this creek intersects the mapped edge of the Whynot Sill.
- The Whynot Sill and working section seem to be represented within the data as a conductive layer readily traced along the hillsides as well as down into the vertical AgTEM transects. Considerable detail of folding and faulting is captured in this data.

Suggested alluvium boundaries + AgTEM Modelled Resistivity at 2m deep



Contents

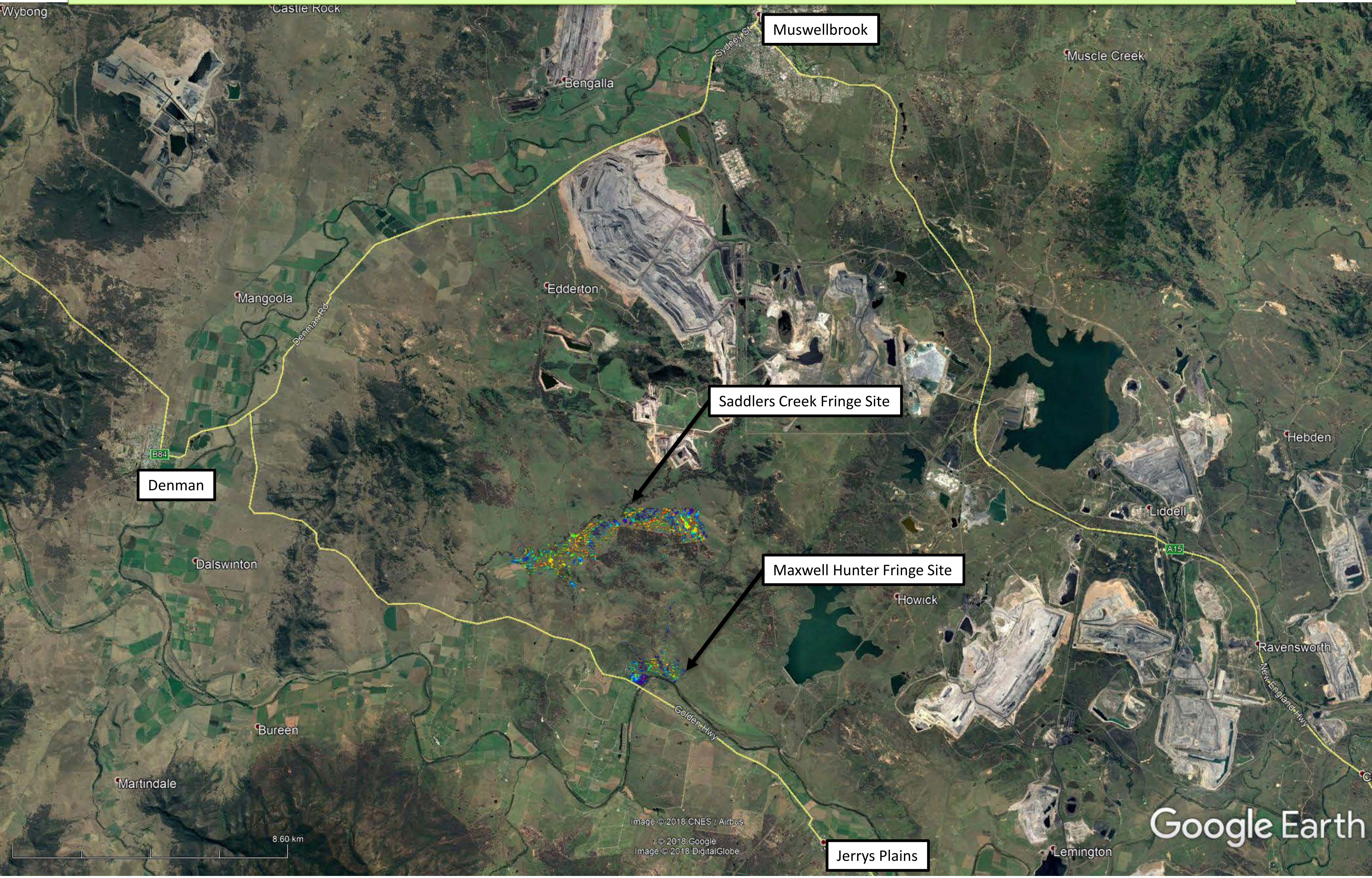
Context and Aim

- Careful consideration and assessment of potential impacts on alluvial groundwater is required as part of the NSW planning process. Even though alluvium is difficult to define in marginal circumstances ('Alluvium' being a term referring to sediment origin, not sediment description), detailed 3D mapping helps greatly with quantification in the resulting debate.
- Aim - Regolith is to be detailed for groundwater conceptual modelling, especially with respect to identification of thickness of alluvium.

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



Muswellbrook
Saddlers Creek Fringe Site
Maxwell Hunter Fringe Site
Denman
Jerrys Plains
Wybong
Castle Rock
Bengalla
Muscle Creek
Mangoola
Edderton
Denman Rd
Sydney St
Hebden
Liddell
A15
B84
Dalswinton
Howick
Ravensworth
New England Hwy
Golden Hwy
Bureen
Martindale
Lemington
8.60 km
Image © 2018 CNES / Airbus
© 2018 Google
Image © 2018 DigitalGlobe
Google Earth

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

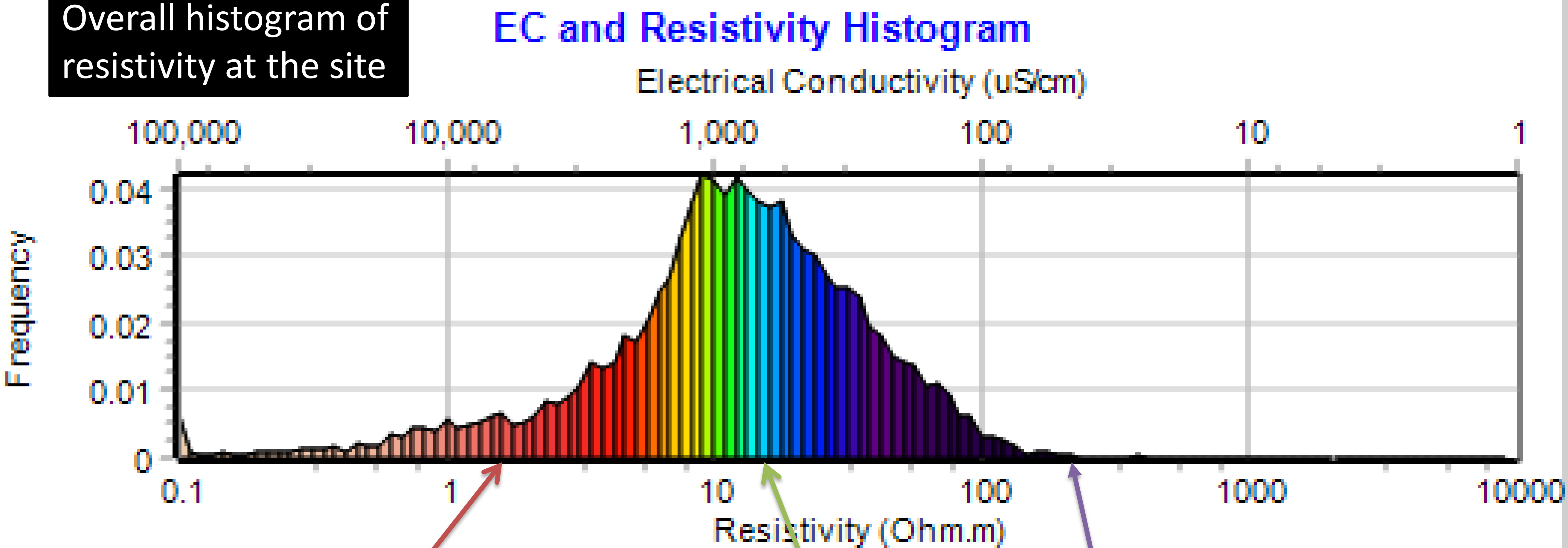
Results Presentation

- TEM data has been presented as depth slices in Google Earth
- In order to understand the TEM data, it has also been plotted in 3D. This helps with observation of the geometry of features in vertical transects.
- The curtain images (actually triangular prisms) plotted in 3D are simply projected 30 to 60m up from the Google Earth DEM. The data is plotted against depth but draped over the Google Earth DEM.
- 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



Saline moisture typically in weathered rock and clay

Fresh ground moisture typically in sand and gravel

Impermeable hard rock such as granite and limestone.
Air filled gravel, pebbles or cobbles.

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

Full set of depth slices with common colour stretch

The AgTEM4 prototype 2016

Underground mine plan and old documentation of alluvial extents.

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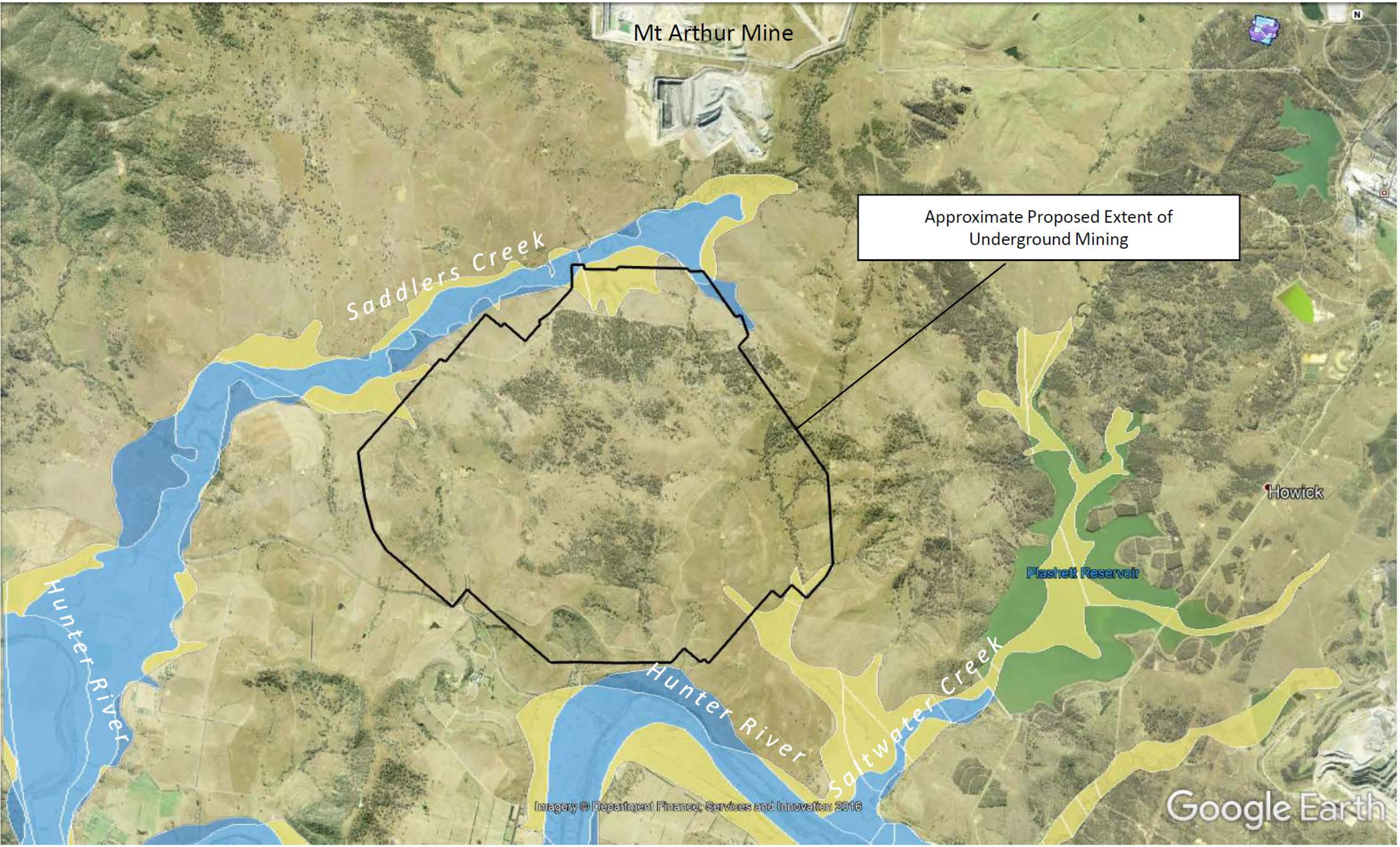
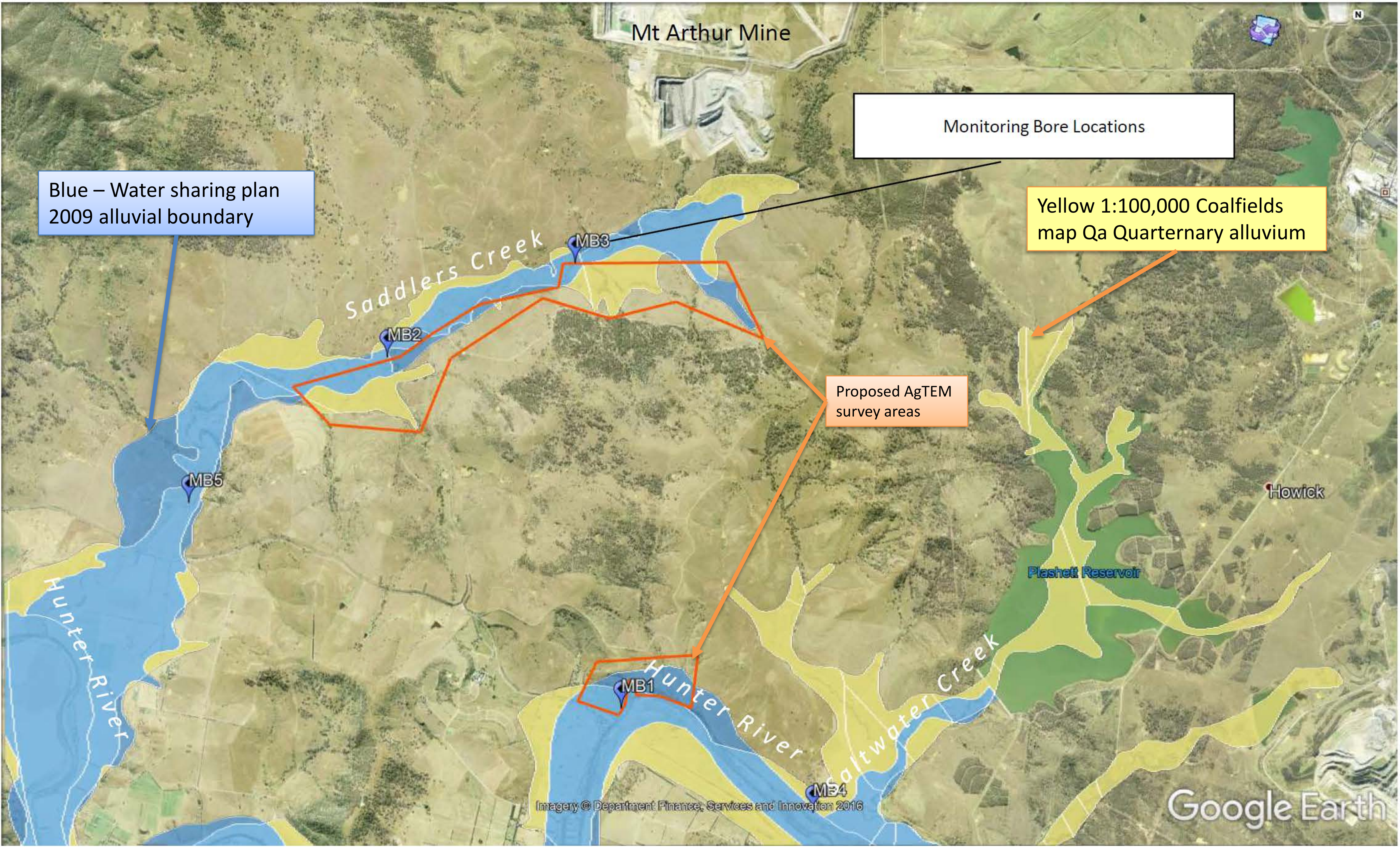
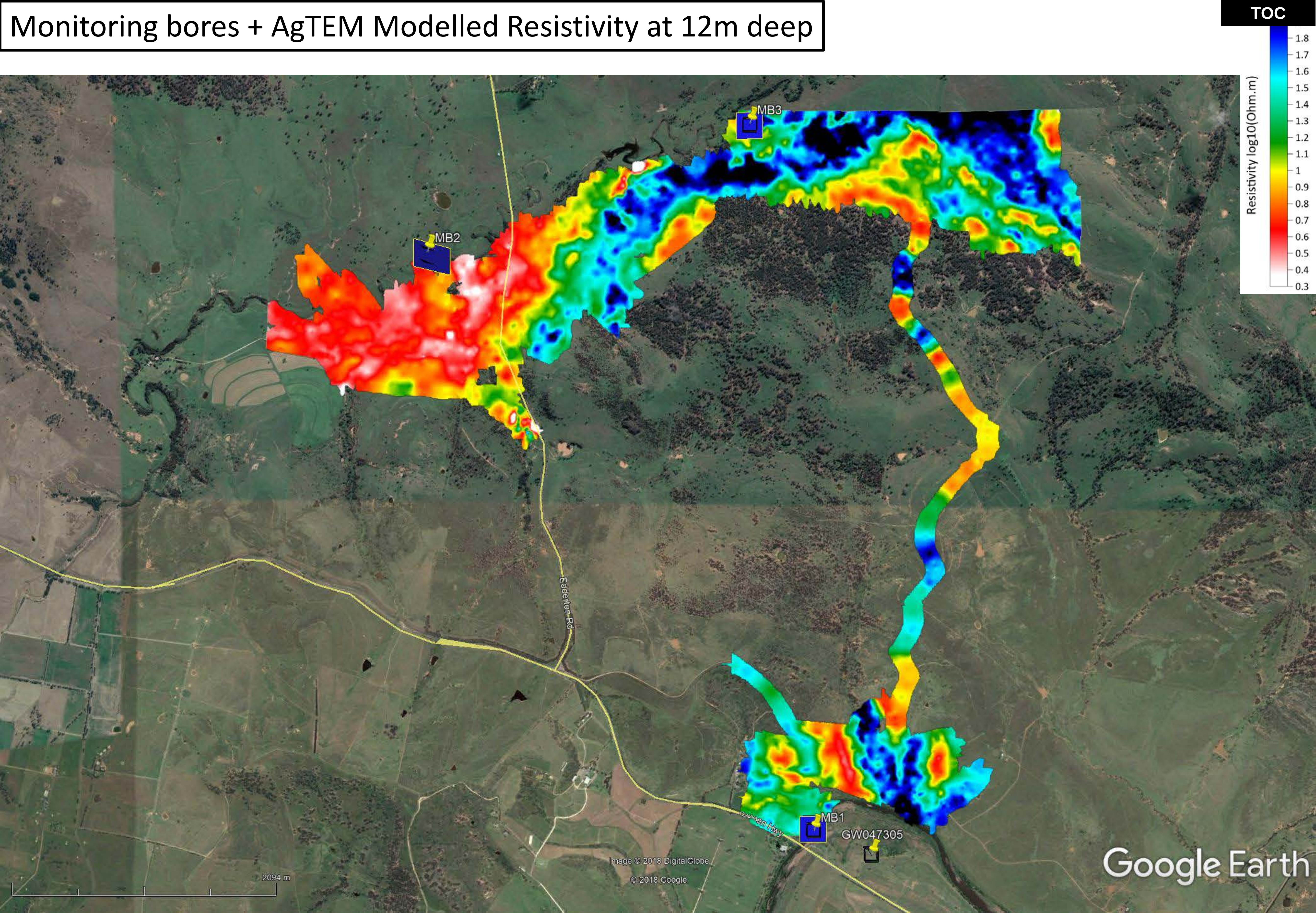


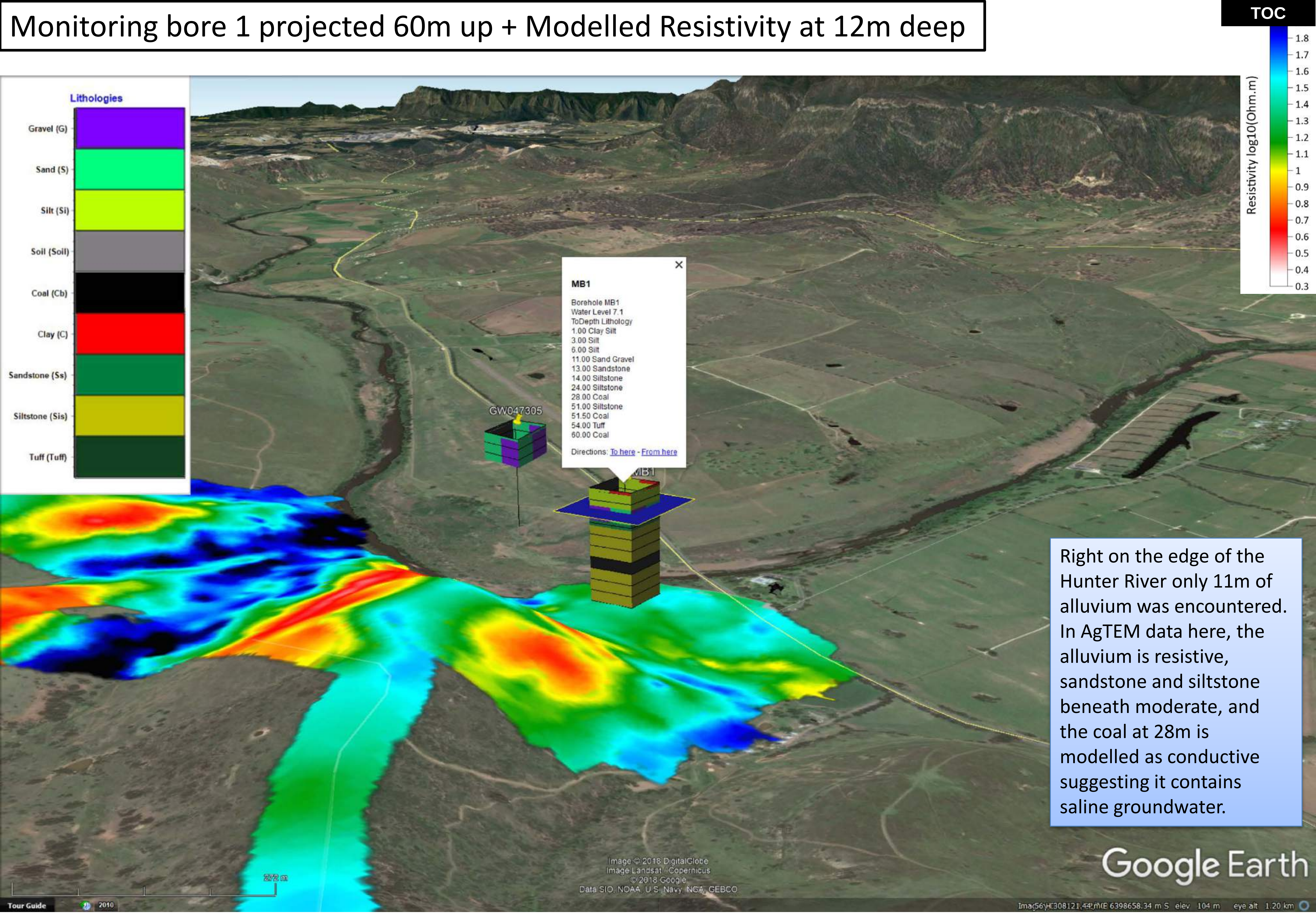
Proposed AgTEM survey, Monitoring bore locations and old documentation of alluvial extents.



Monitoring bores + AgTEM Modelled Resistivity at 12m deep



Monitoring bore 1 projected 60m up + Modelled Resistivity at 12m deep



Right on the edge of the Hunter River only 11m of alluvium was encountered. In AgTEM data here, the alluvium is resistive, sandstone and siltstone beneath moderate, and the coal at 28m is modelled as conductive suggesting it contains saline groundwater.

Hunter River Site - Modelled Resistivity projected 40m up

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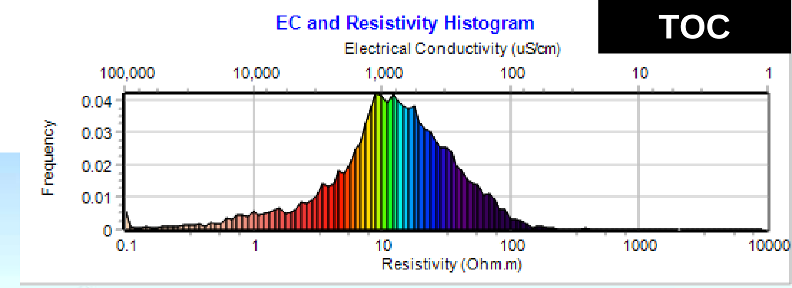

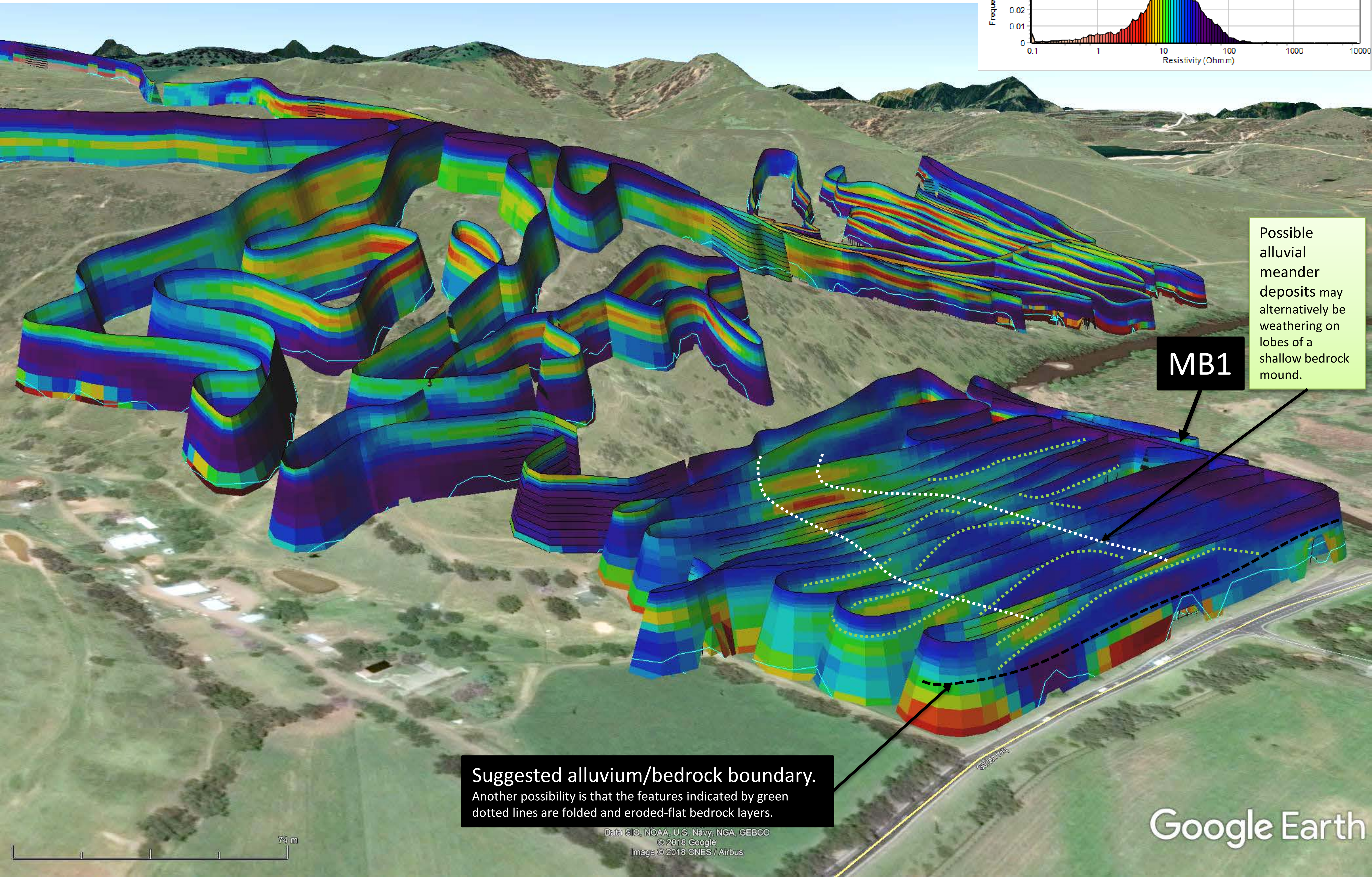

Hunter River Site - Modelled Resistivity projected 40m up

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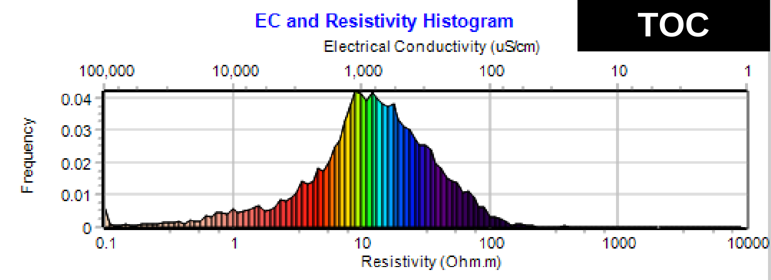
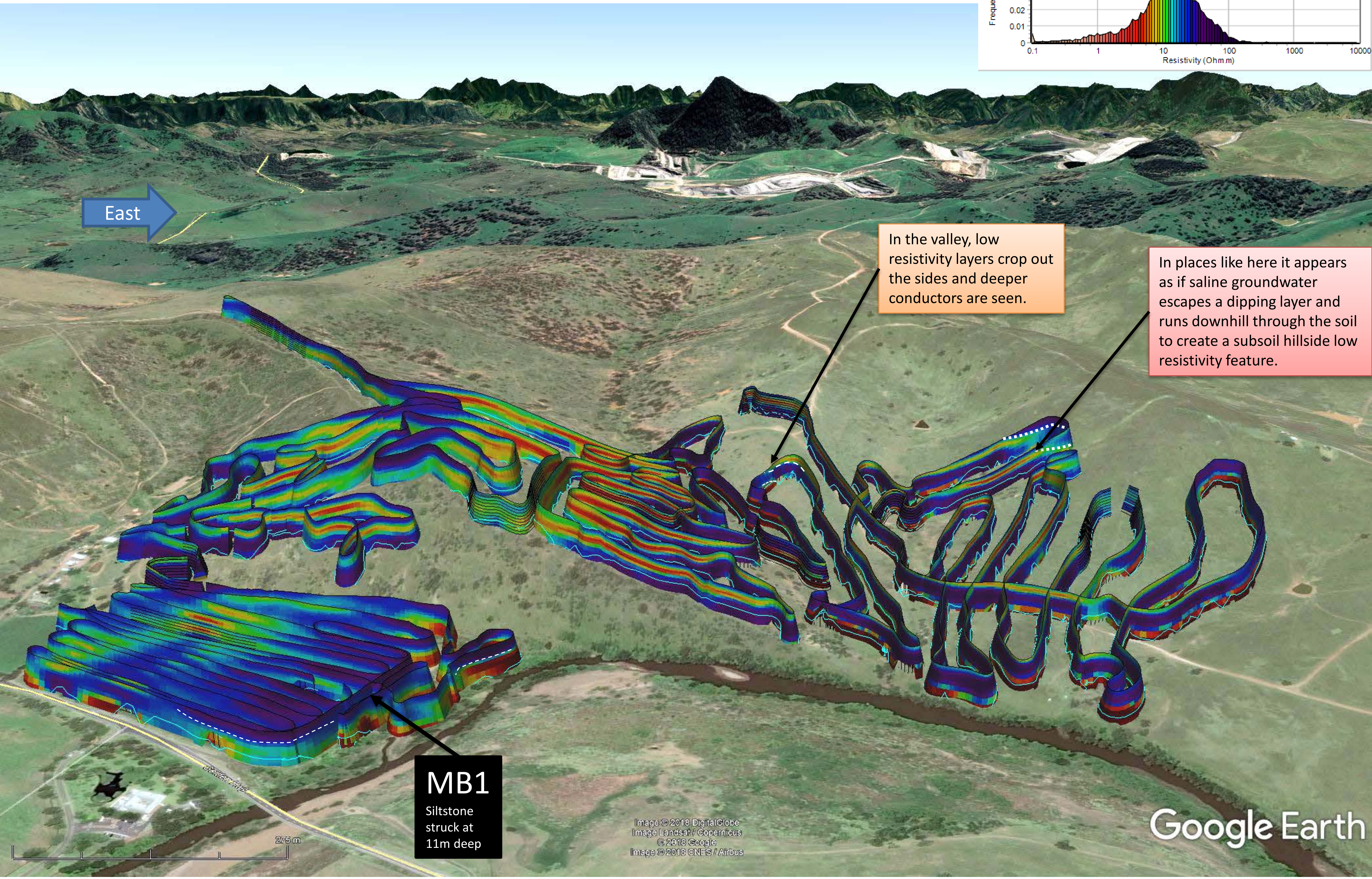
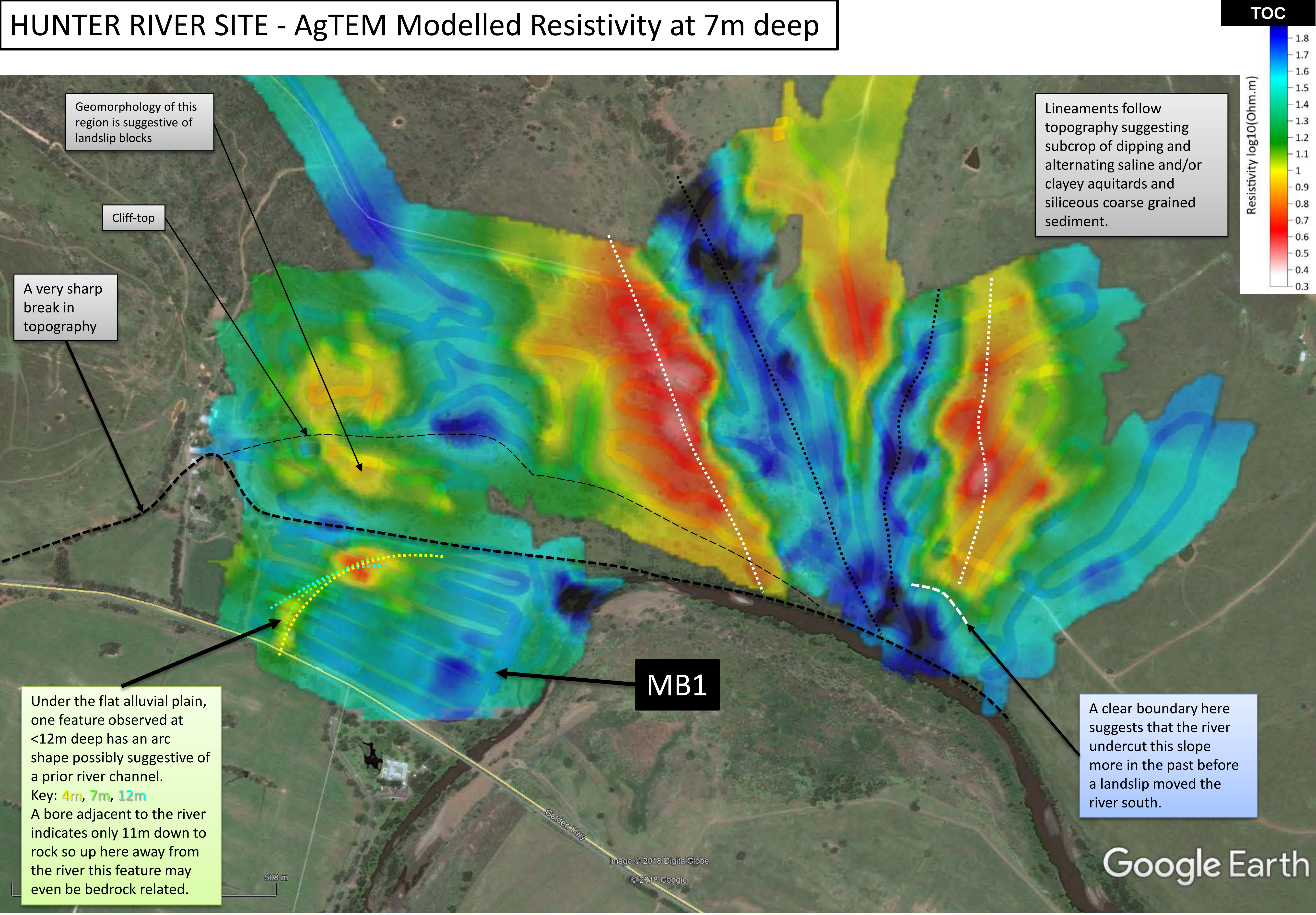
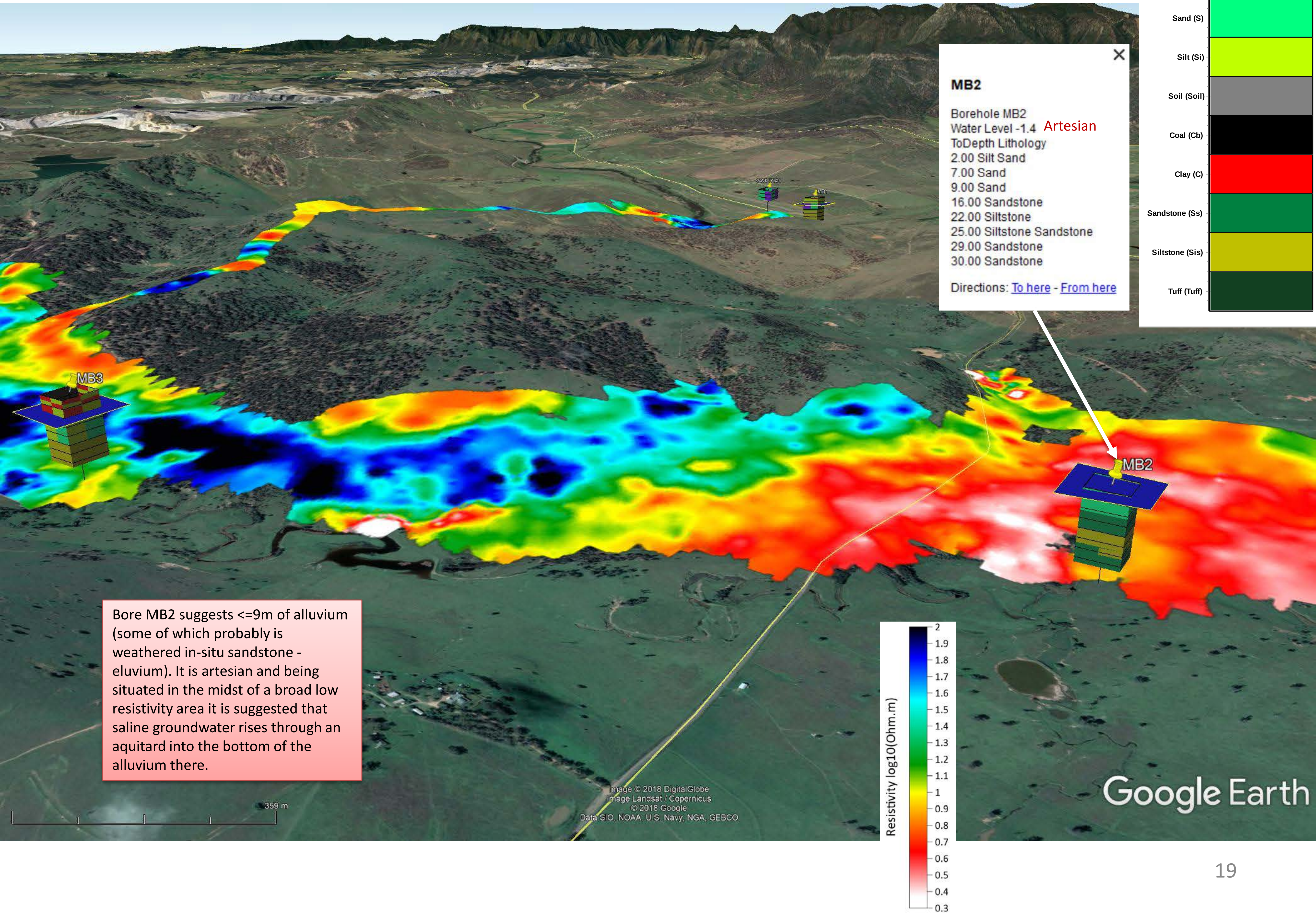




HUNTER RIVER SITE - AgTEM Modelled Resistivity at 7m deep



Monitoring bore 2 projected 60m up + Modelled Resistivity at 12m deep



Bore MB2 suggests <=9m of alluvium (some of which probably is weathered in-situ sandstone - eluvium). It is artesian and being situated in the midst of a broad low resistivity area it is suggested that saline groundwater rises through an aquitard into the bottom of the alluvium there.

Modelled Resistivity projected 40m up

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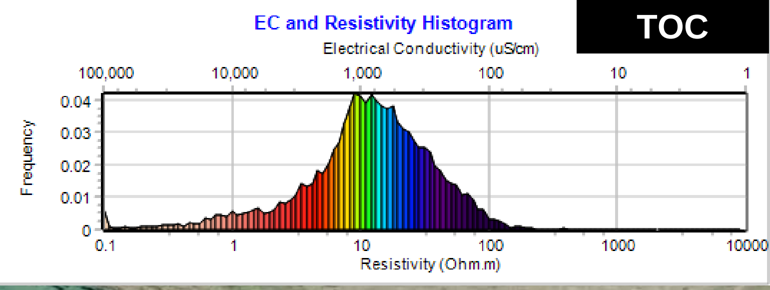
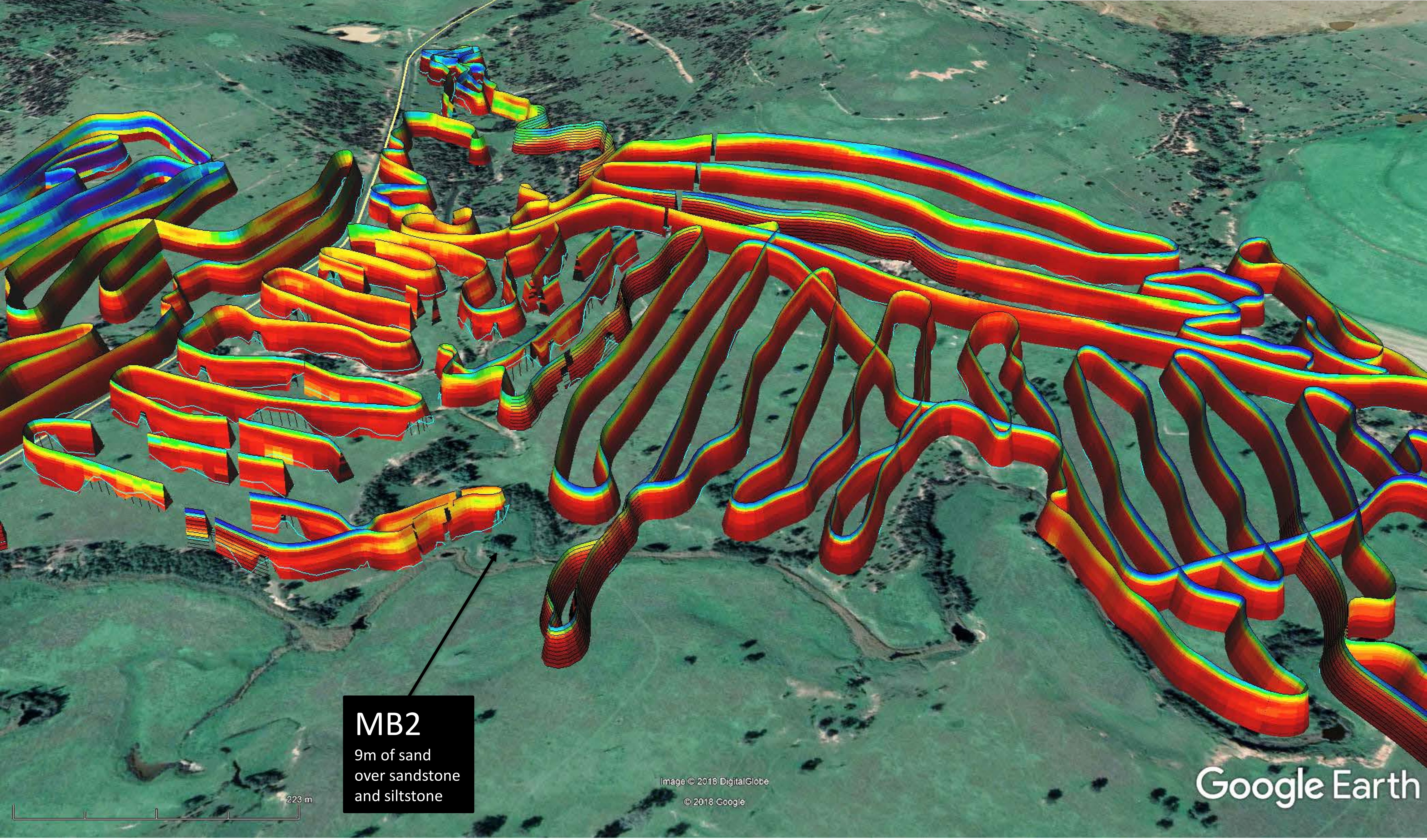
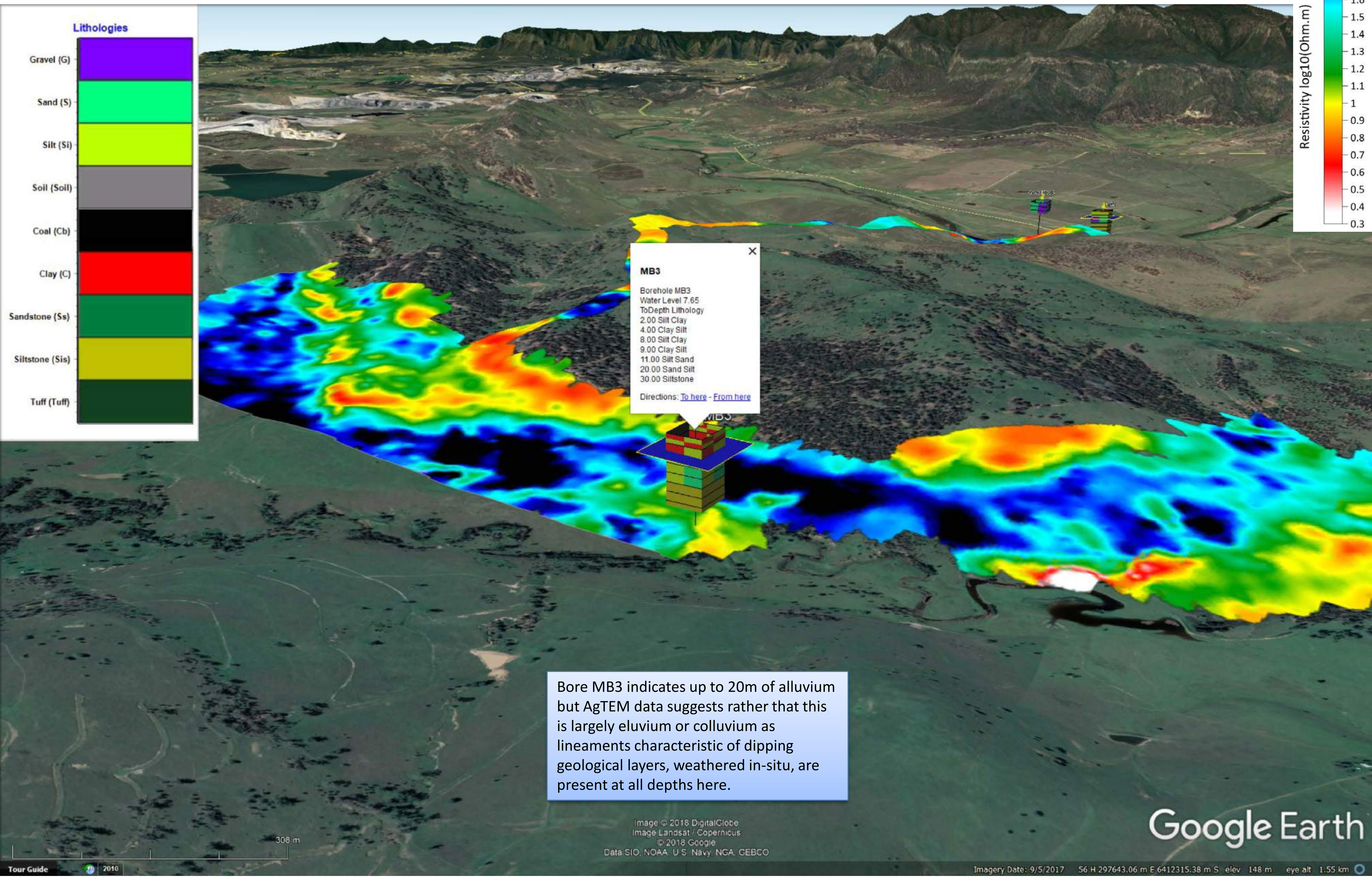




Monitoring bore 3 projected 60m up + Modelled Resistivity at 12m deep



Bore MB3 indicates up to 20m of alluvium but AgTEM data suggests rather that this is largely eluvium or colluvium as lineaments characteristic of dipping geological layers, weathered in-situ, are present at all depths here.

Monitoring Bore 3 & Modelled Resistivity projected 40m up

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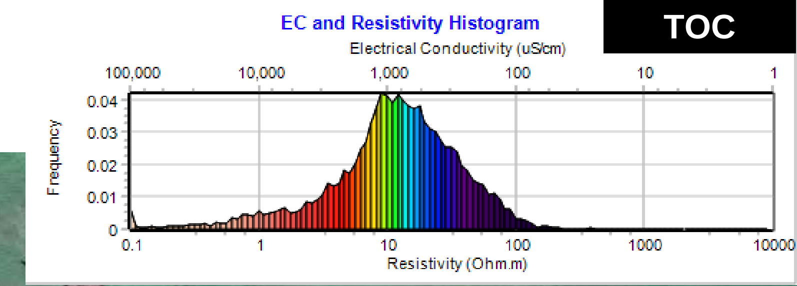

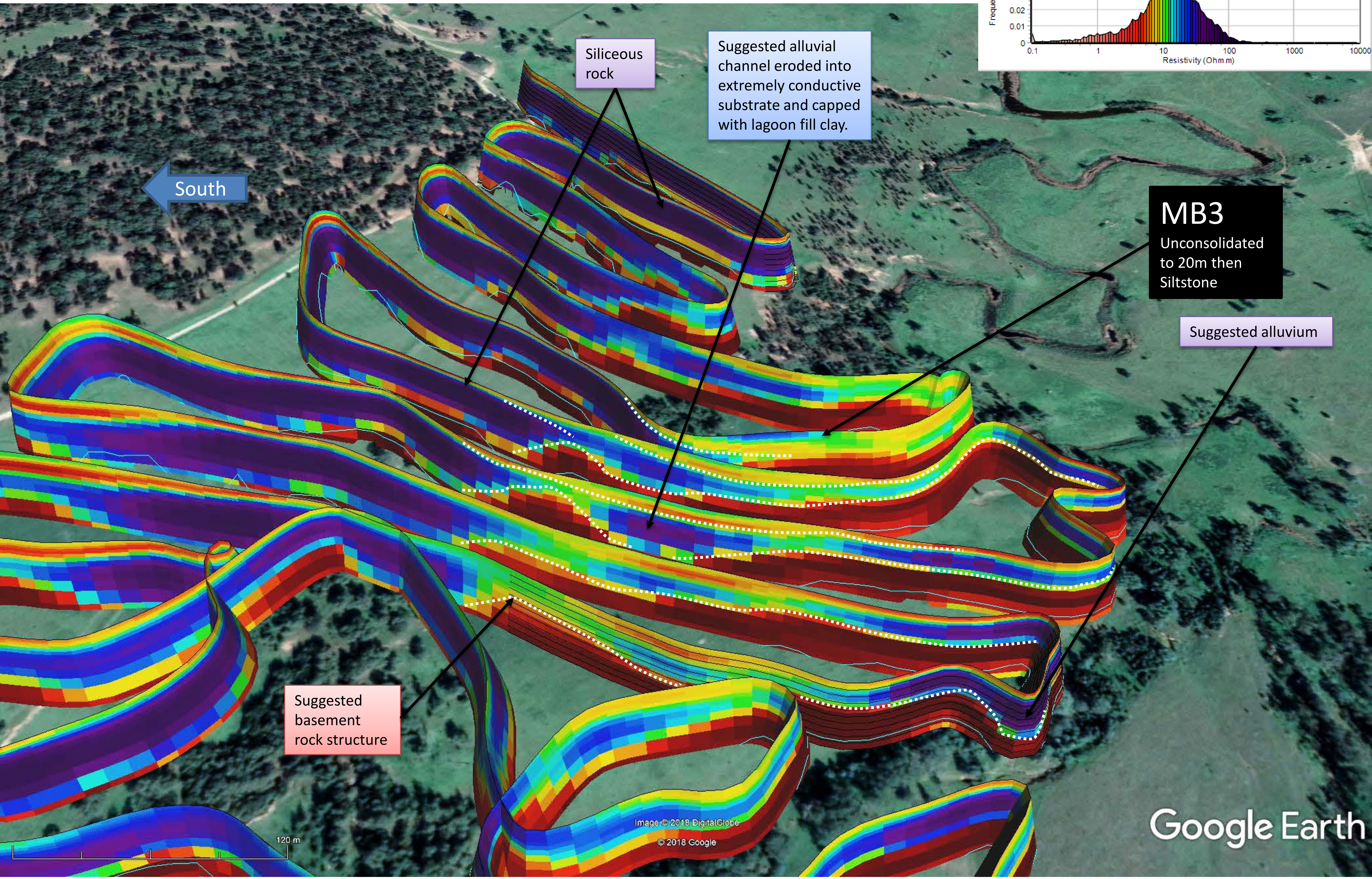

Suggested alluvium boundaries + AgTEM Modelled Resistivity at 2m deep

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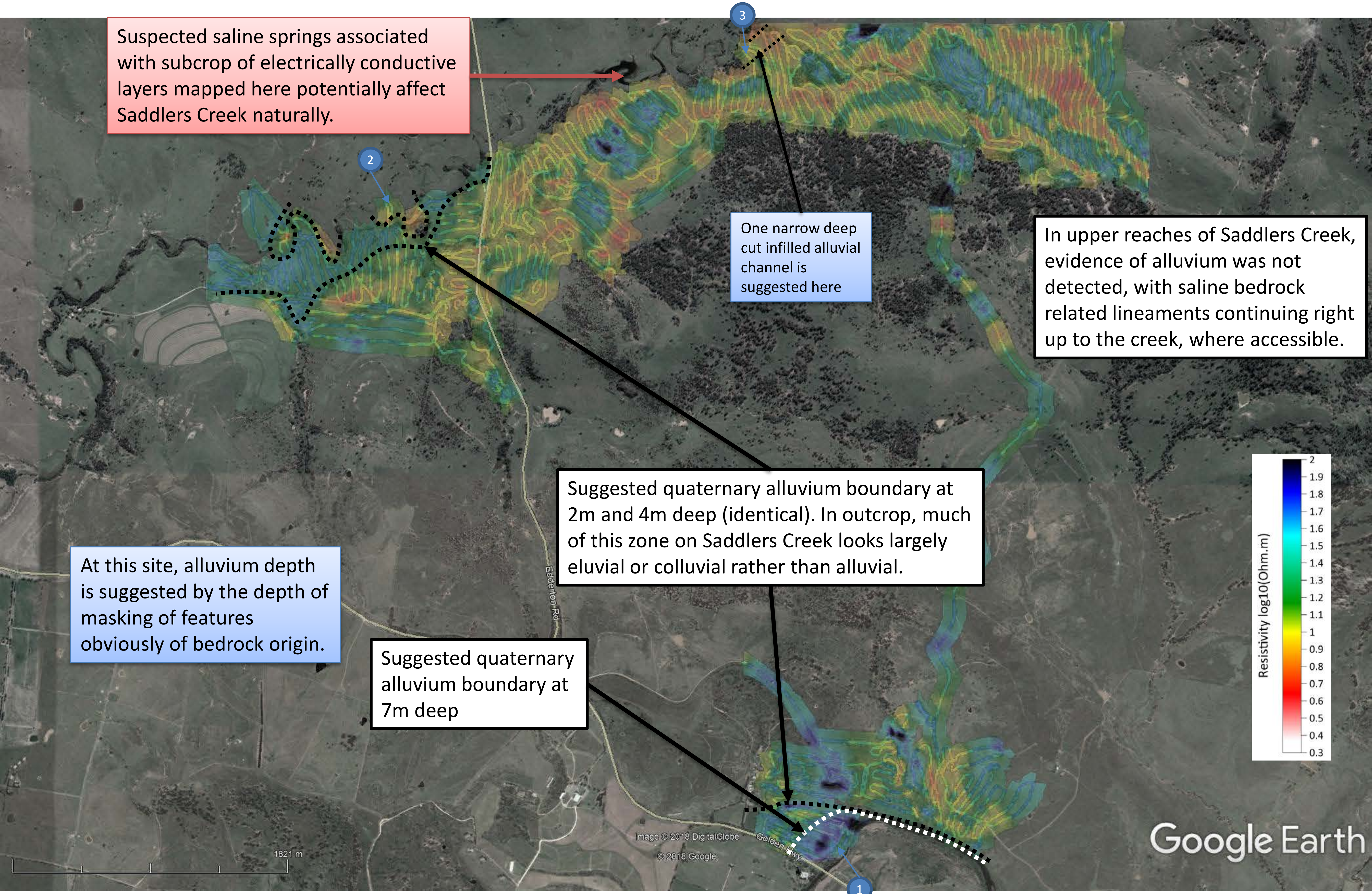

Mapped dyke and seam subcrop locations over modelled resistivity at 7m deep

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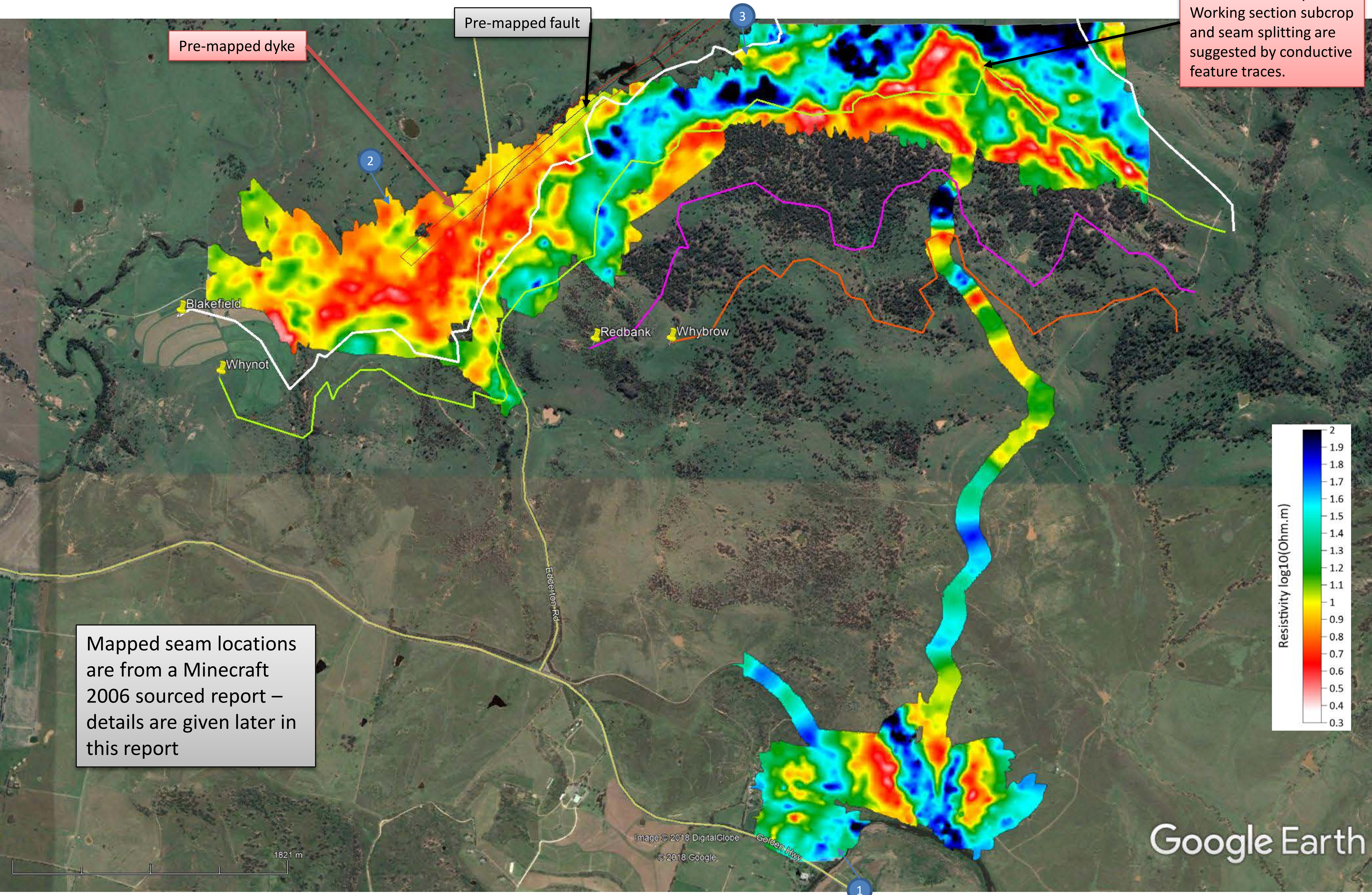
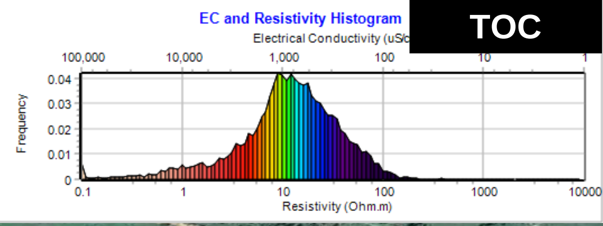


Modelled Resistivity projected 40m up



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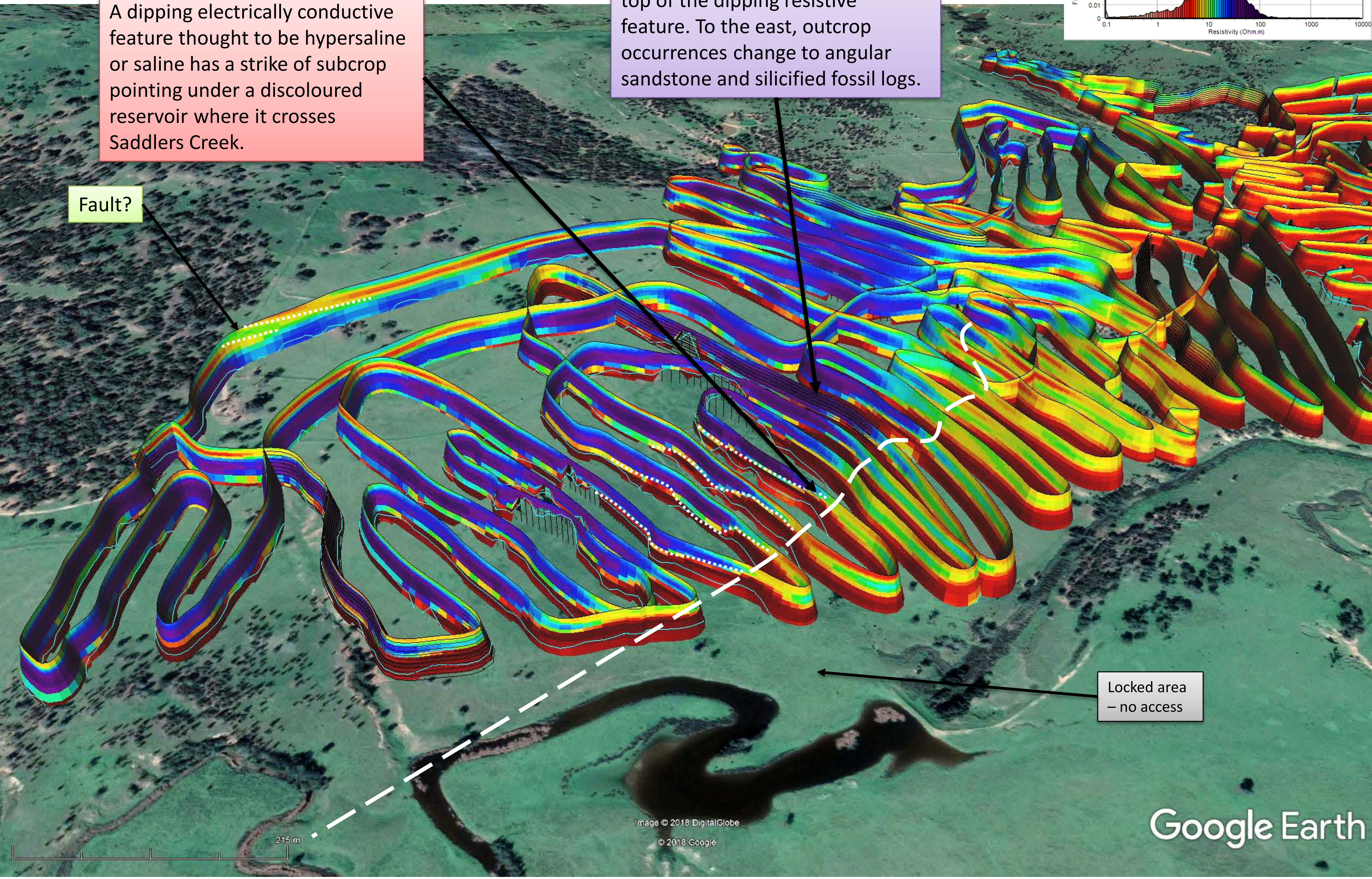
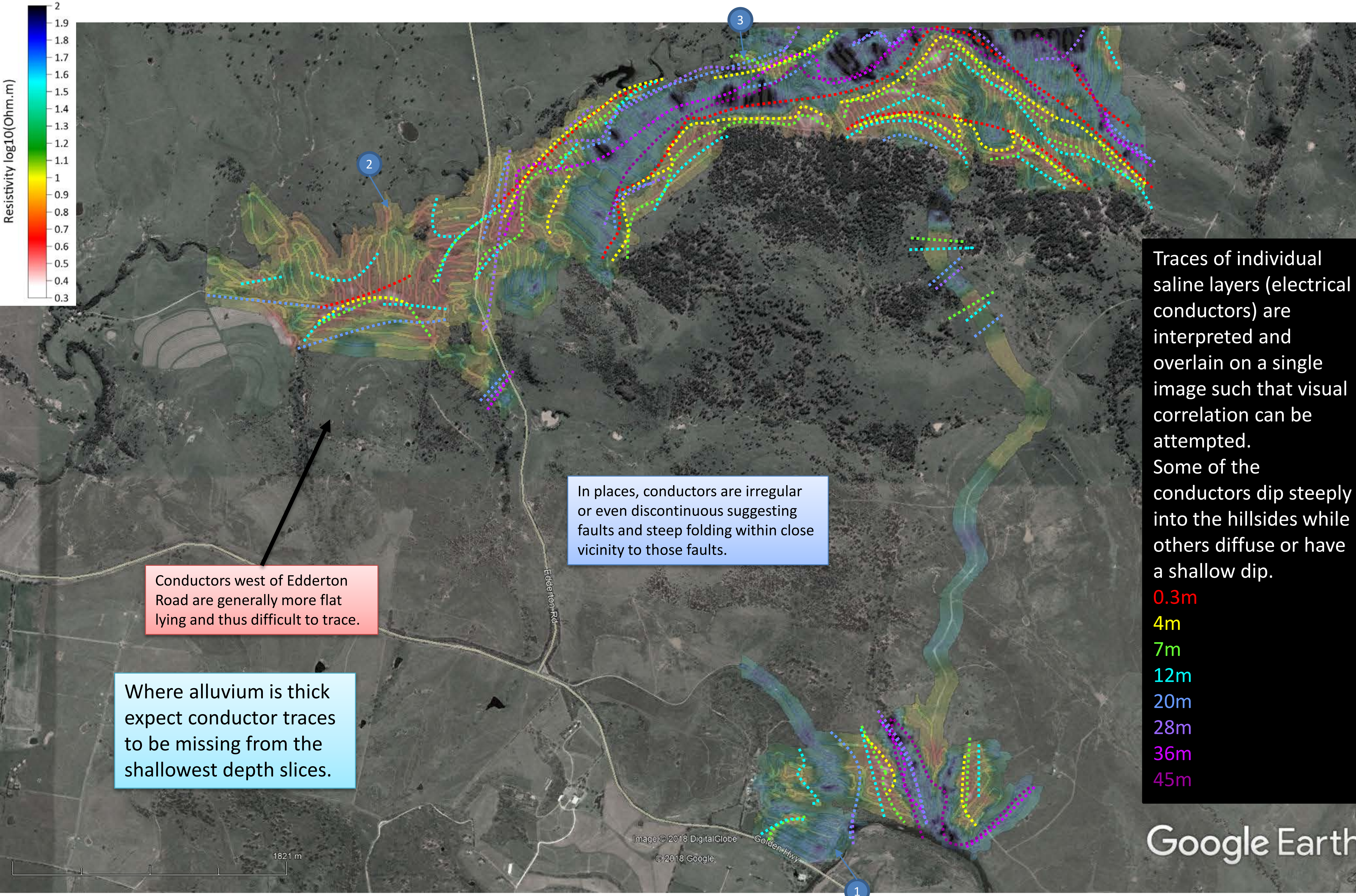


Interpreted conductor intersections at various depths + AgTEM Modelled Resistivity at 7m deep



Traces of individual saline layers (electrical conductors) are interpreted and overlain on a single image such that visual correlation can be attempted. Some of the conductors dip steeply into the hillsides while others diffuse or have a shallow dip.

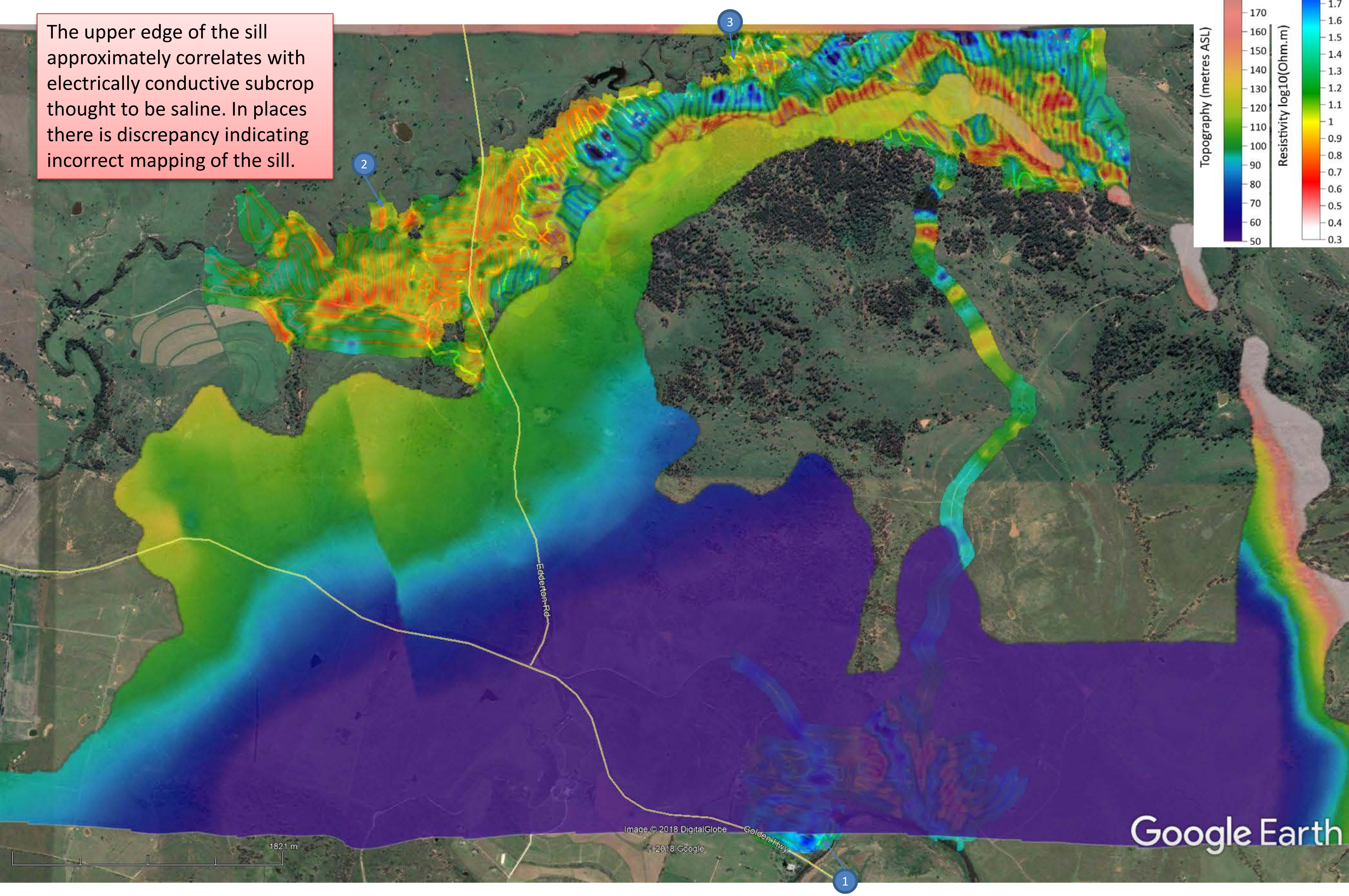
In places, conductors are irregular or even discontinuous suggesting faults and steep folding within close vicinity to those faults.

Conductors west of Edderton Road are generally more flat lying and thus difficult to trace.

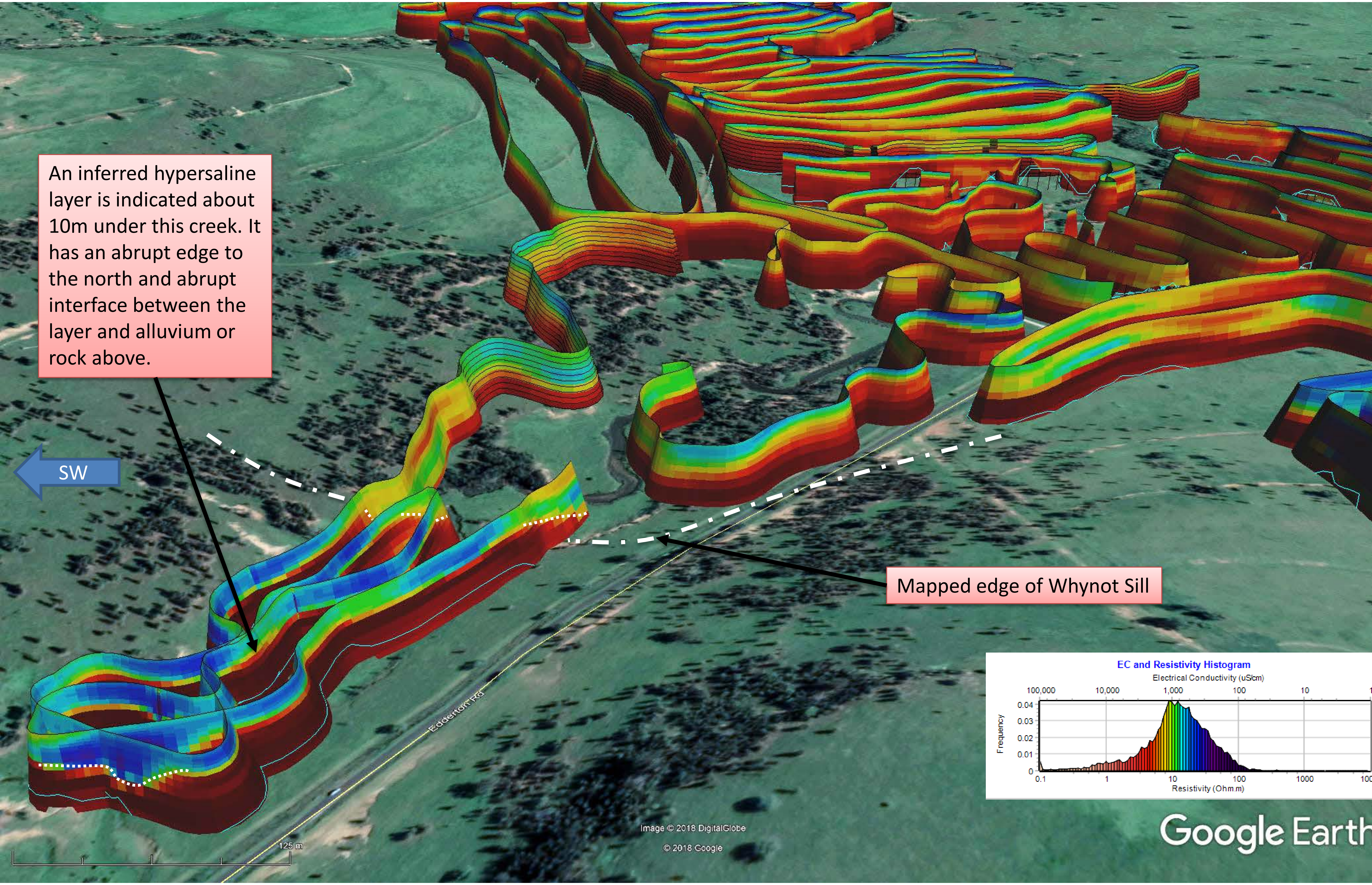
Where alluvium is thick expect conductor traces to be missing from the shallowest depth slices.

Elevation of the **Whynot Igneous Sill** + AgTEM Modelled Resistivity at 4m deep

The upper edge of the sill approximately correlates with electrically conductive subcrop thought to be saline. In places there is discrepancy indicating incorrect mapping of the sill.



Edge of Whynot Sill adjacent to Edderton Road - Modelled Resistivity projected 40m up



Background Image

Saline layers (electrical conductors) at 7m deep are inferred.

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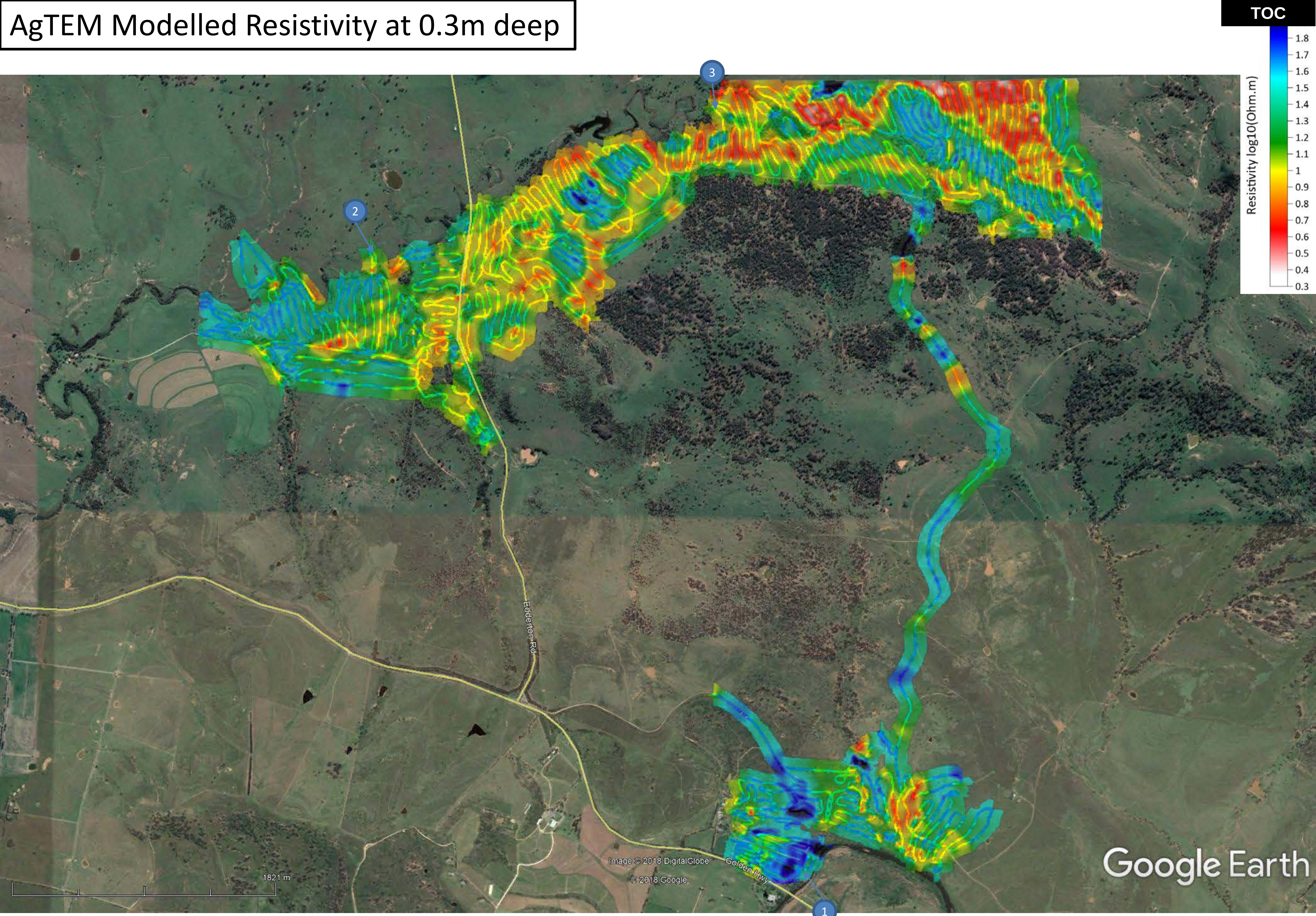
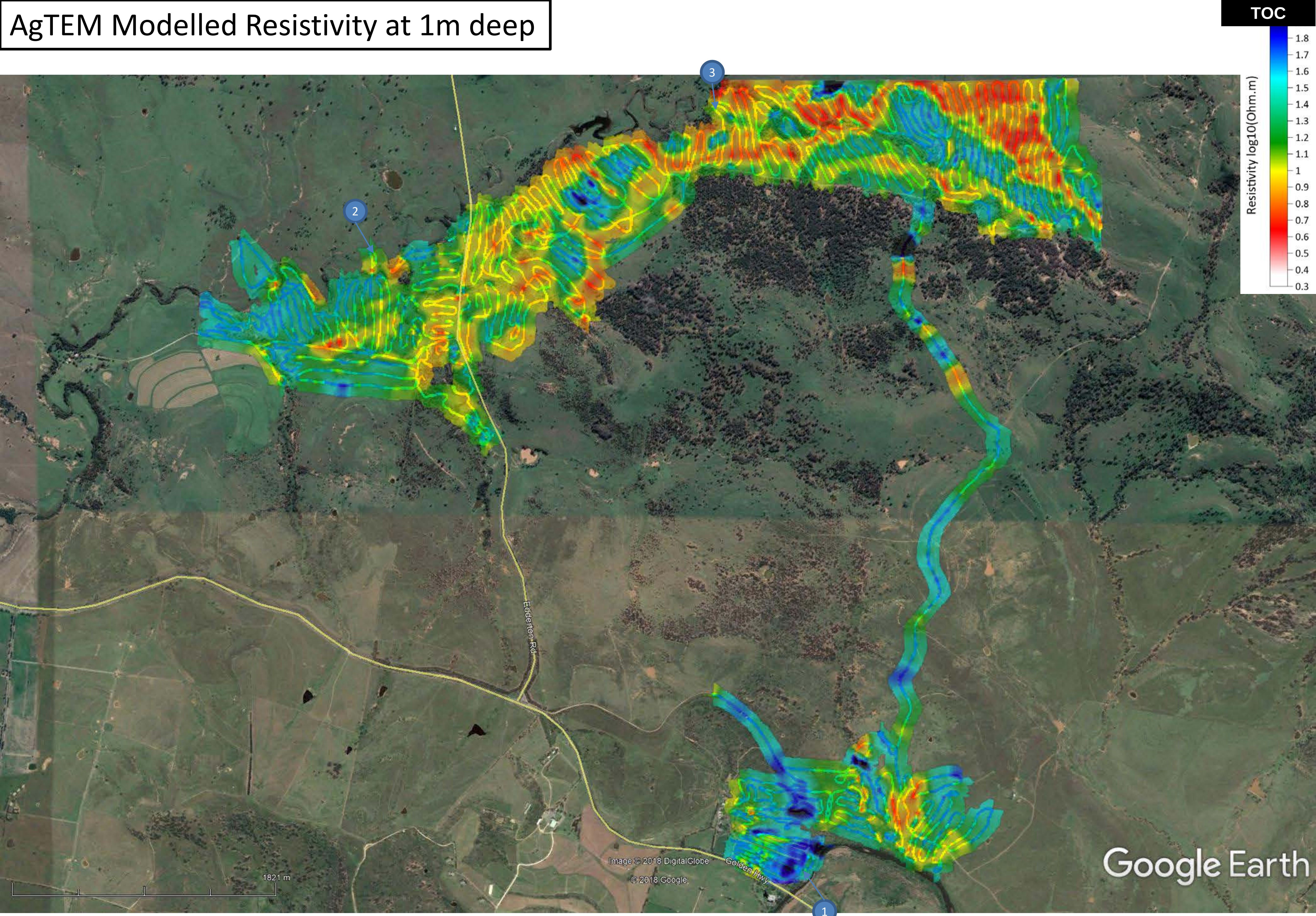
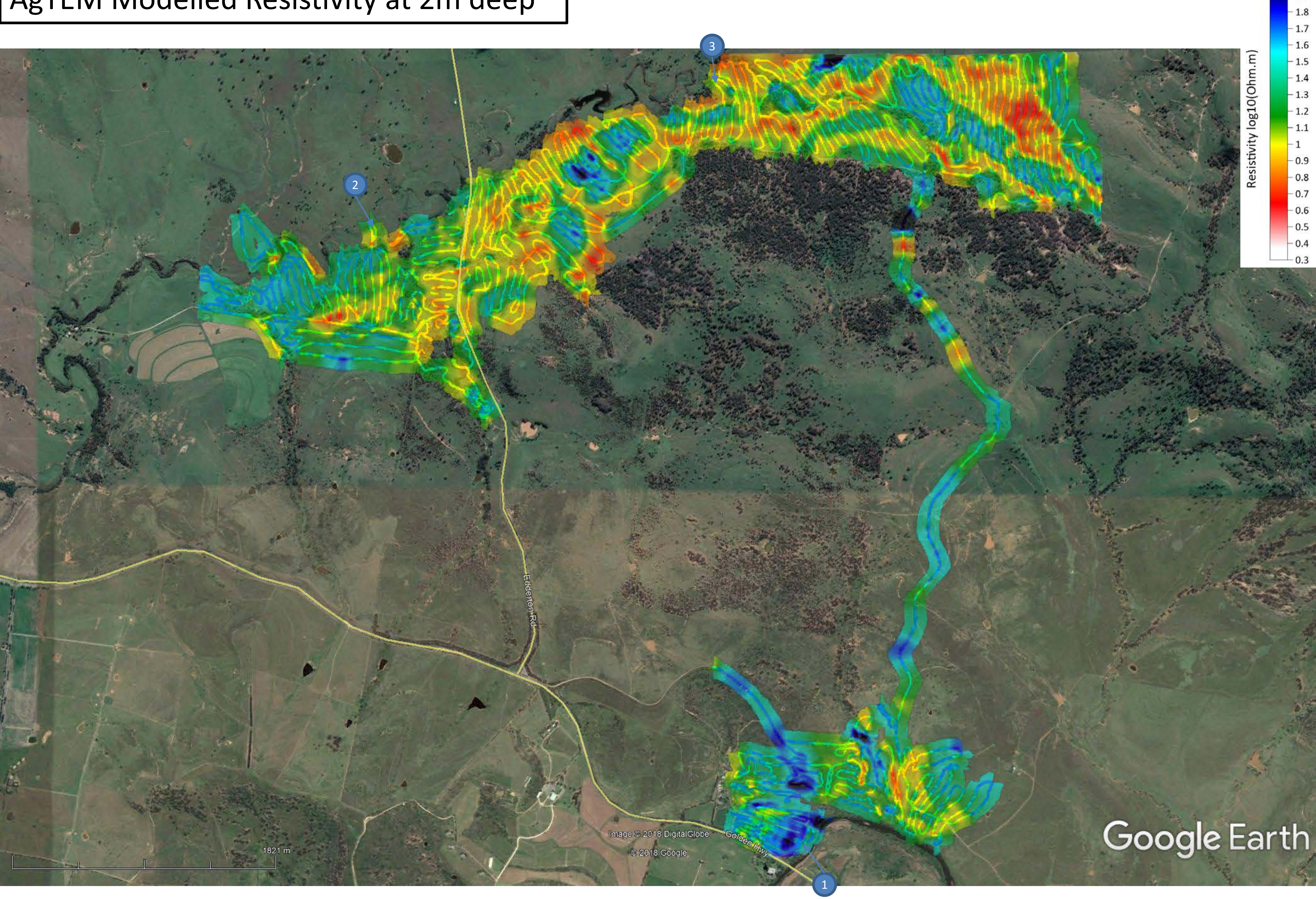
AgTEM Modelled Resistivity at 0.3m deep



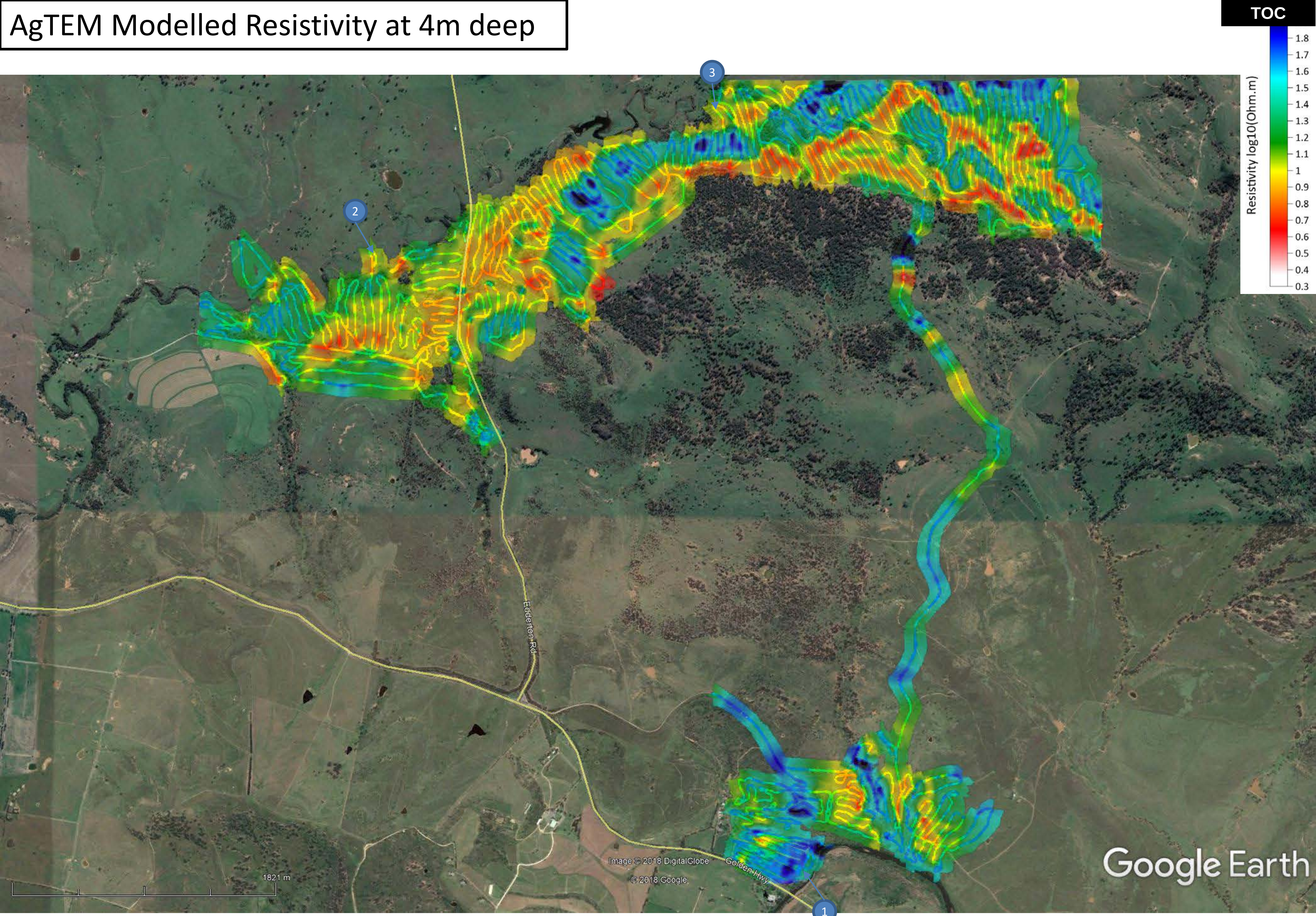
AgTEM Modelled Resistivity at 1m deep



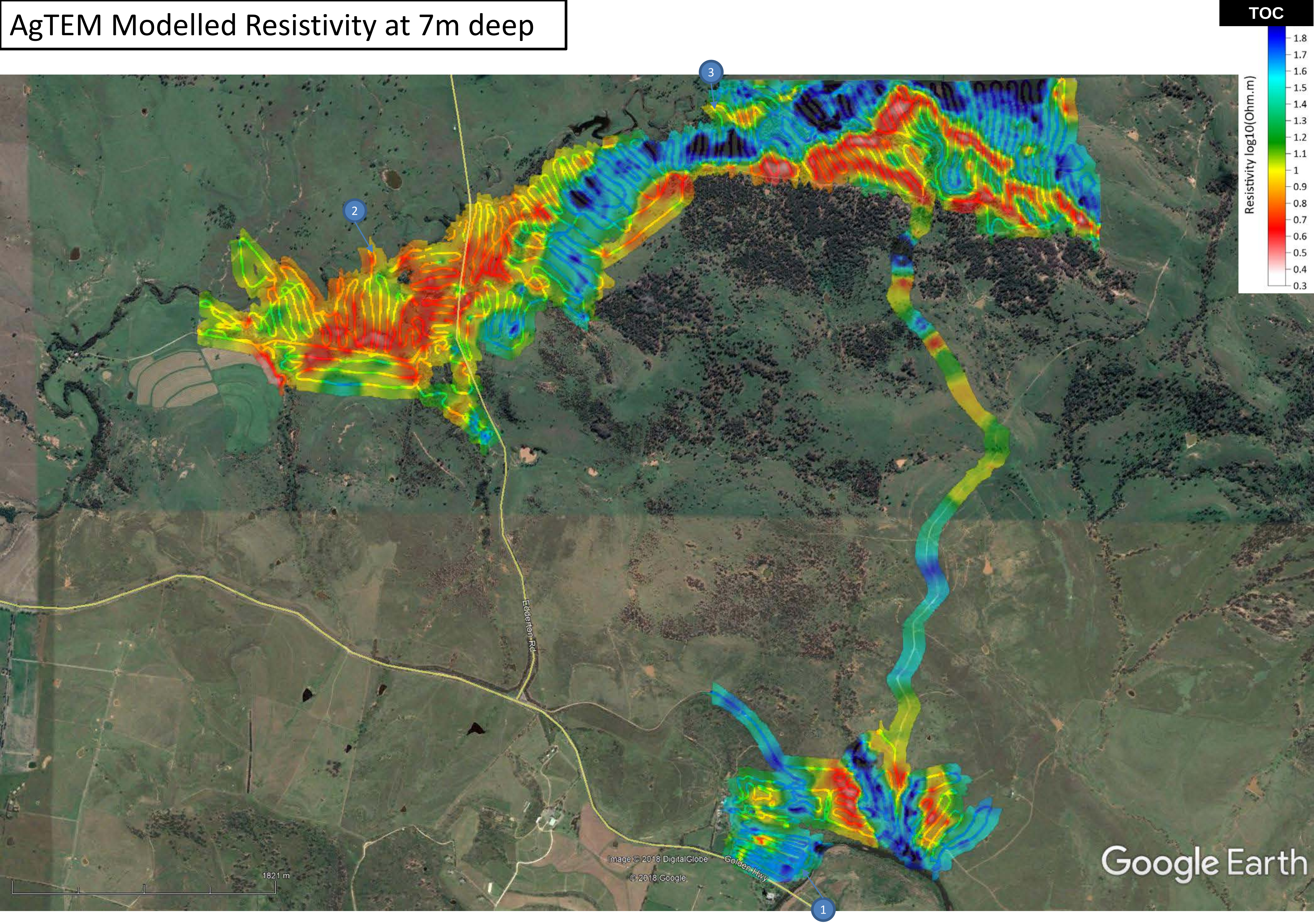
AgTEM Modelled Resistivity at 2m deep



AgTEM Modelled Resistivity at 4m deep



AgTEM Modelled Resistivity at 7m deep



AgTEM Modelled Resistivity at 12m deep

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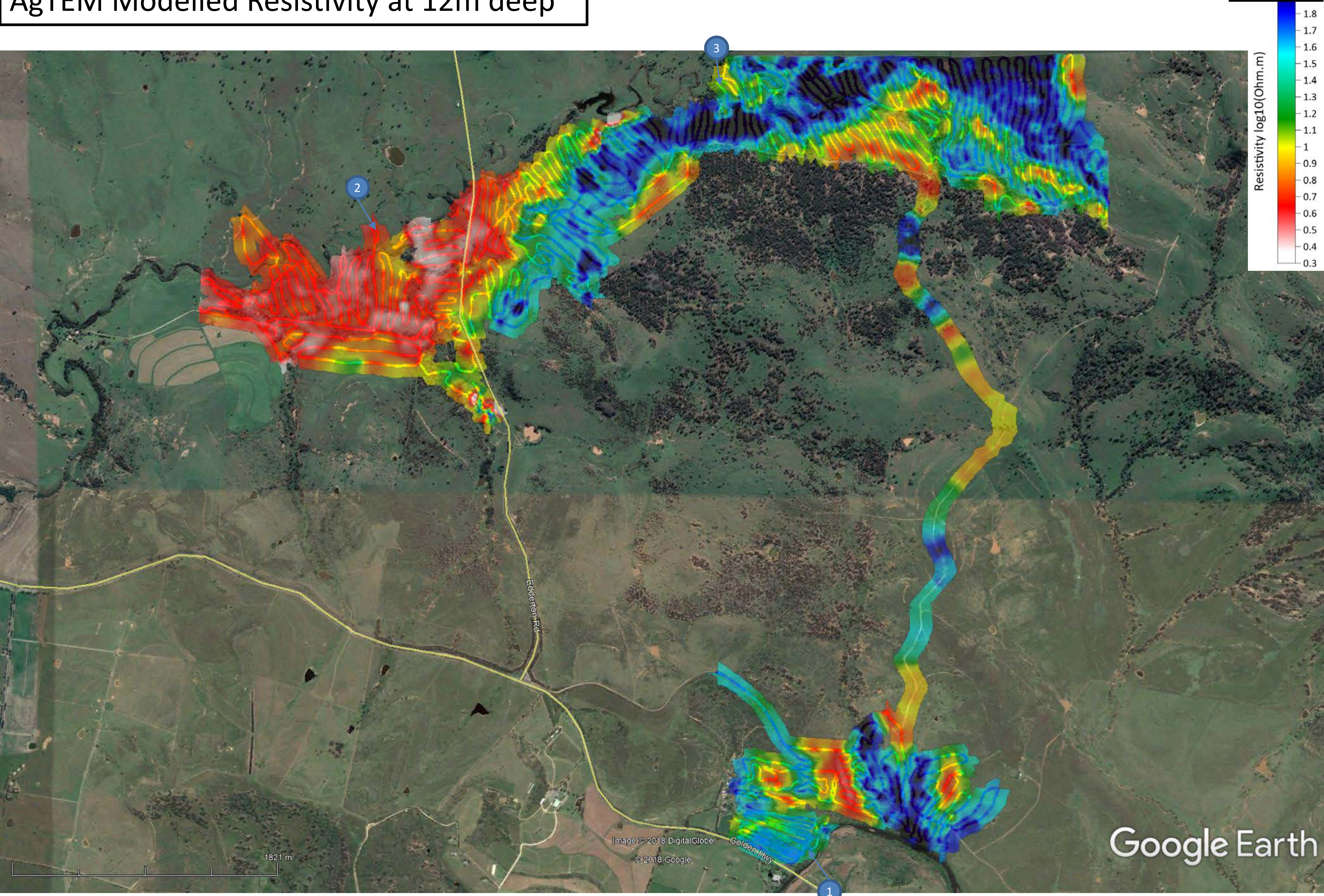
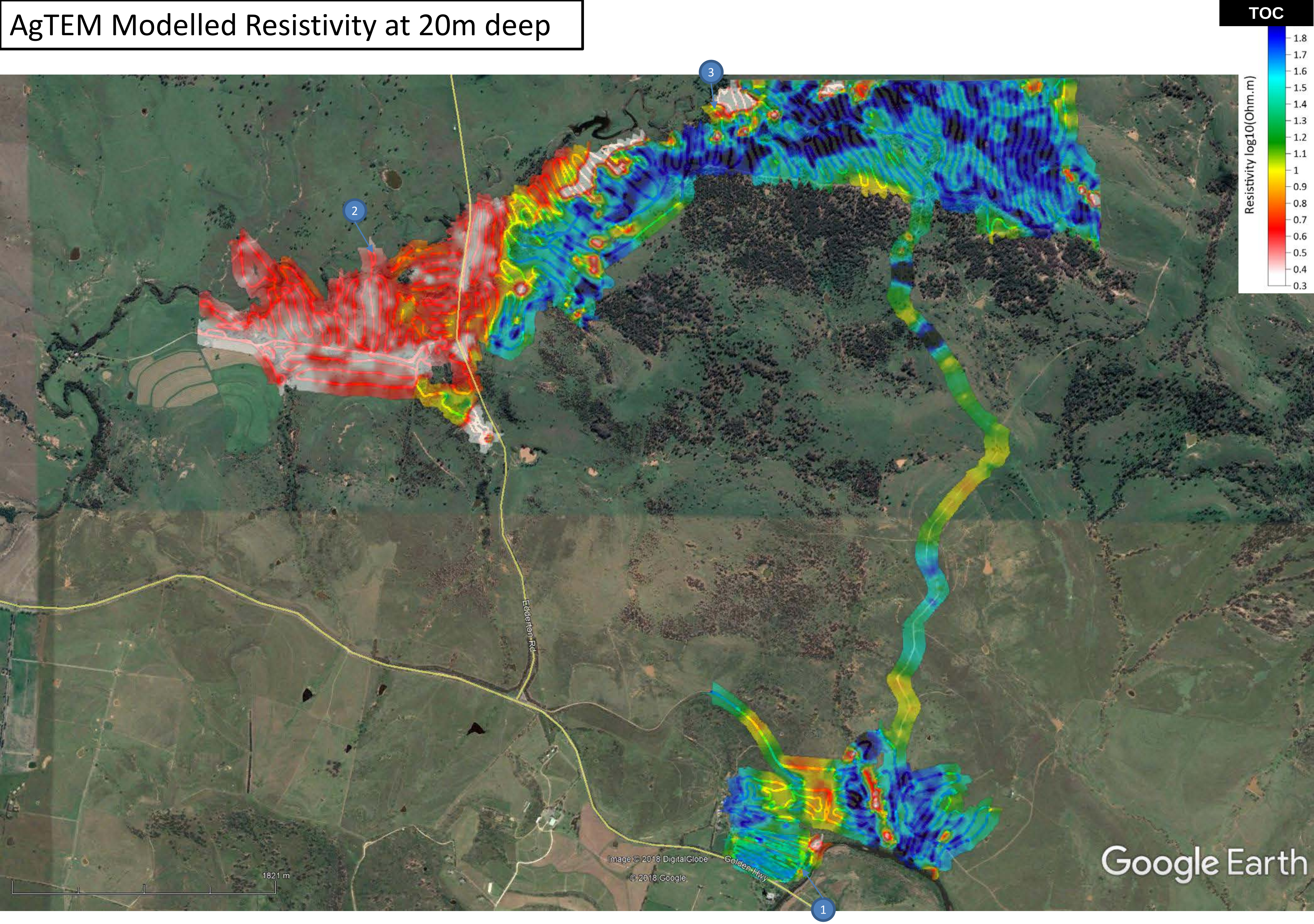
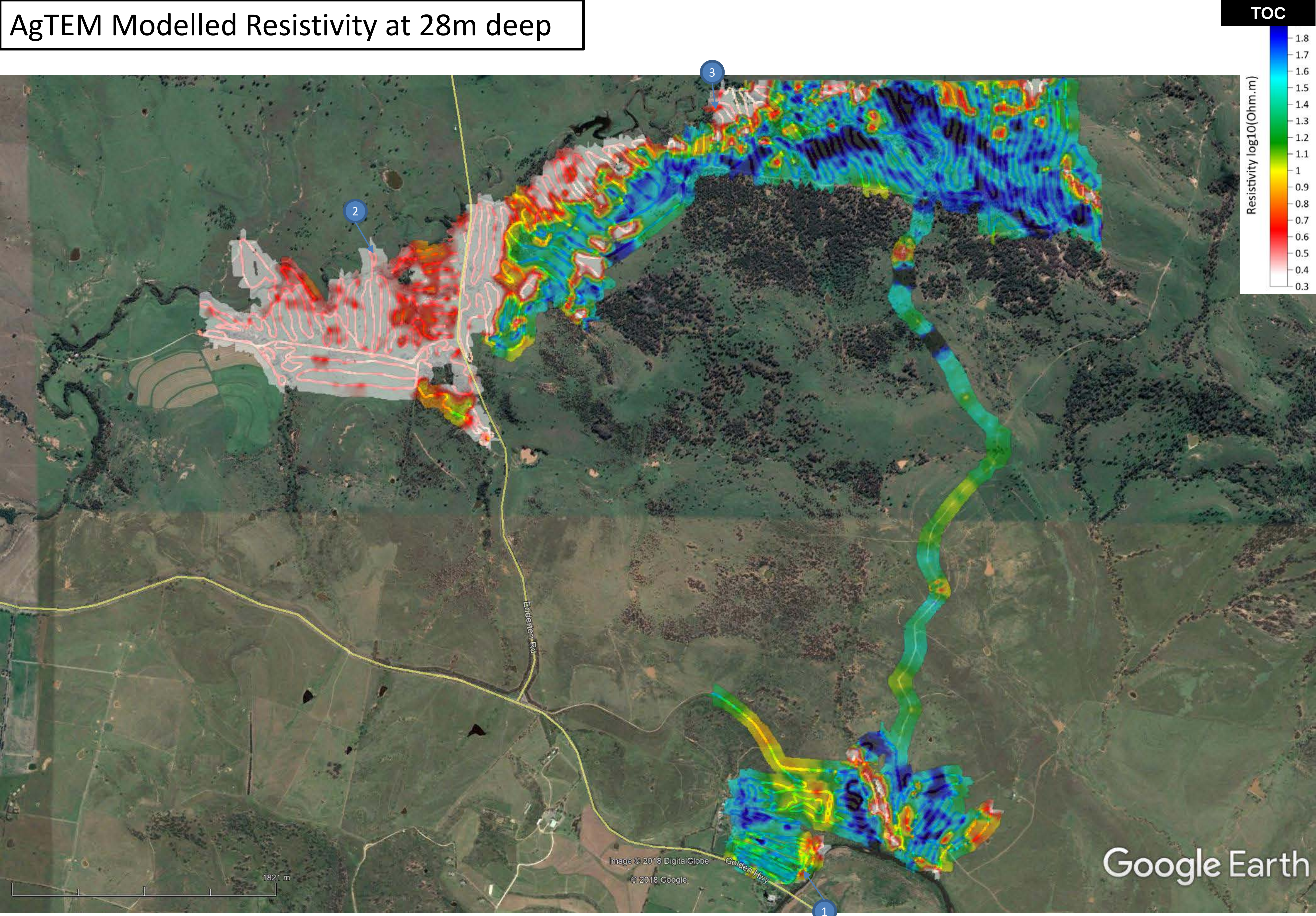


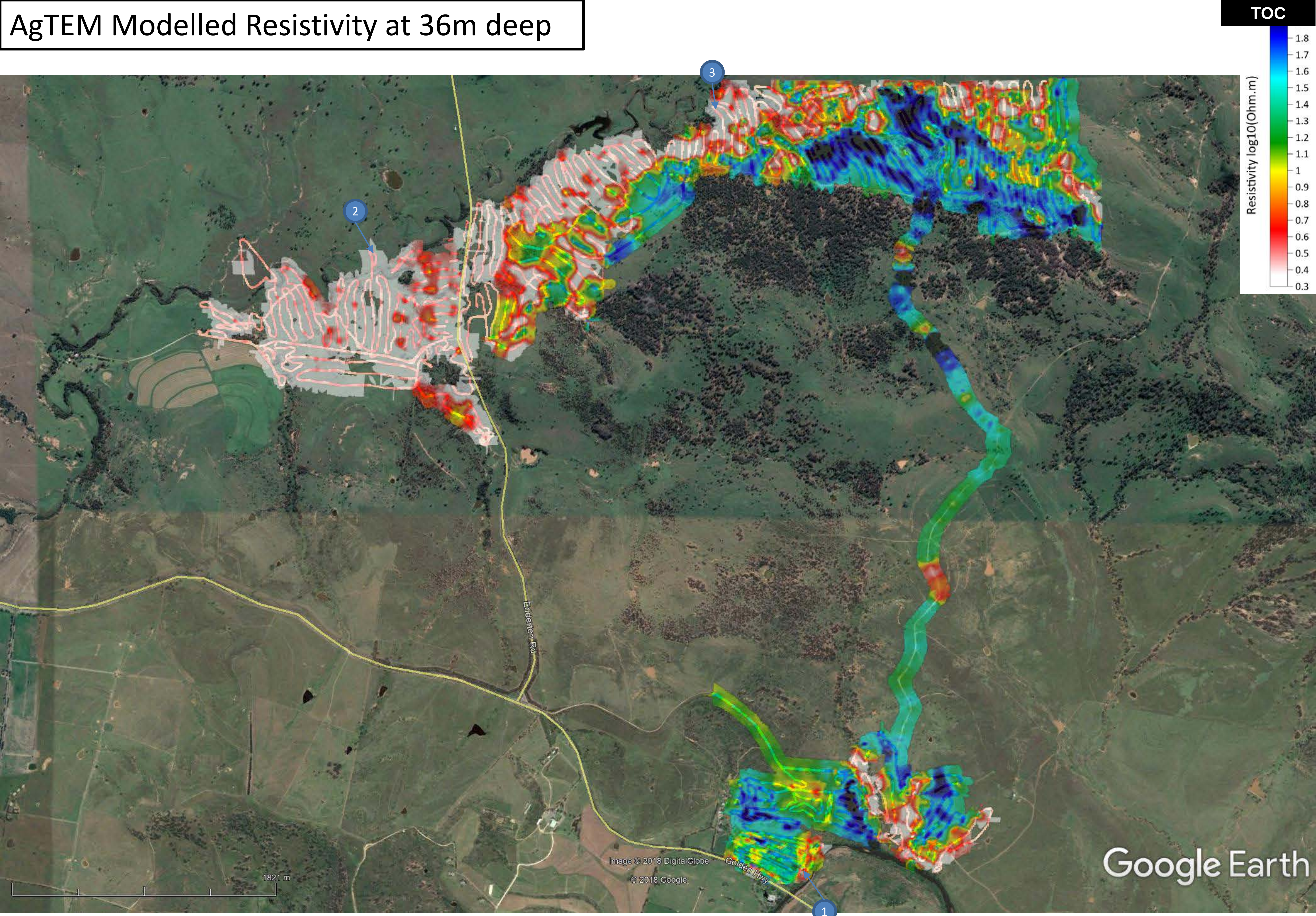
AgTEM Modelled Resistivity at 20m deep



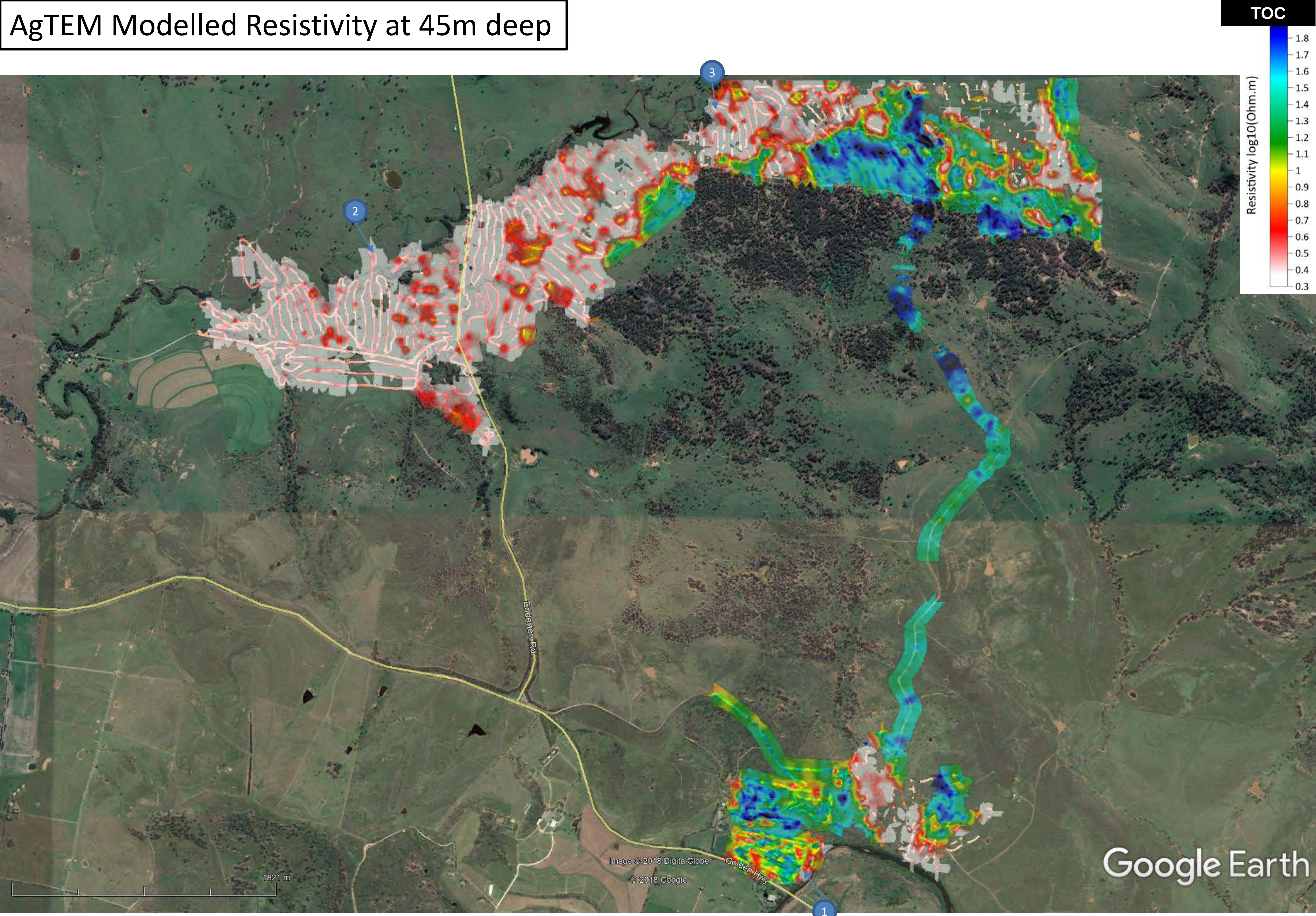
AgTEM Modelled Resistivity at 28m deep



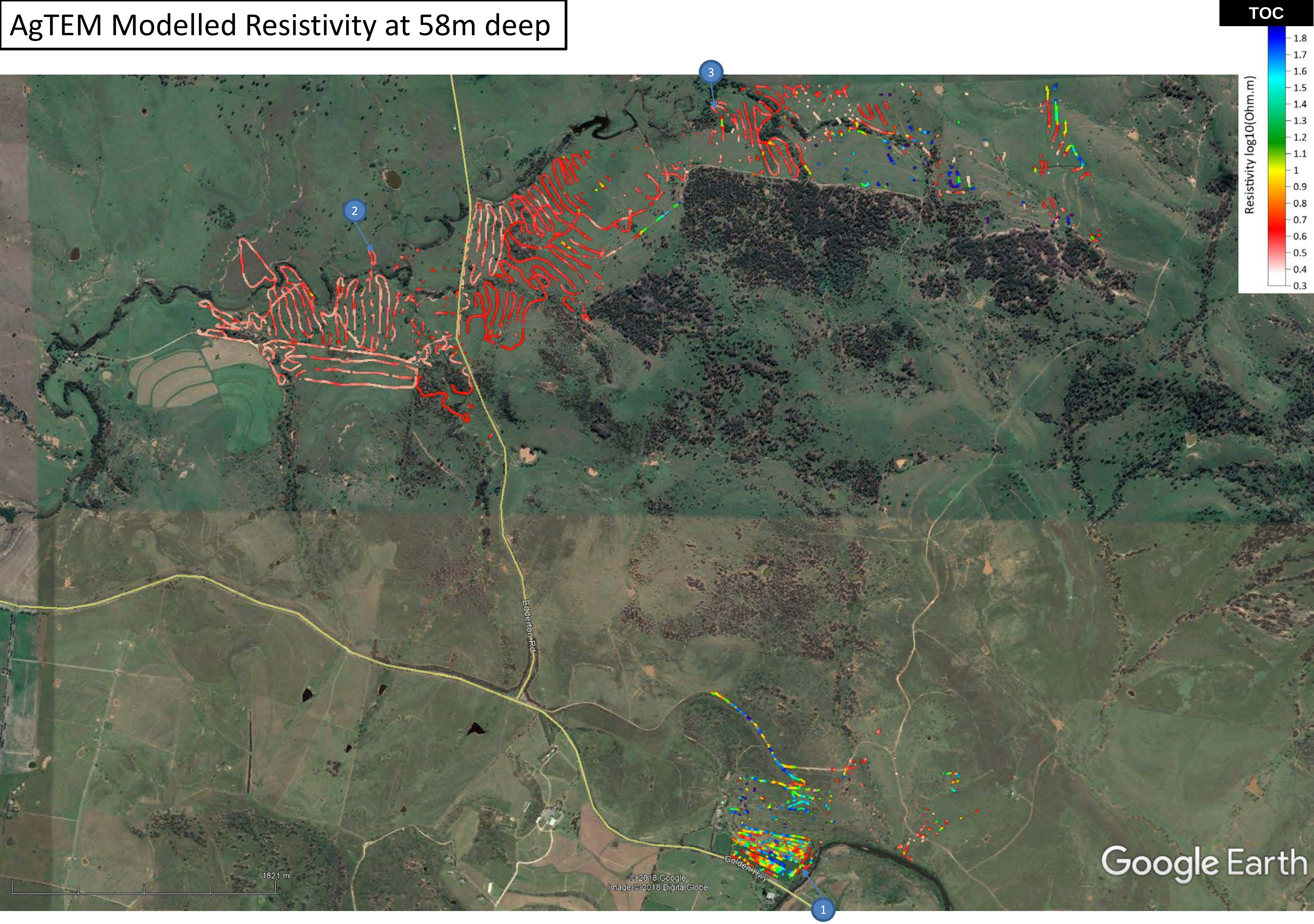
AgTEM Modelled Resistivity at 36m deep



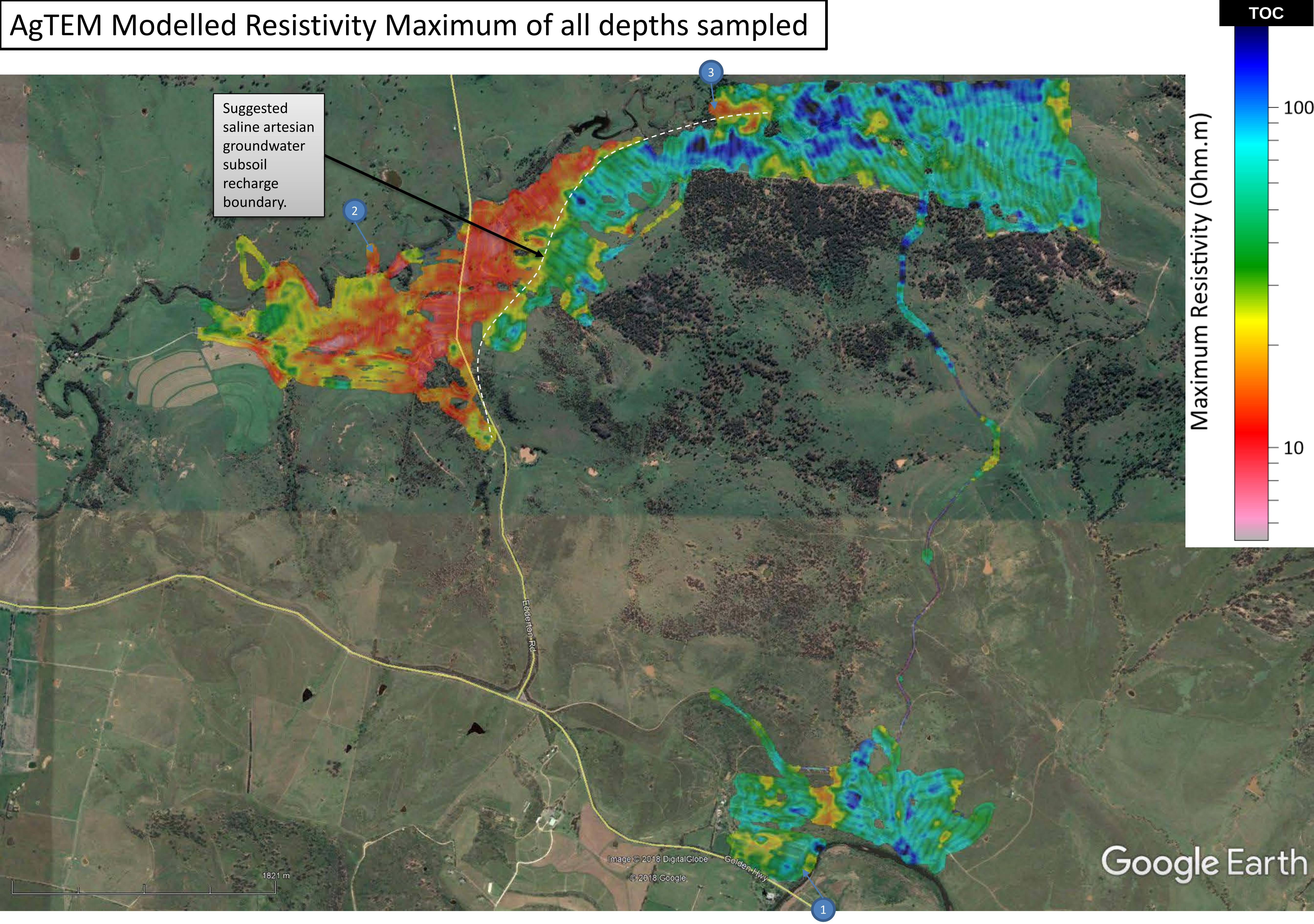
AgTEM Modelled Resistivity at 45m deep



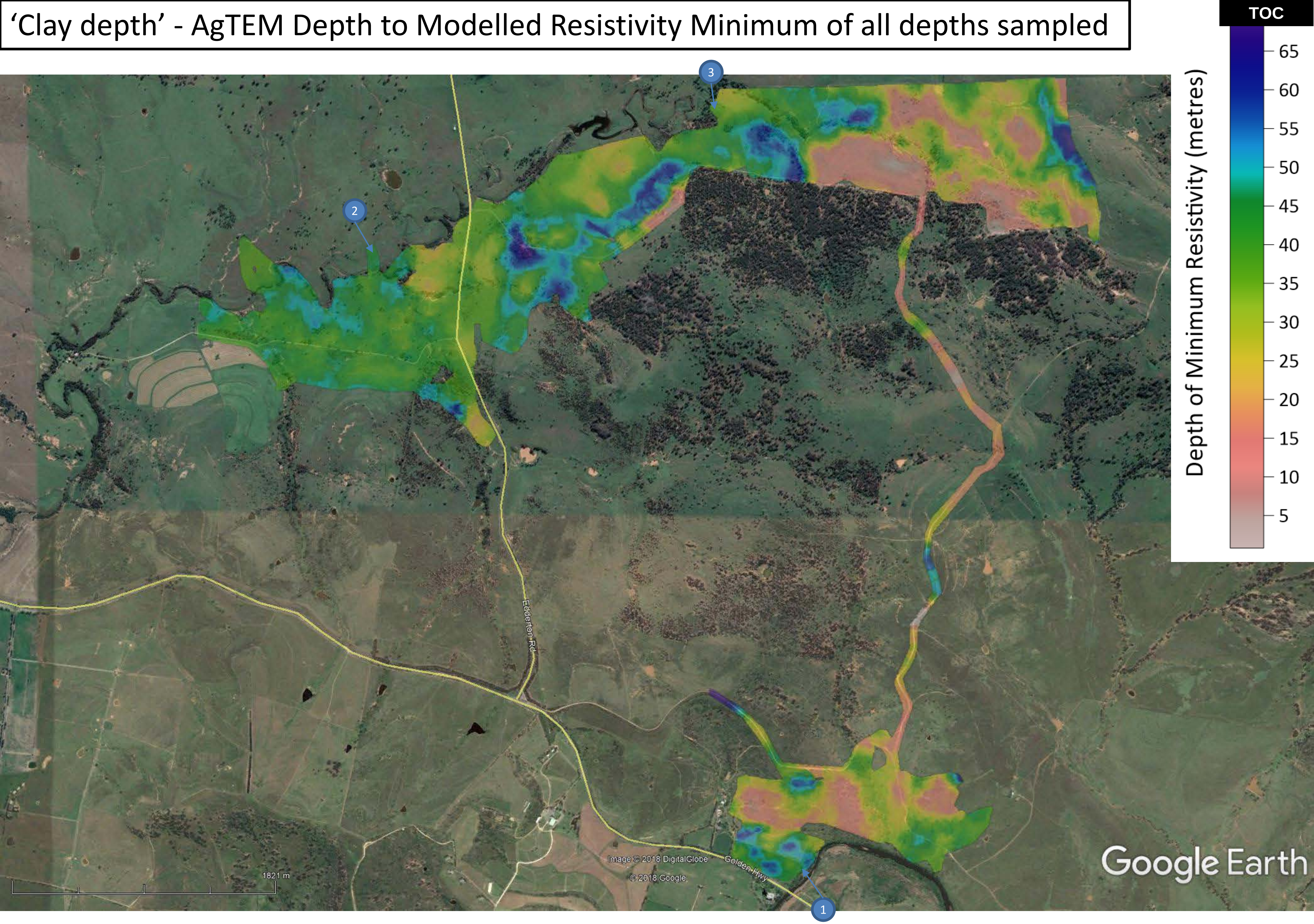
AgTEM Modelled Resistivity at 58m deep



AgTEM Modelled Resistivity Maximum of all depths sampled



‘Clay depth’ - AgTEM Depth to Modelled Resistivity Minimum of all depths sampled



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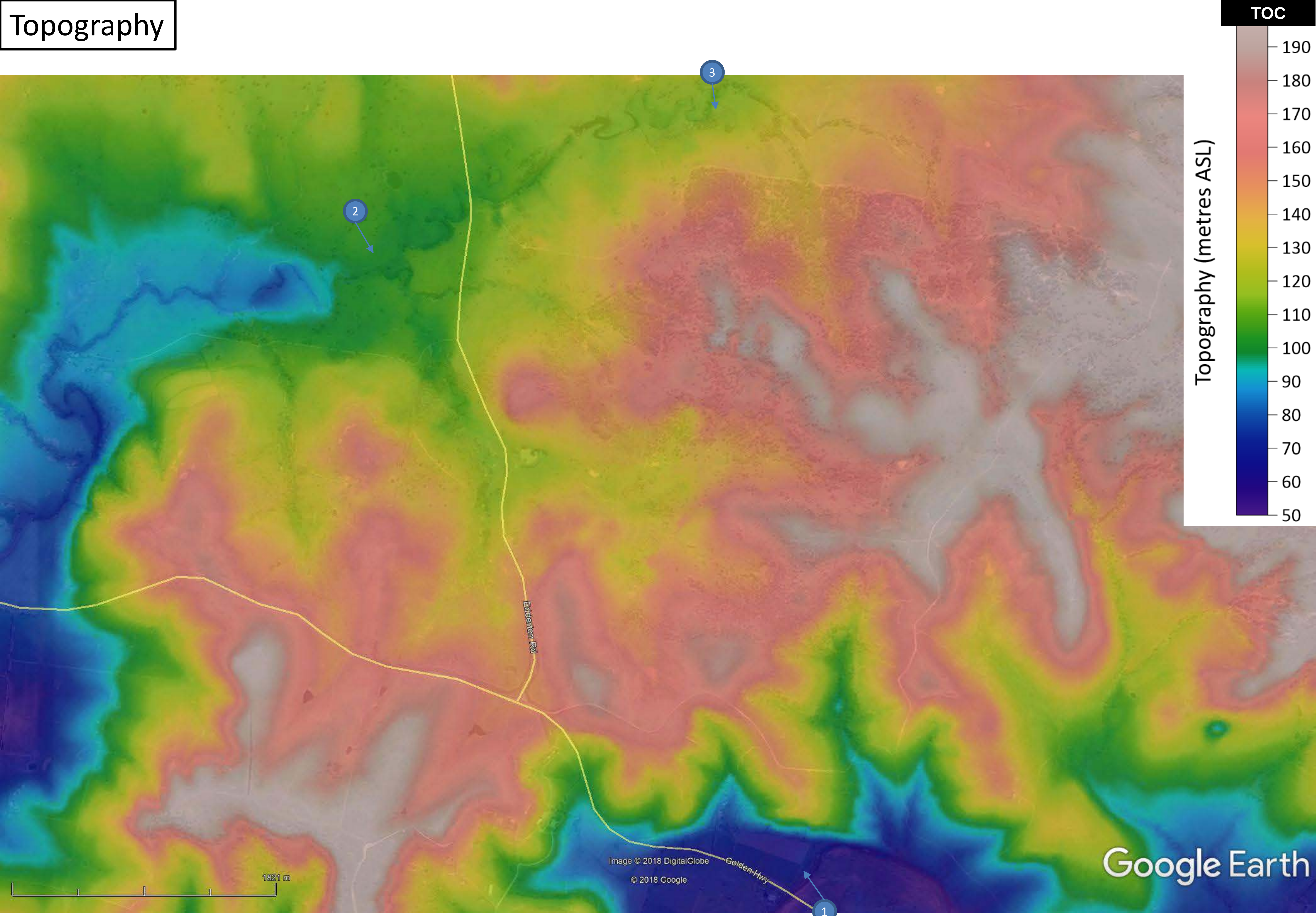
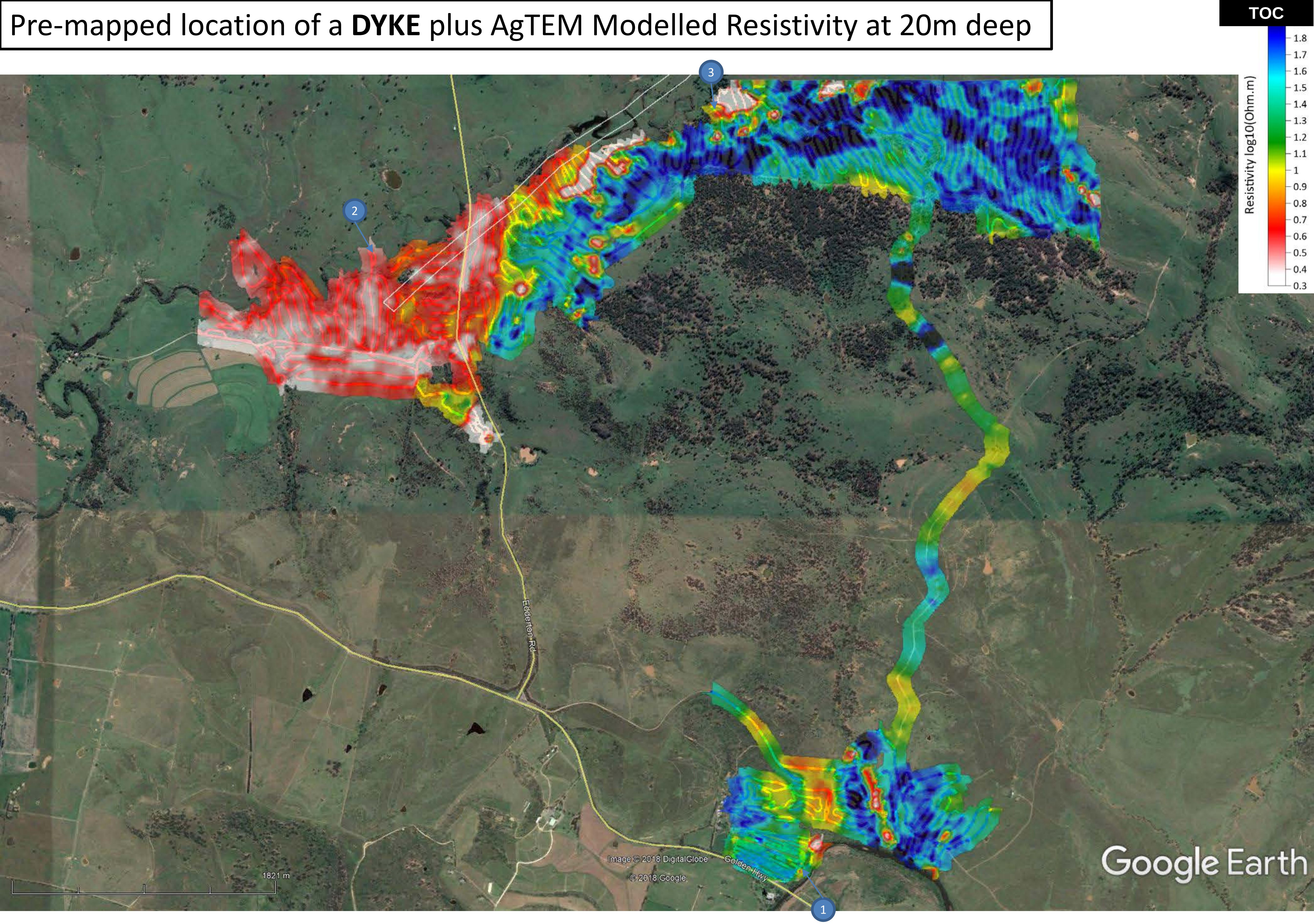


TOC
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
Topography (metres ASL)
3
2
1
Edderton Rd
Golden Hwy
1821 m
Image © 2018 DigitalGlobe
© 2018 Google
Google Earth

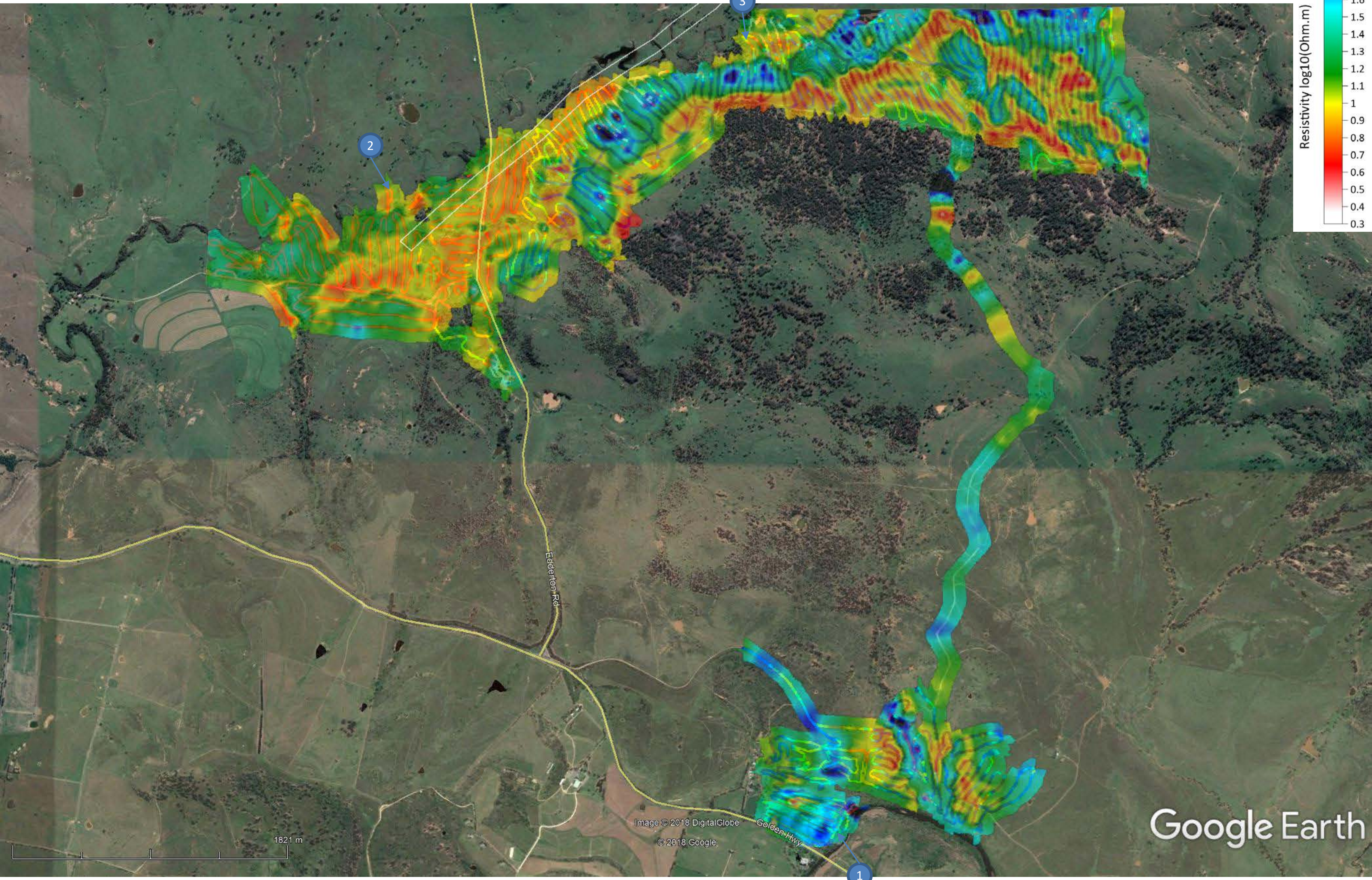
Pre-mapped location of a **DYKE** plus AgTEM Modelled Resistivity at 20m deep

TOC

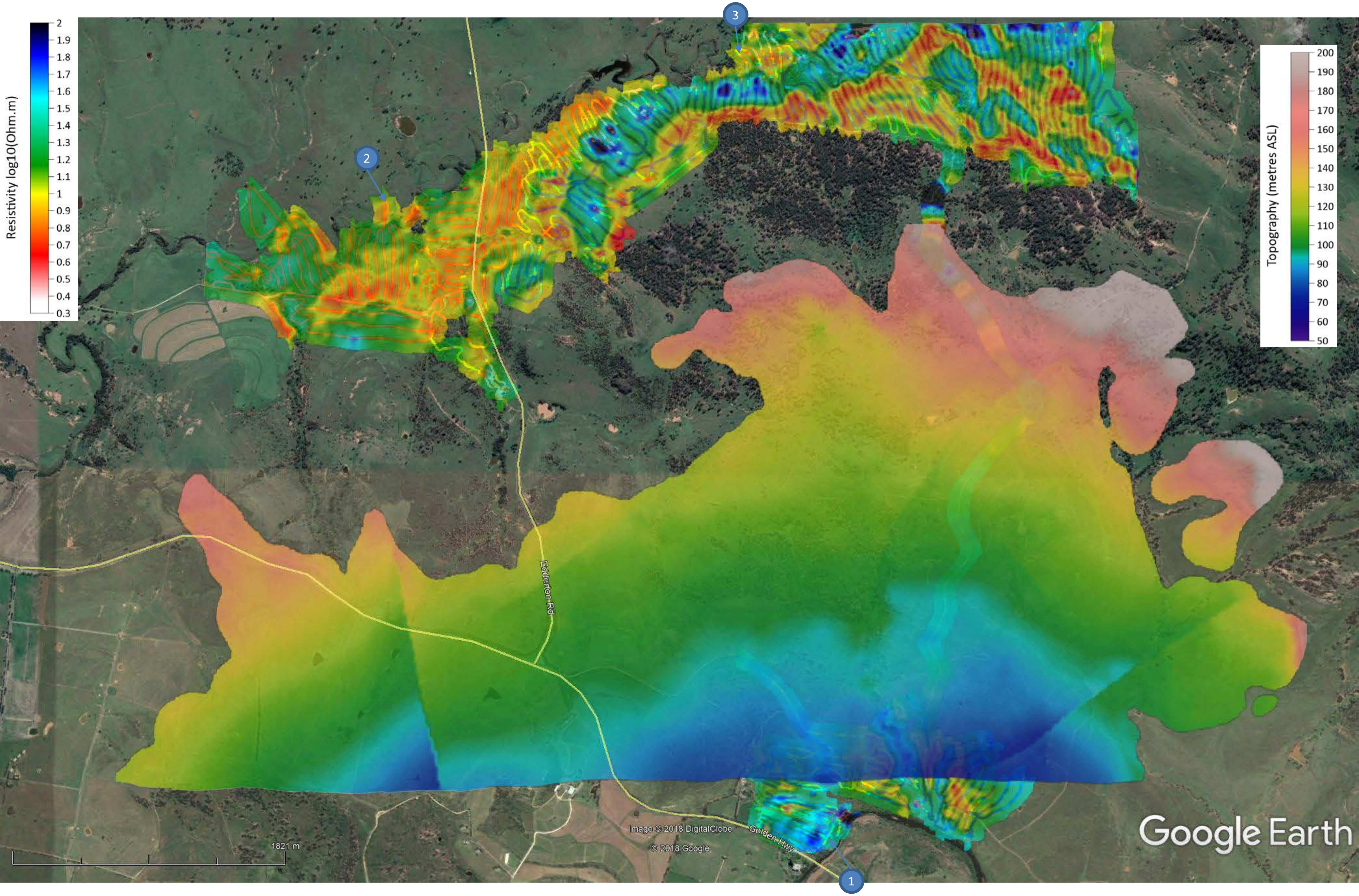


Pre-mapped location of a **DYKE** plus AgTEM Modelled Resistivity at 4m deep

TOC

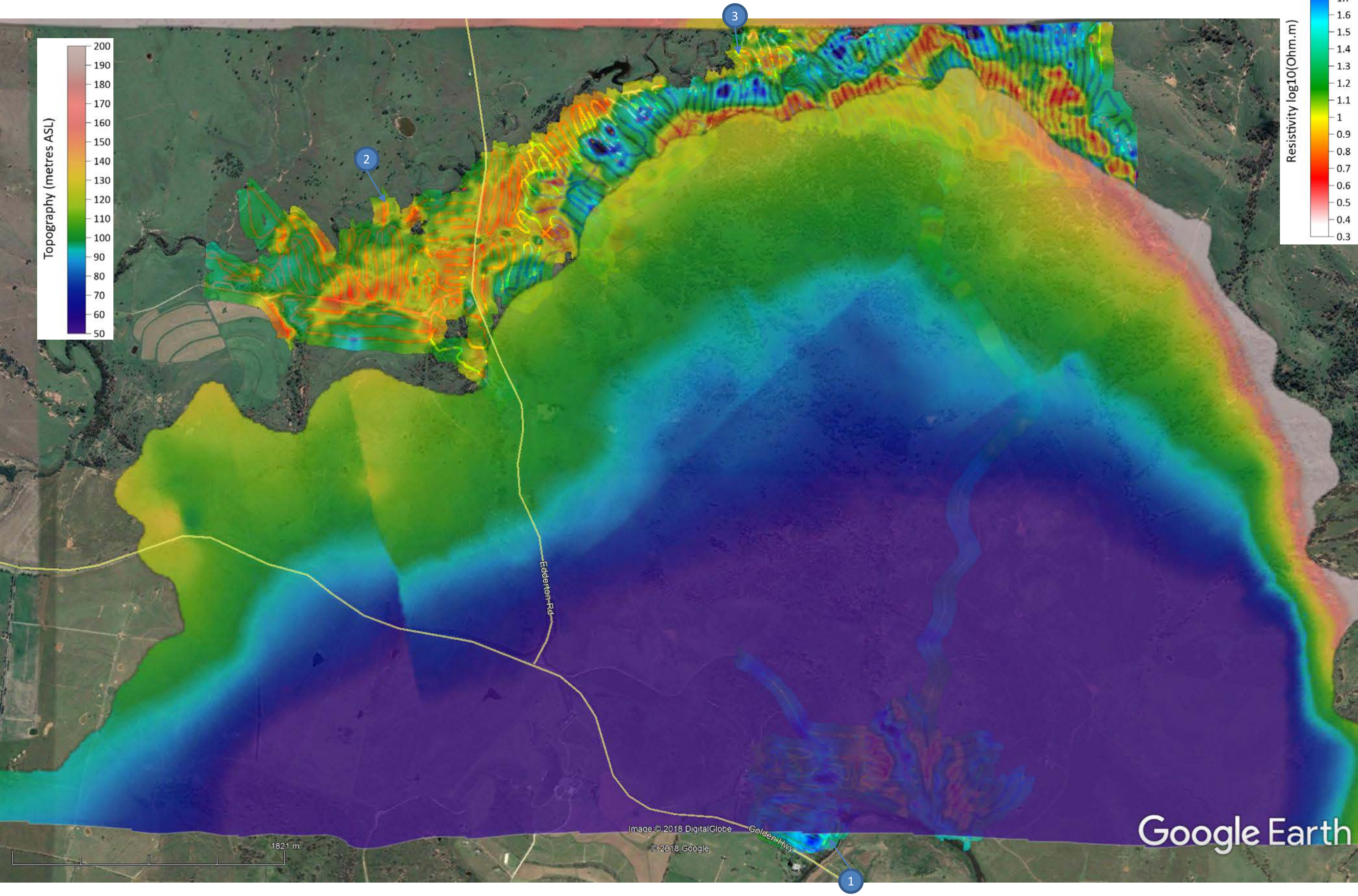


Elevation of the roof of the **Whybrow Working Section** + AgTEM Modelled Resistivity at 4m deep

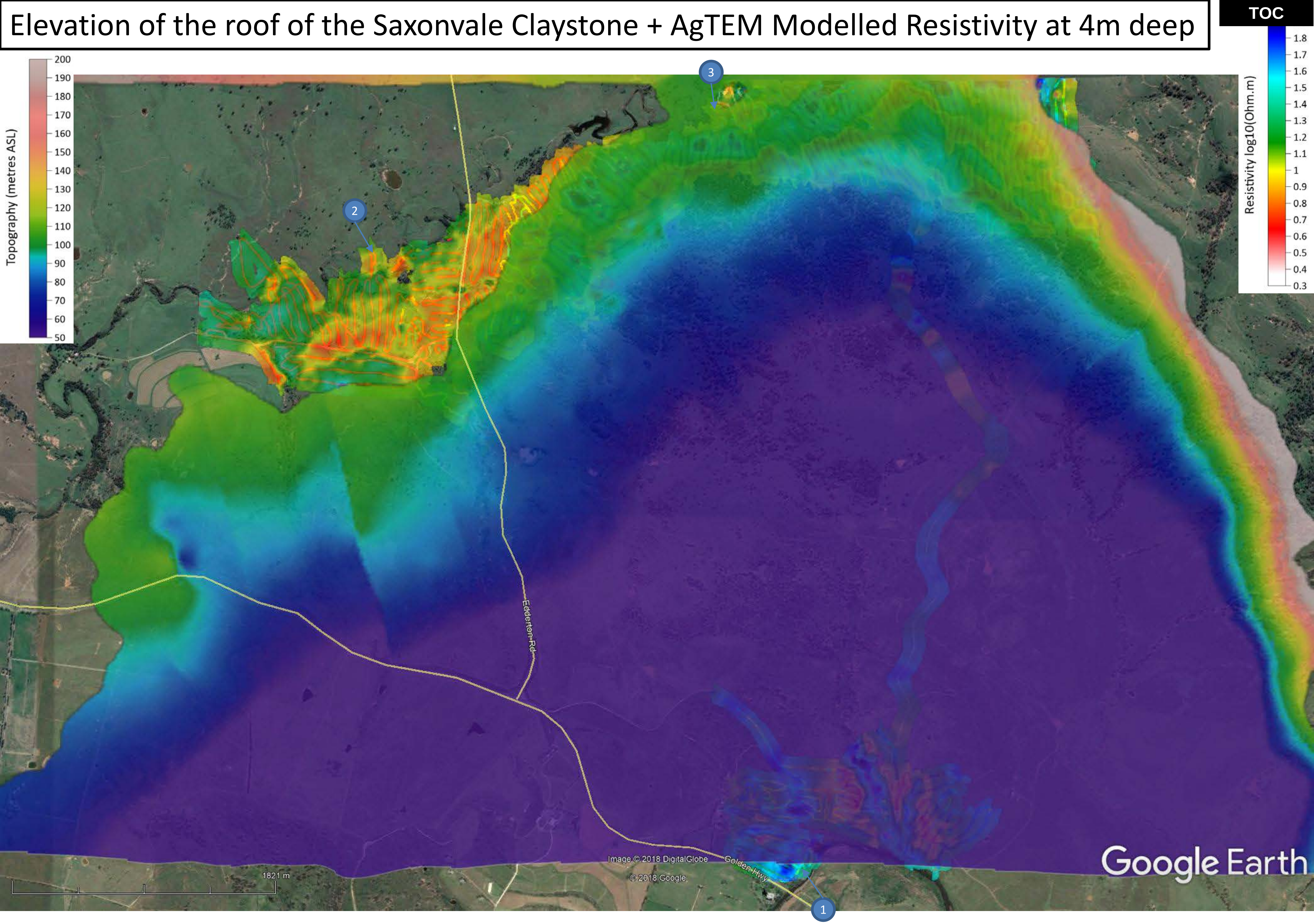


Elevation of the roof of the Whynot Seam WS + AgTEM Modelled Resistivity at 4m deep

TOC

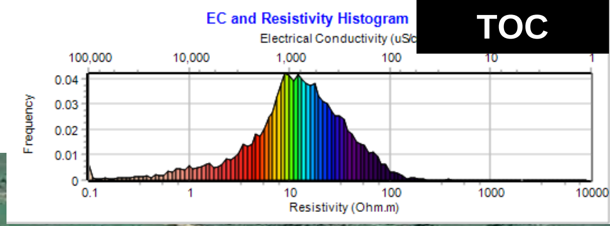


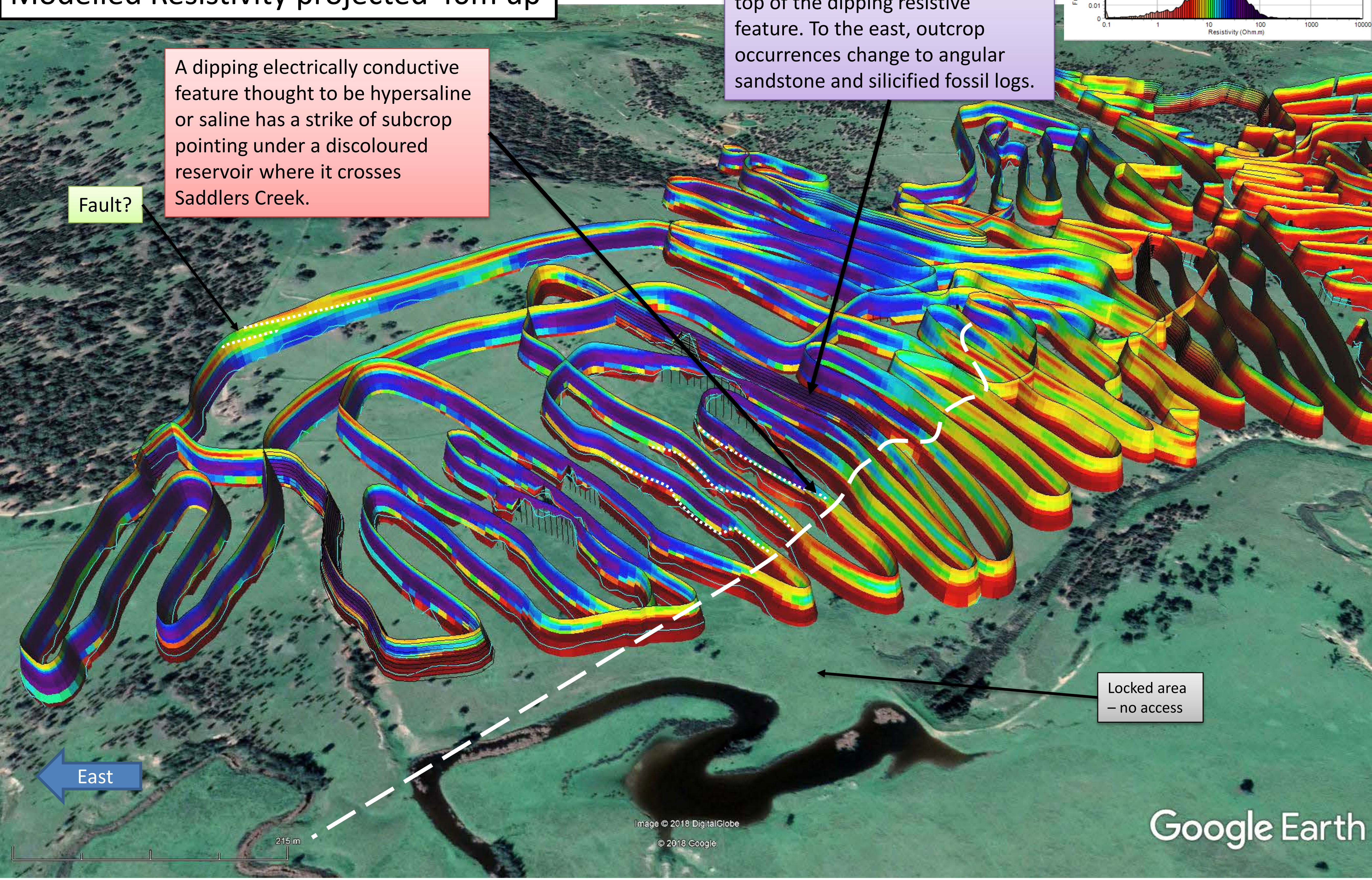
Elevation of the roof of the Saxonvale Claystone + AgTEM Modelled Resistivity at 4m deep



Subcrop of the Saxonville Claystone - Modelled Resistivity projected 40m up

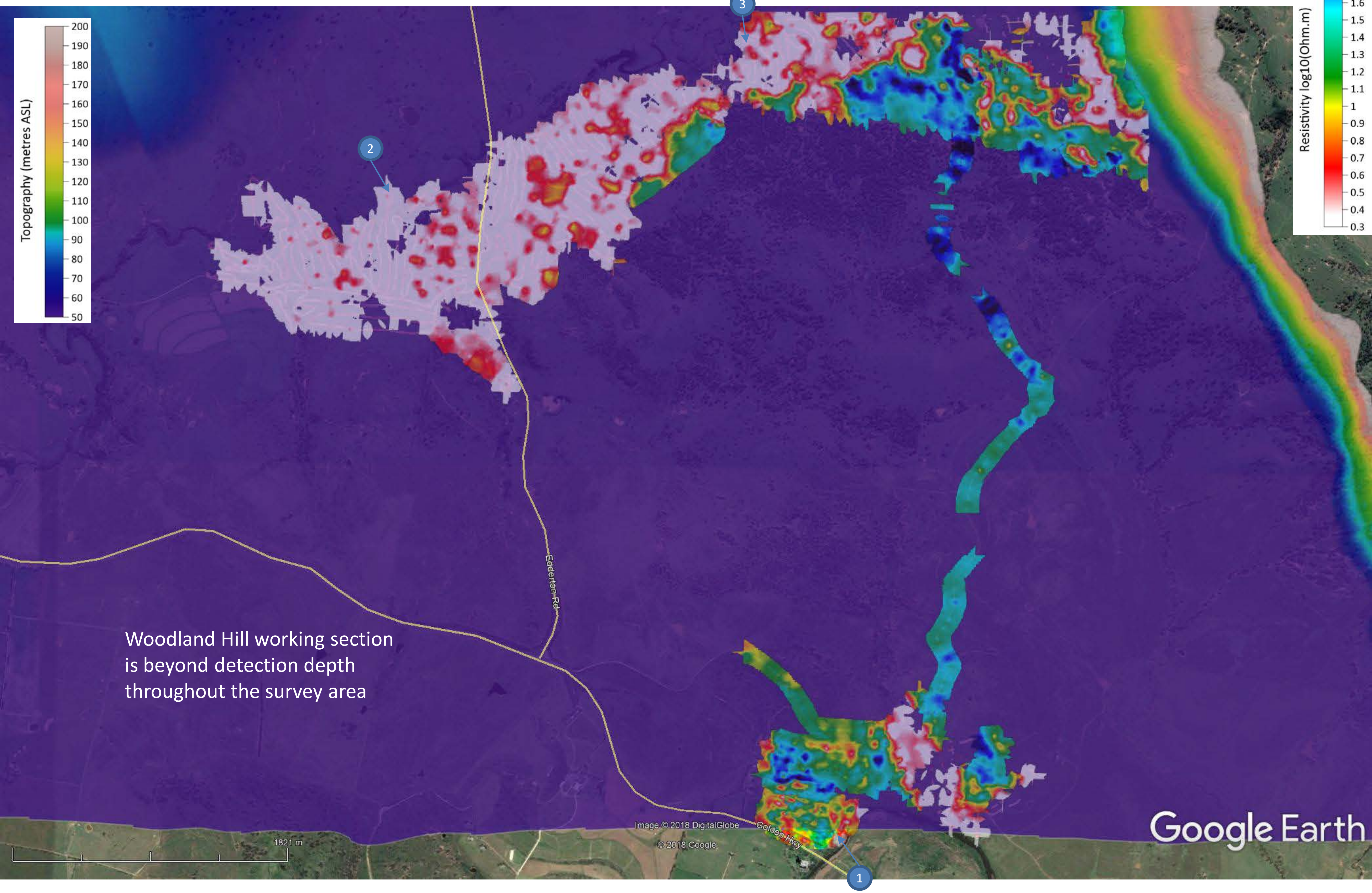
TOC





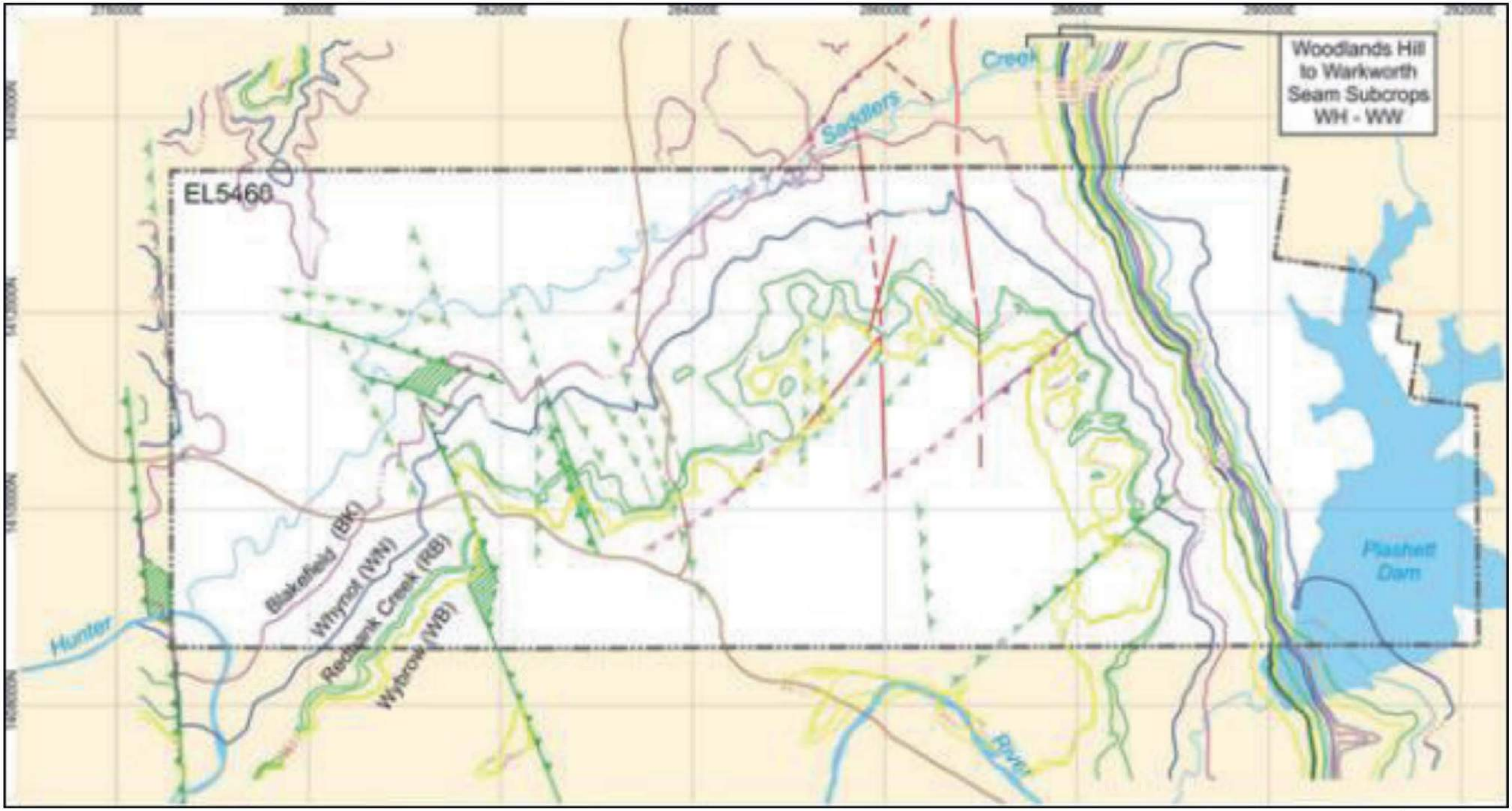
Elevation of the roof of the Woodlands Hill WS + AgTEM Modelled Resistivity at 45m deep

TOC



Subcrop and fault positions from an old report

Subcrops have been transcribed onto an image in this report to improve viewability



Source: MineCraft, 2006

Sourced from

Project number	G1725
Document title	Drayton South Coal Project EIS – Groundwater Impact Assessment
Site address	Hansen Bailey Environmental Consultants Pty Ltd
File name	G1725_Drayton_South_Final_V2.docx

HUNTER RIVER SITE - Background Image

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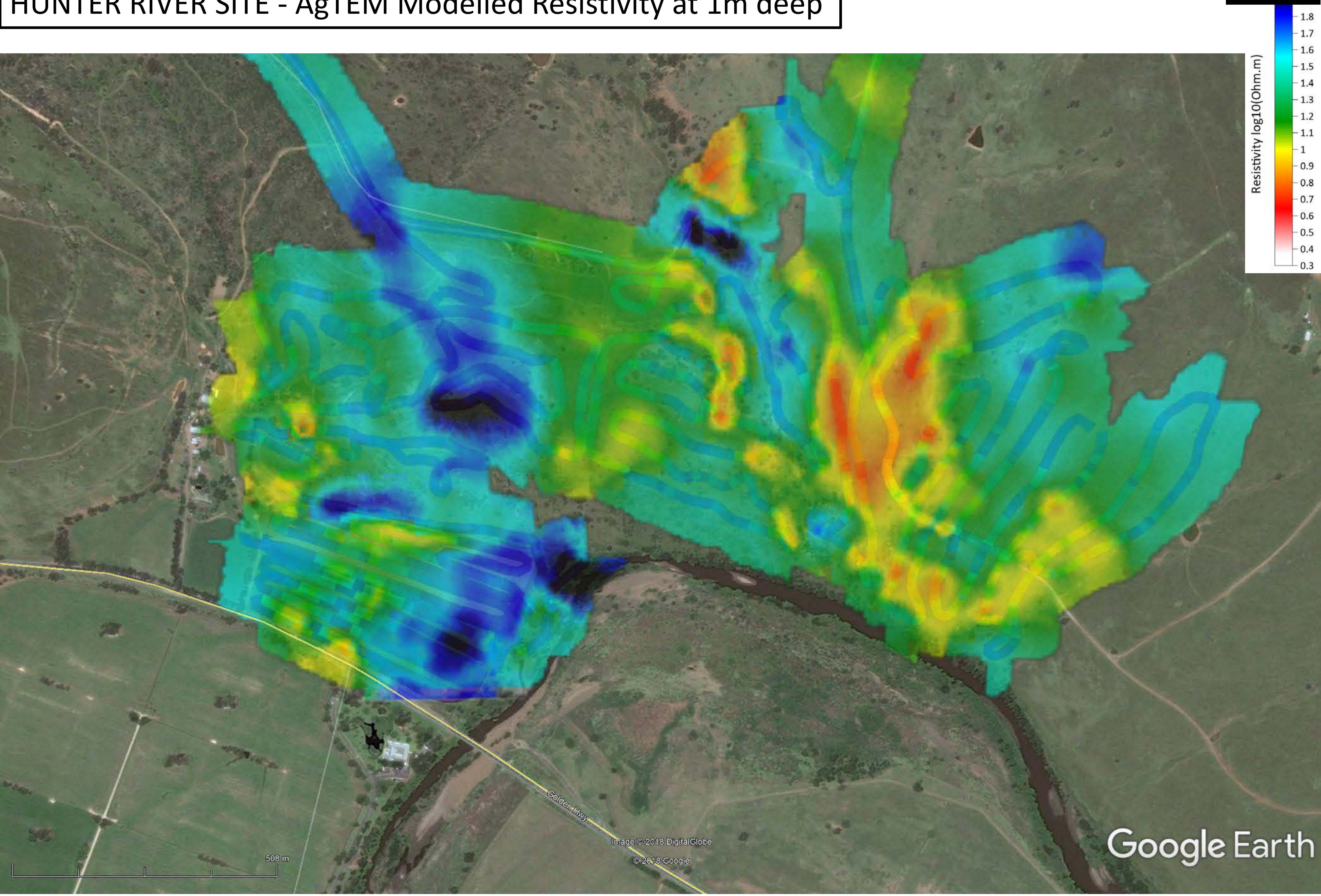
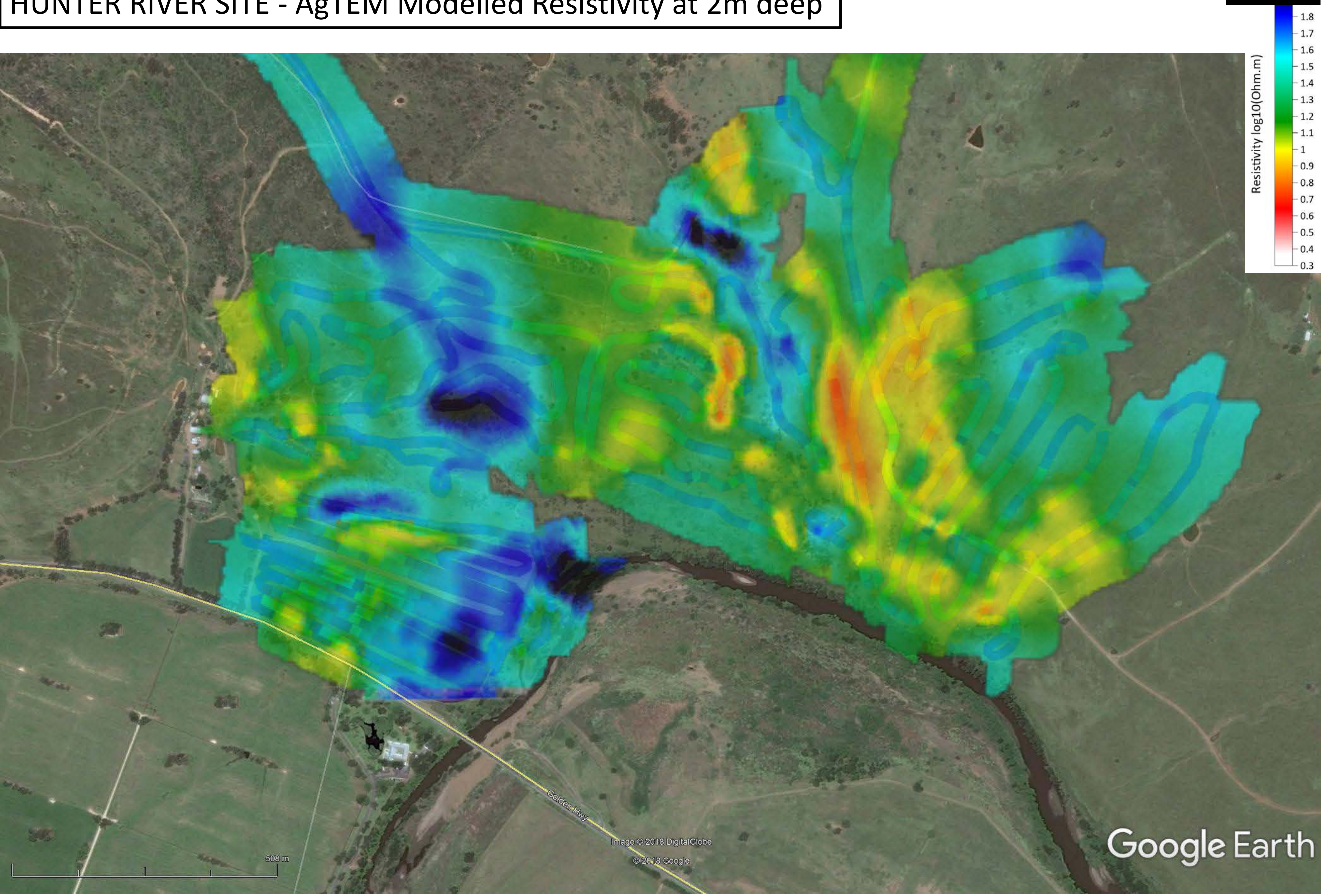
HUNTER RIVER SITE - AgTEM Modelled Resistivity at 1m deep

TOC



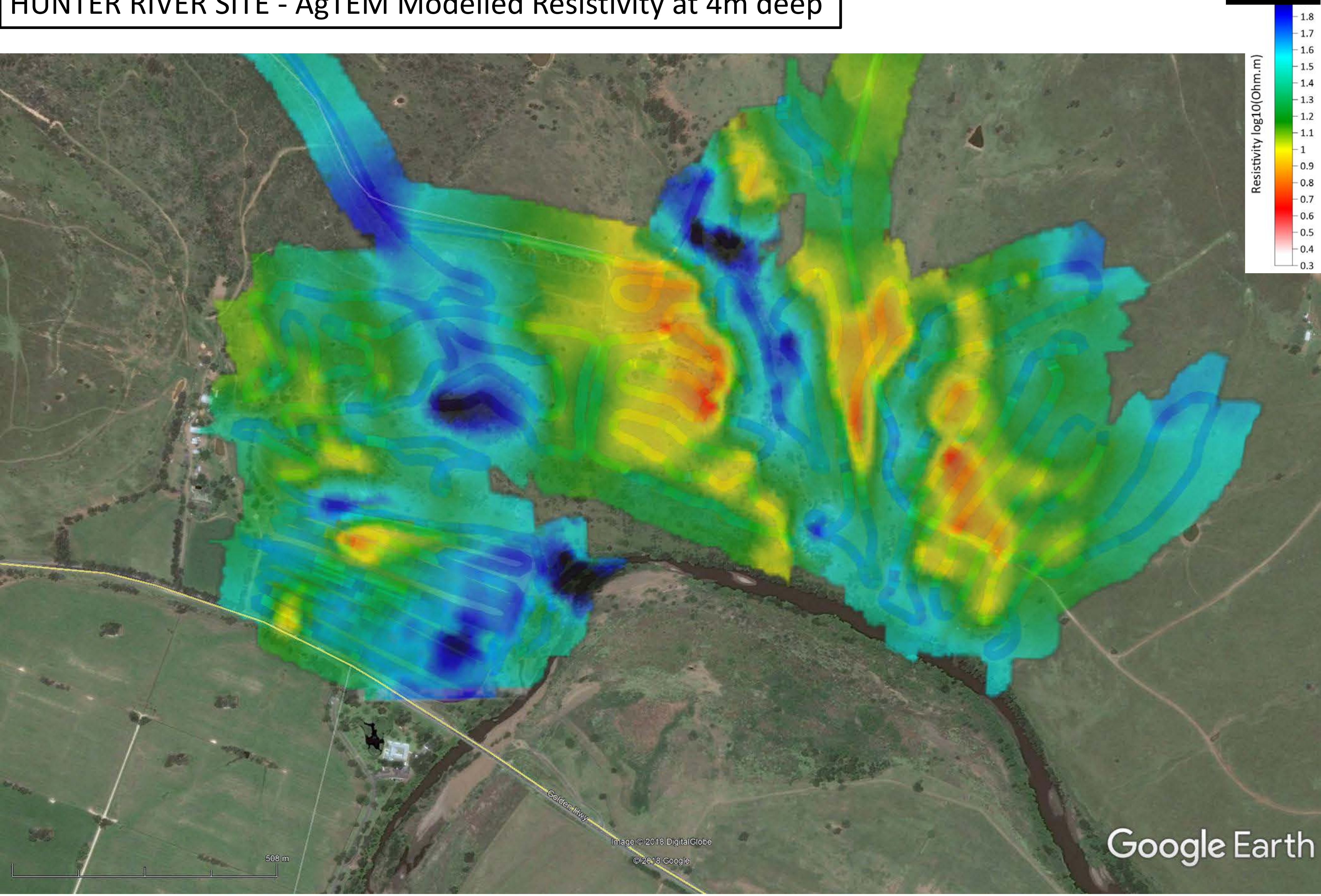
HUNTER RIVER SITE - AgTEM Modelled Resistivity at 2m deep

TOC

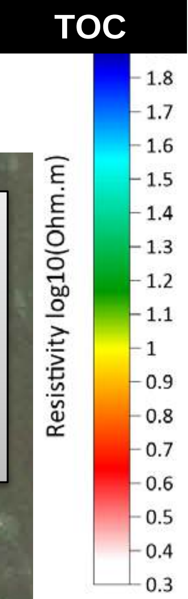


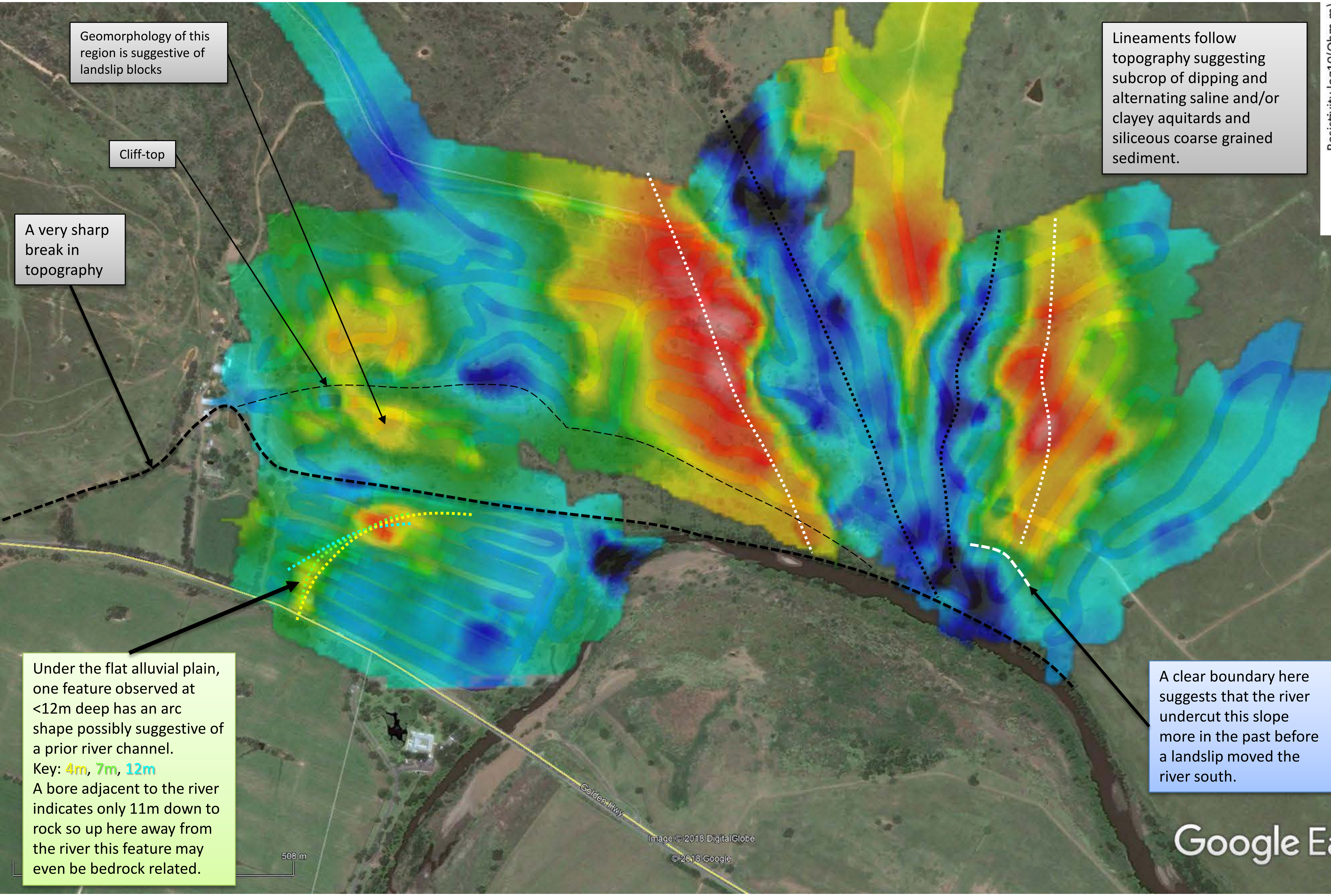
HUNTER RIVER SITE - AgTEM Modelled Resistivity at 4m deep

TOC



HUNTER RIVER SITE - AgTEM Modelled Resistivity at 7m deep





HUNTER RIVER SITE - AgTEM Modelled Resistivity at 12m deep

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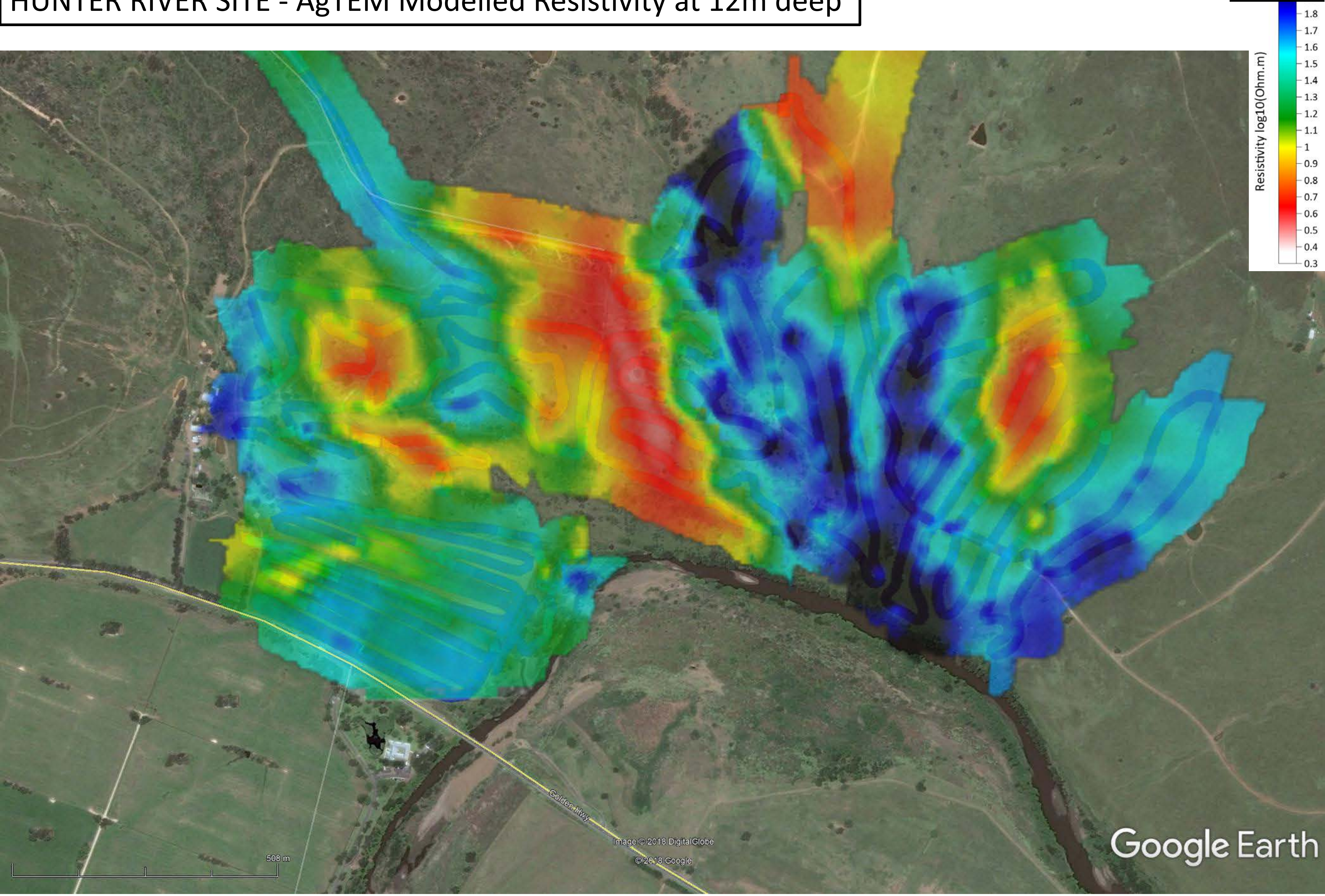
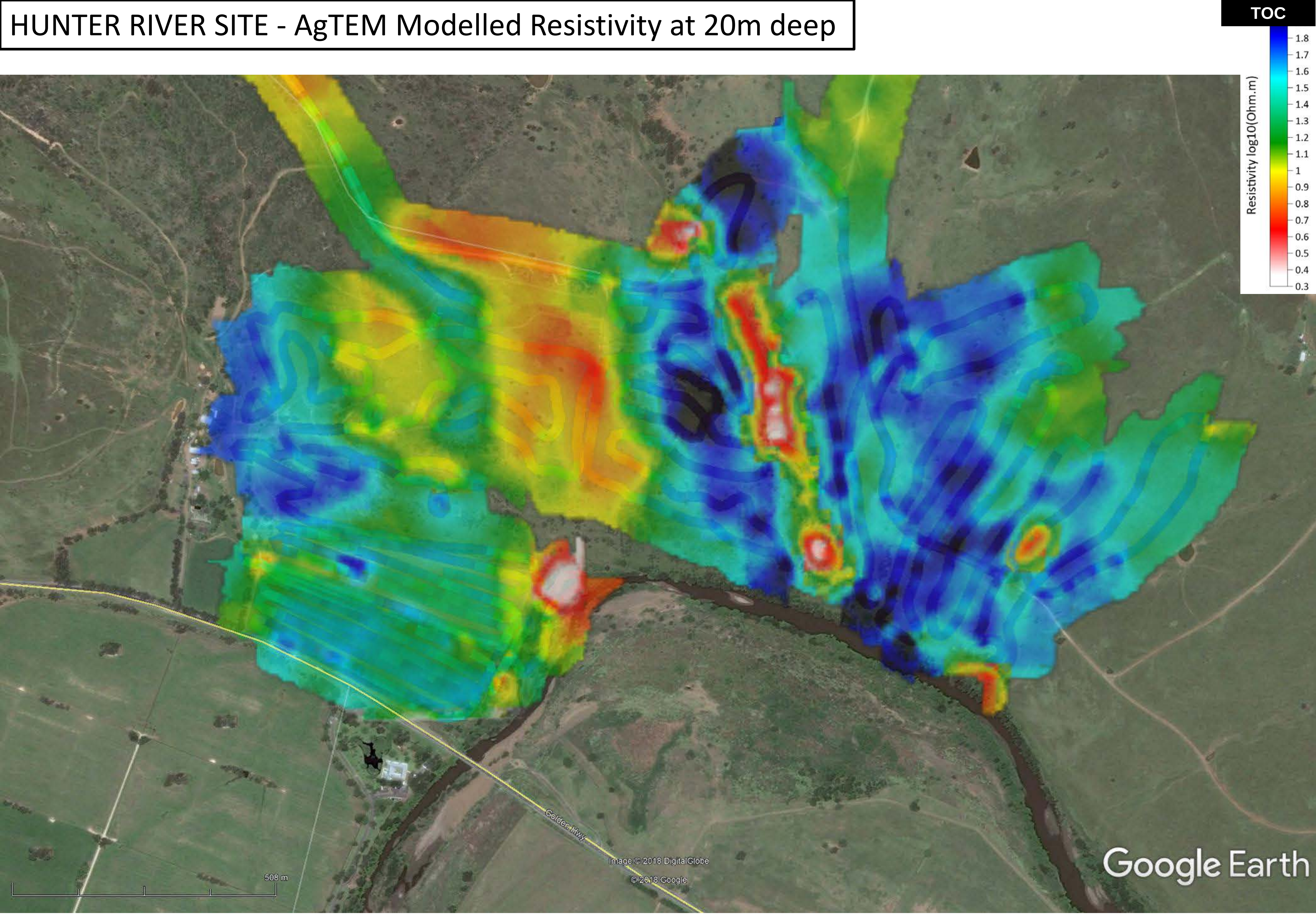
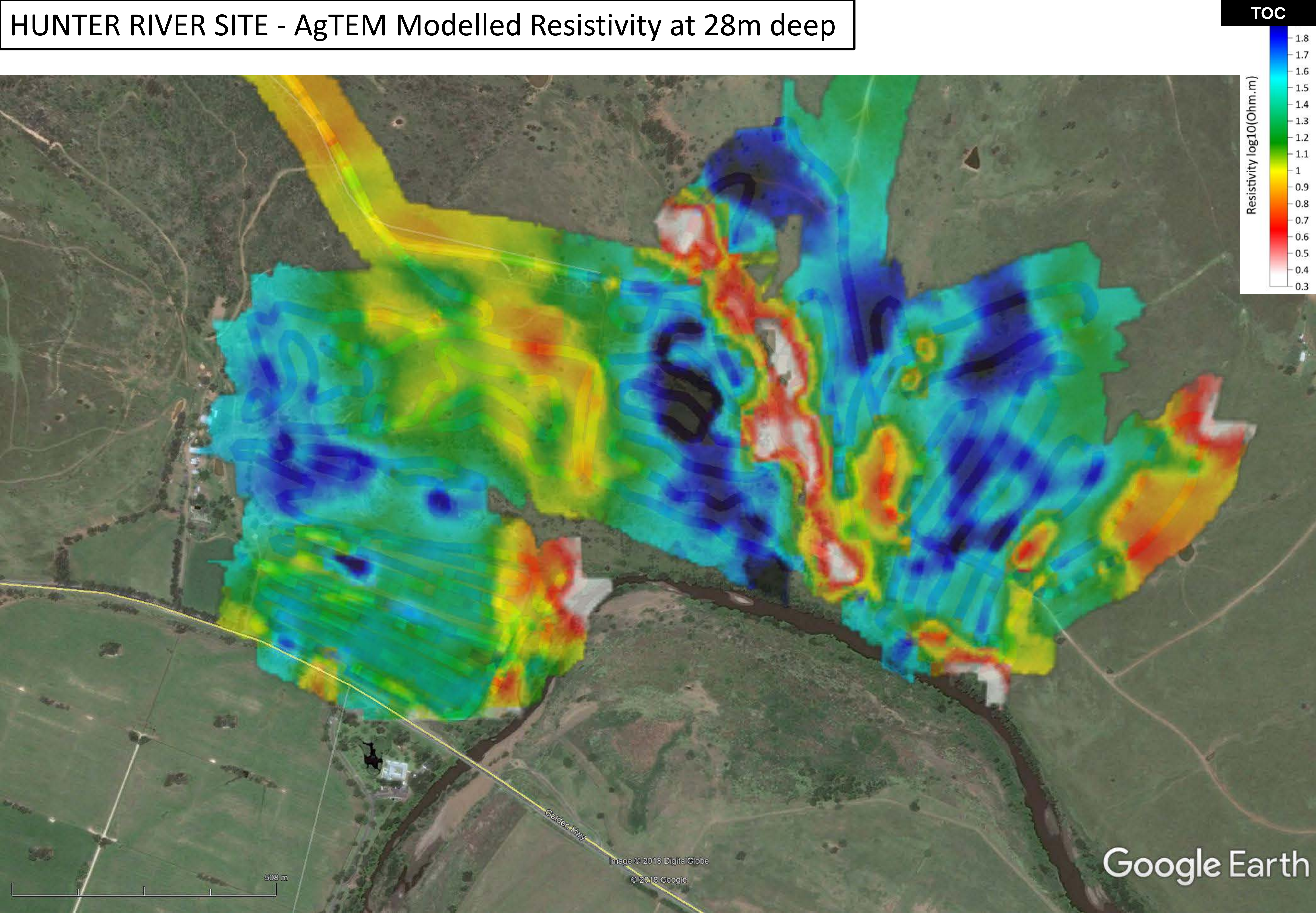


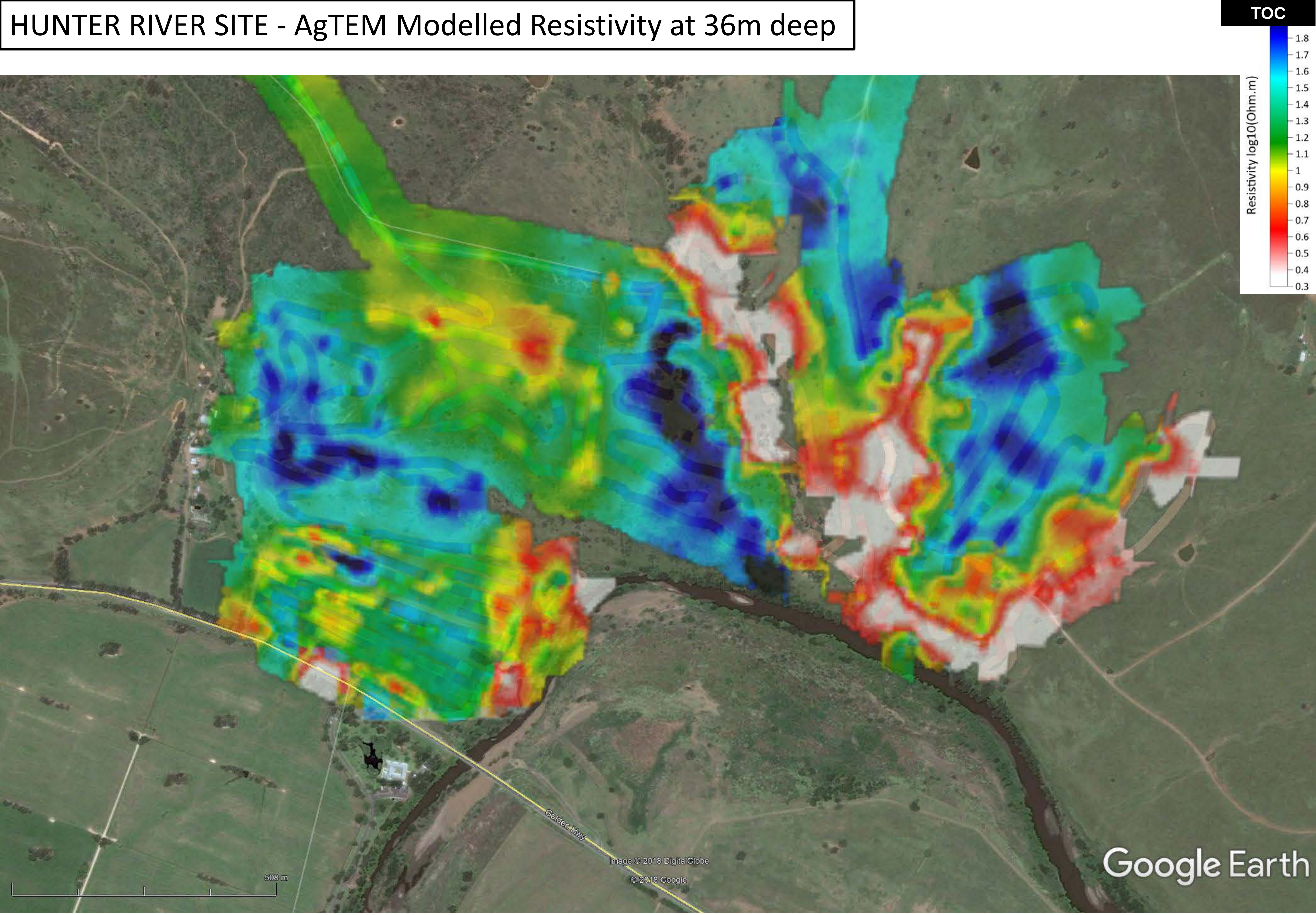
HUNTER RIVER SITE - AgTEM Modelled Resistivity at 20m deep



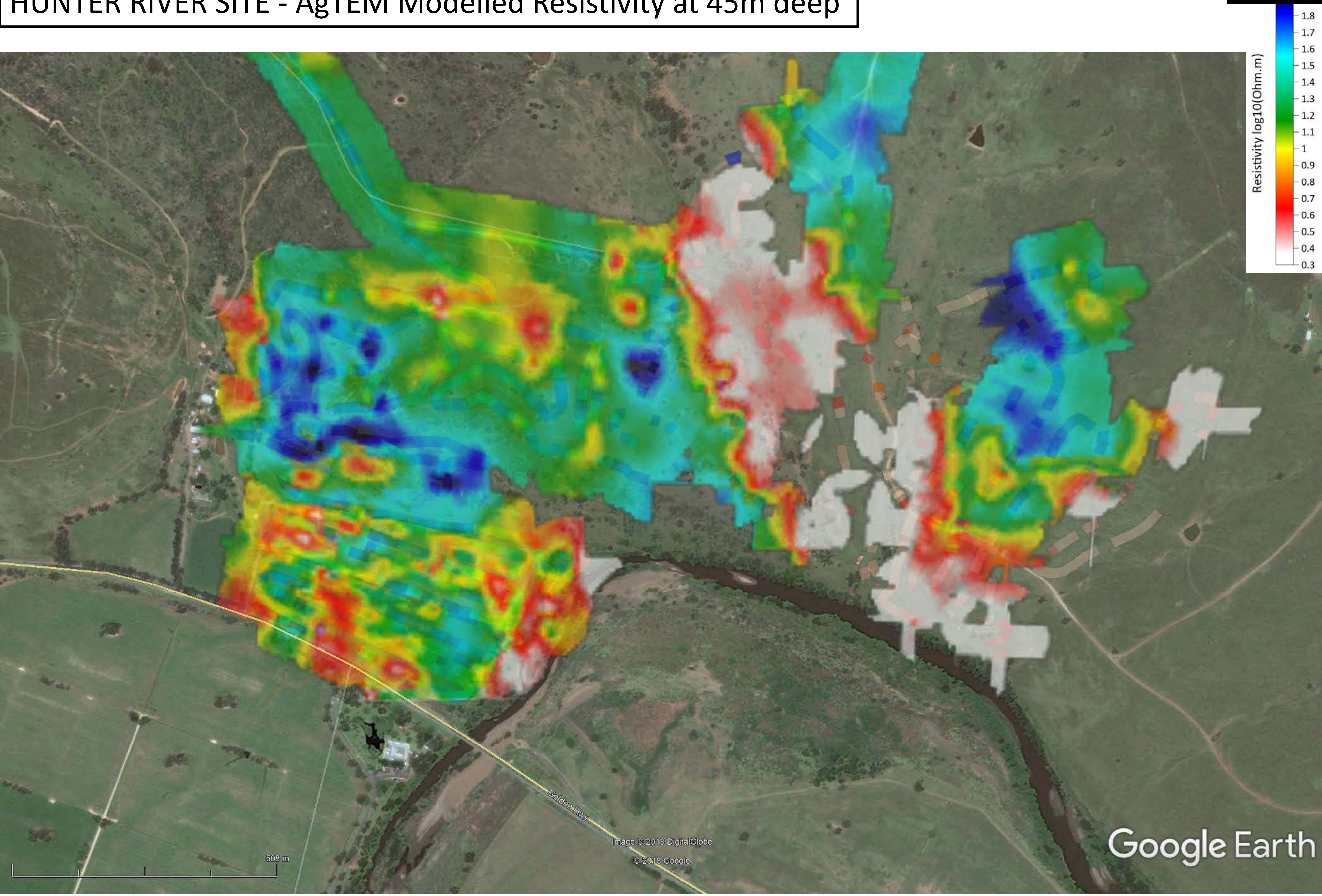
HUNTER RIVER SITE - AgTEM Modelled Resistivity at 28m deep



HUNTER RIVER SITE - AgTEM Modelled Resistivity at 36m deep

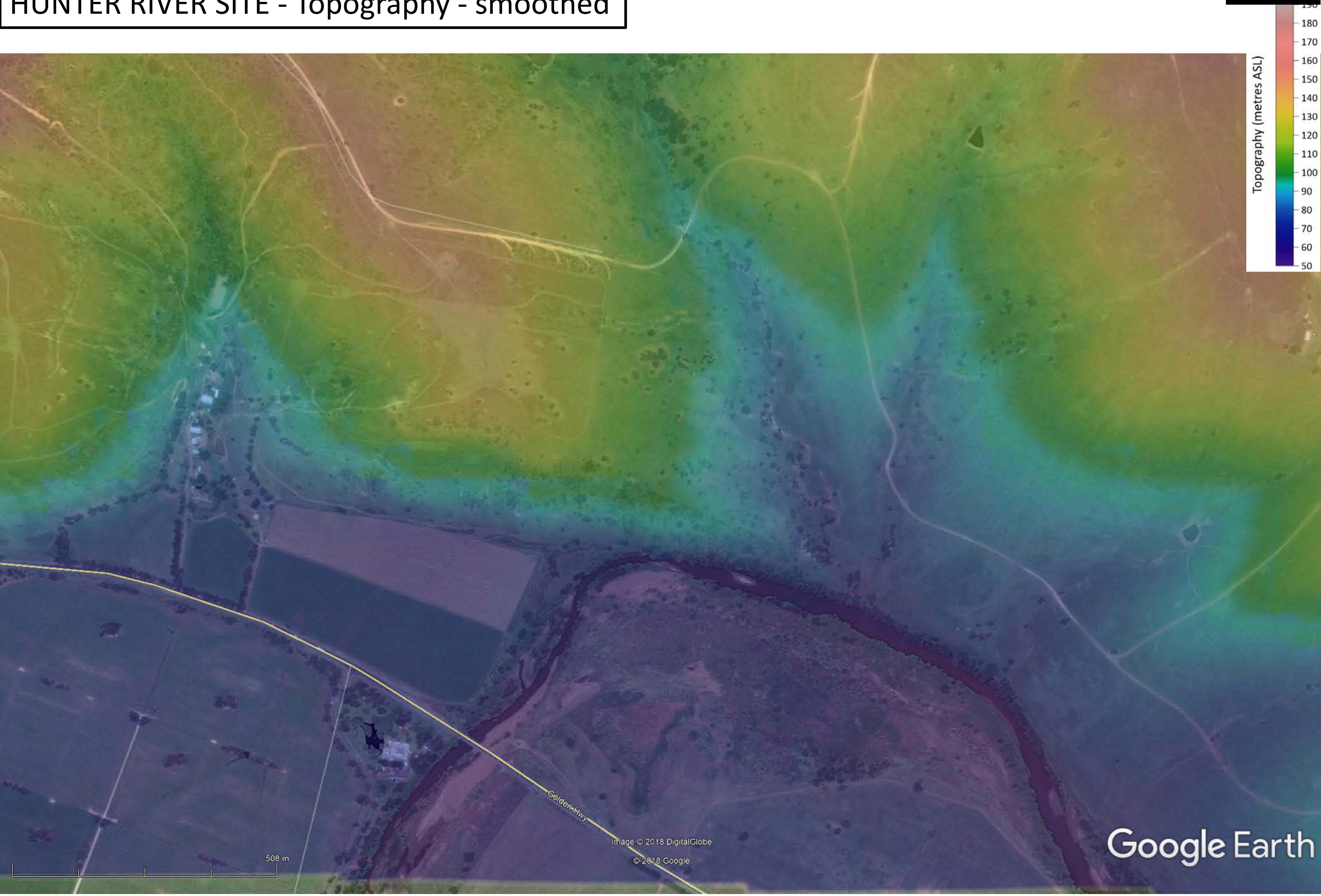


HUNTER RIVER SITE - AgTEM Modelled Resistivity at 45m deep



HUNTER RIVER SITE - Topography - smoothed

TOC



HUNTER RIVER SITE - AgTEM Modelled Resistivity Maximum of all depths sampled

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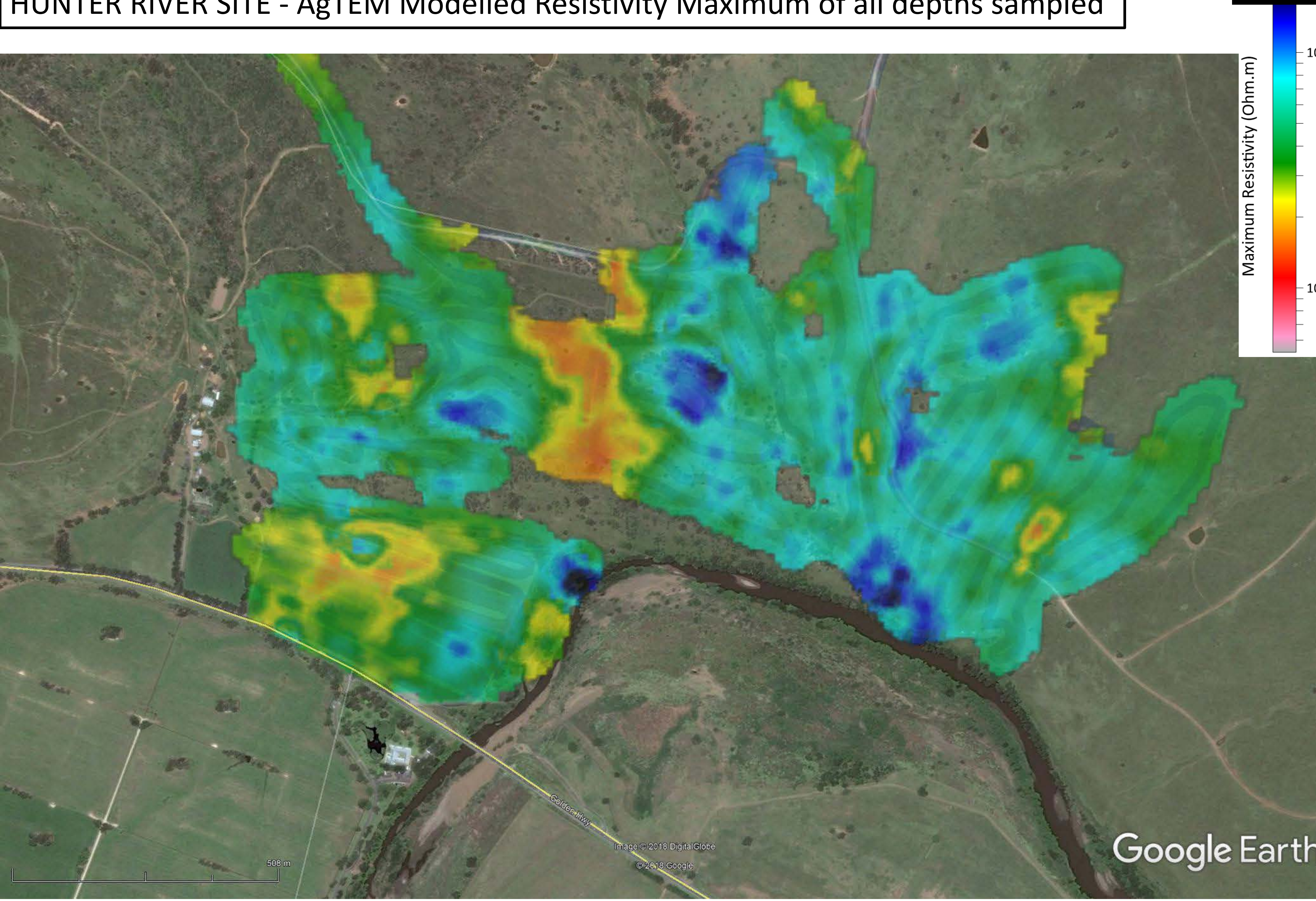
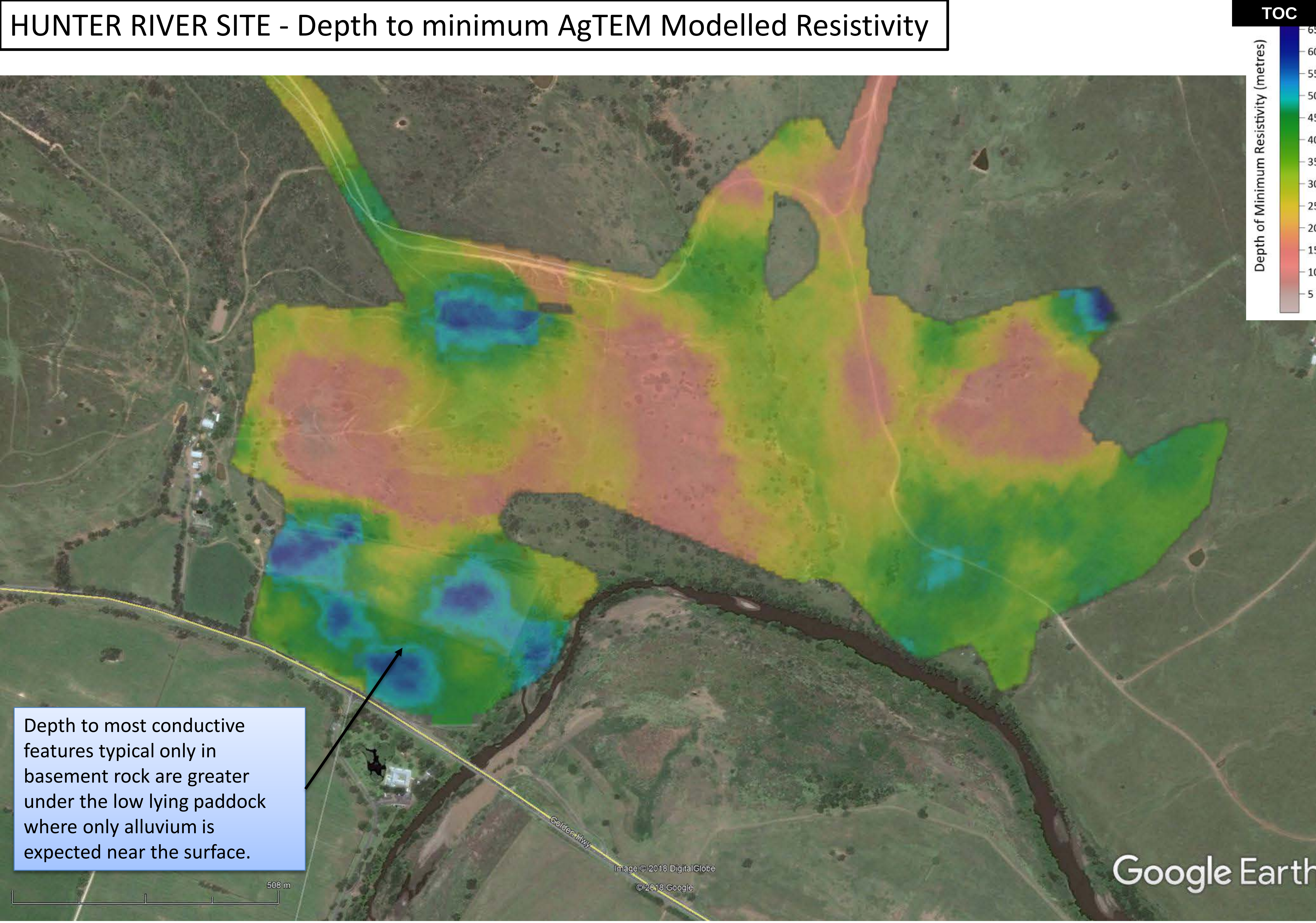
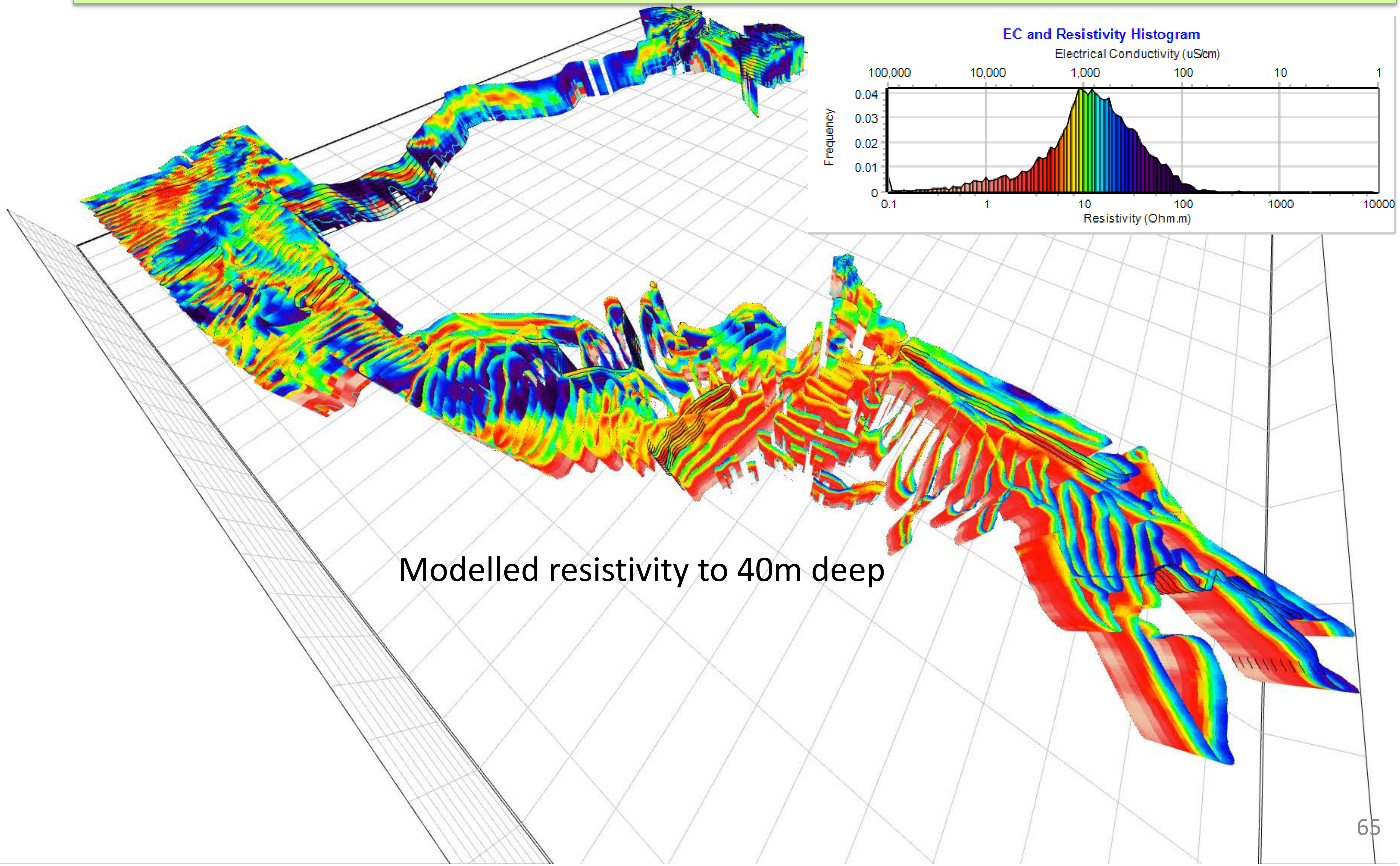


HUNTER RIVER SITE - Depth to minimum AgTEM Modelled Resistivity



3D Curtain images



Modelled resistivity to 40m deep

Highland traverse north - Modelled Resistivity projected 40m up

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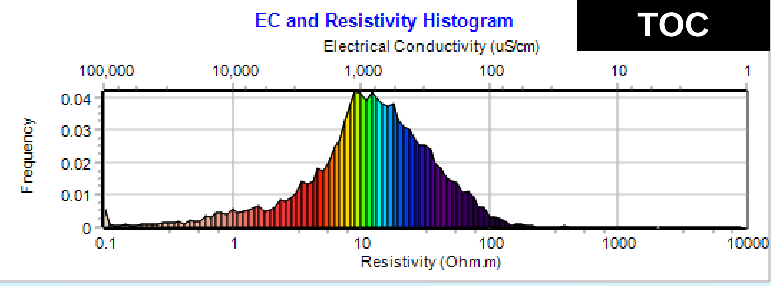
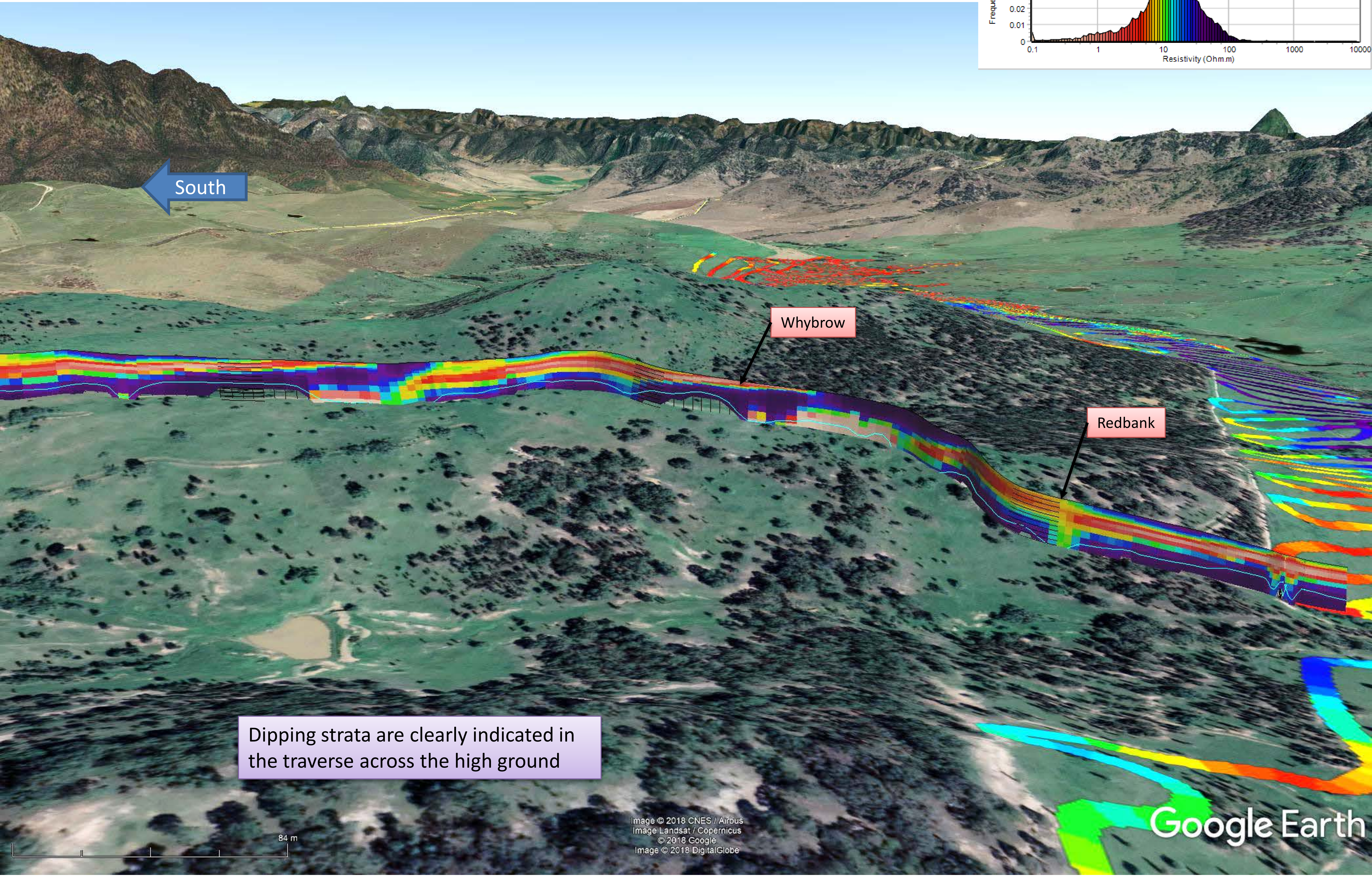
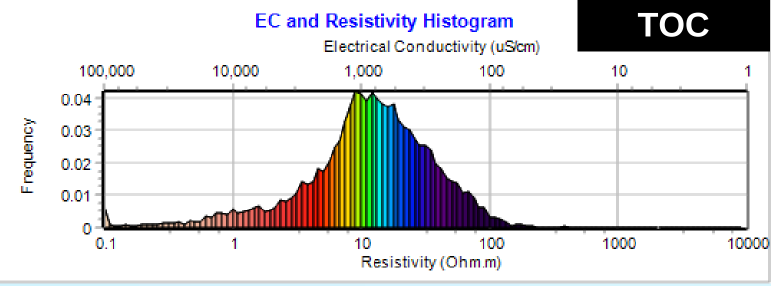




Dipping strata are clearly indicated in the traverse across the high ground

Highland traverse overview - Modelled Resistivity projected 40m up



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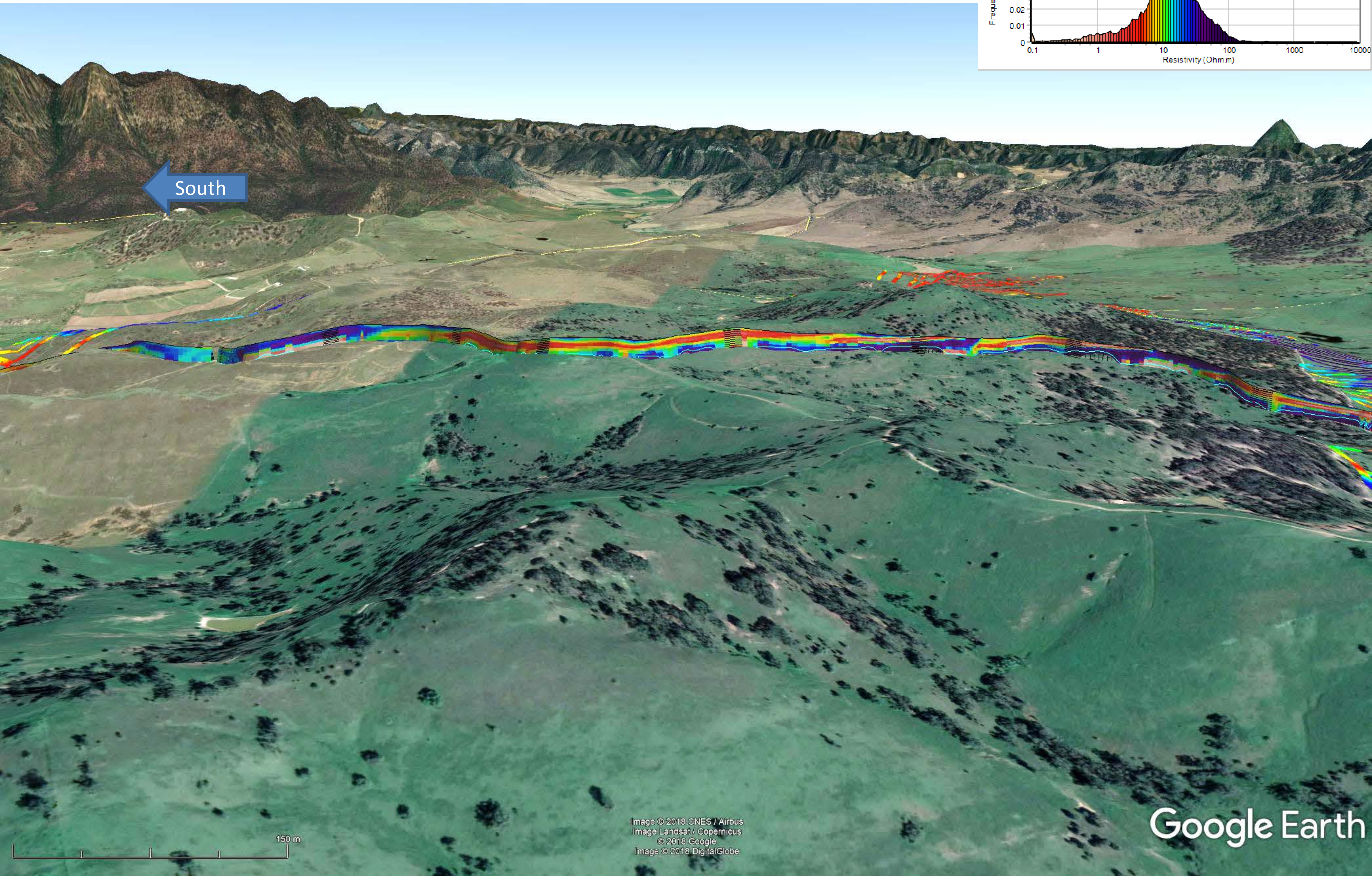

Highland traverse south - Modelled Resistivity projected 40m up

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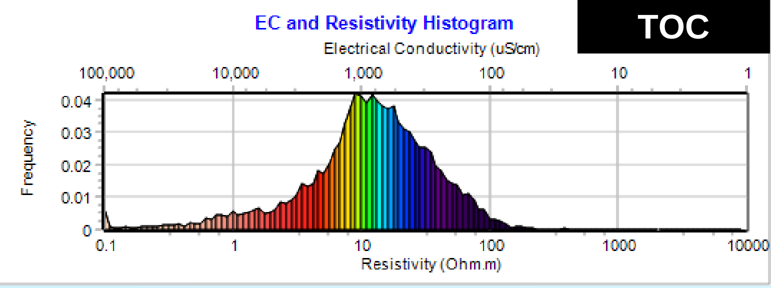

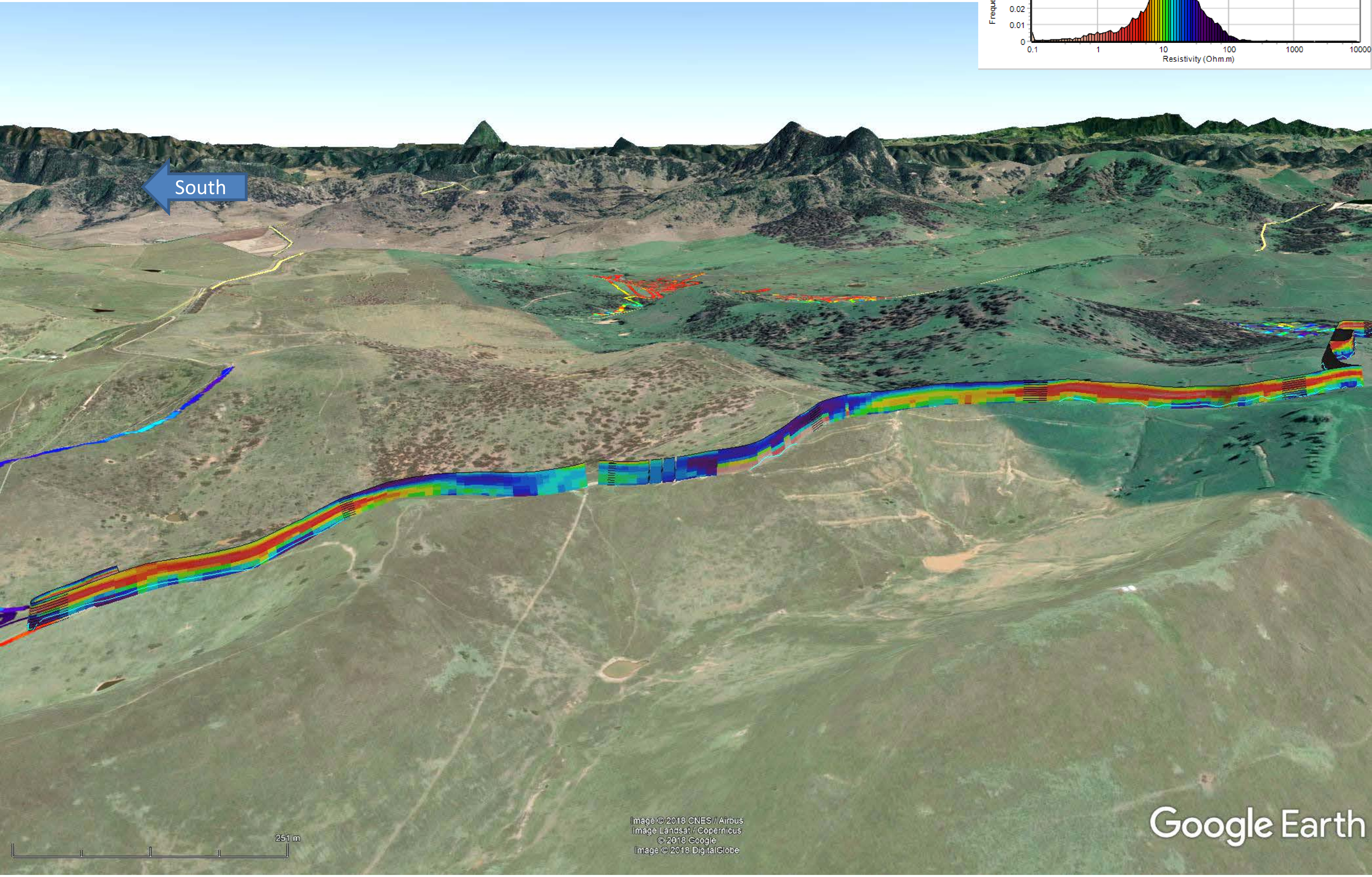

Hunter River Site - Modelled Resistivity projected 40m up

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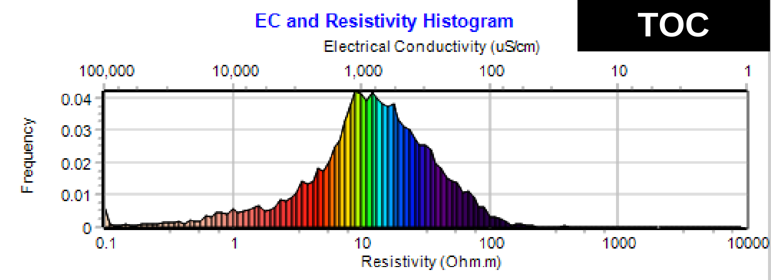
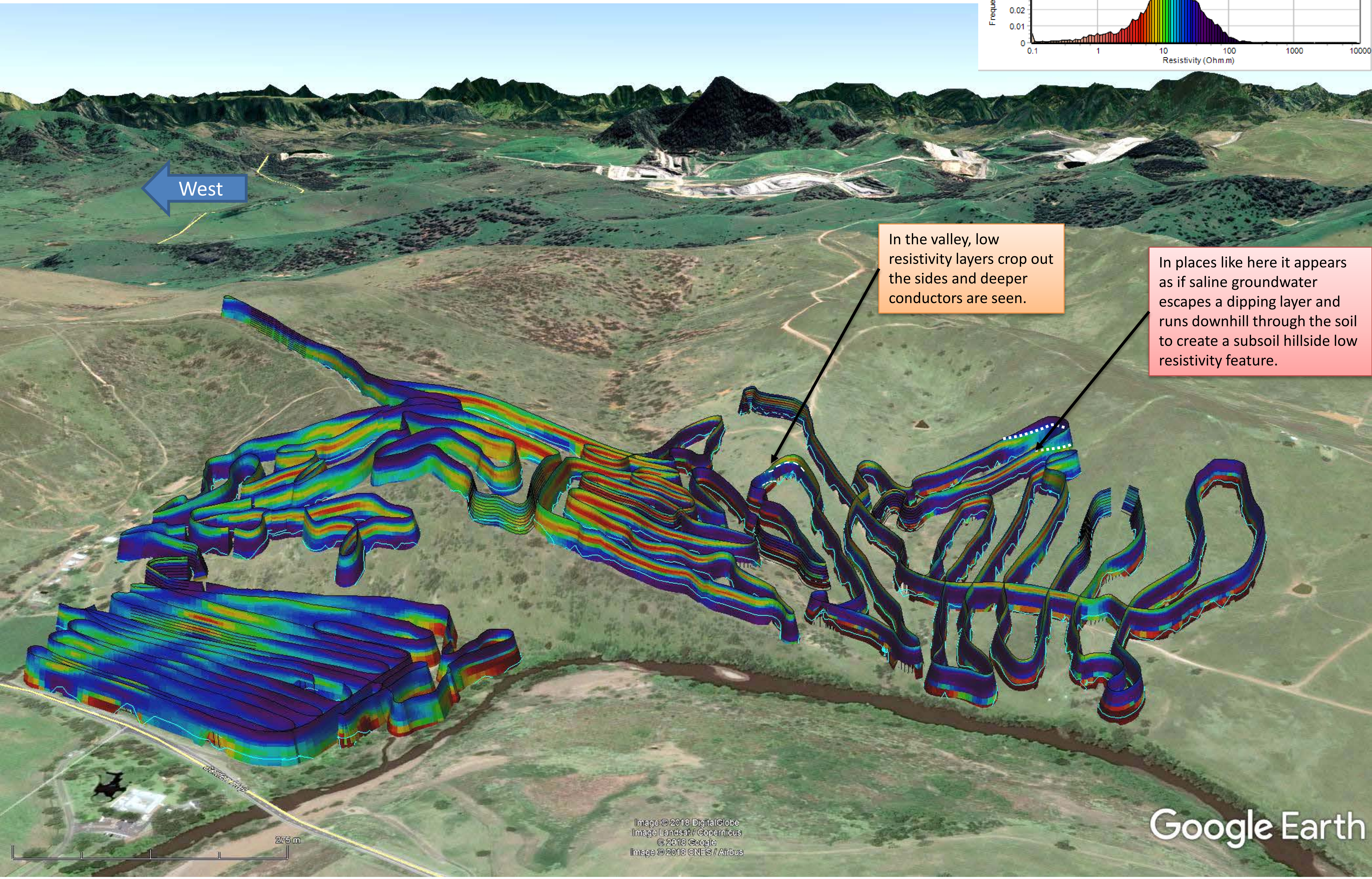
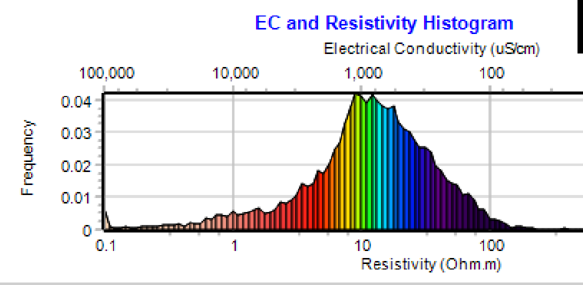




Hunter River Site - Modelled Resistivity projected 40m up



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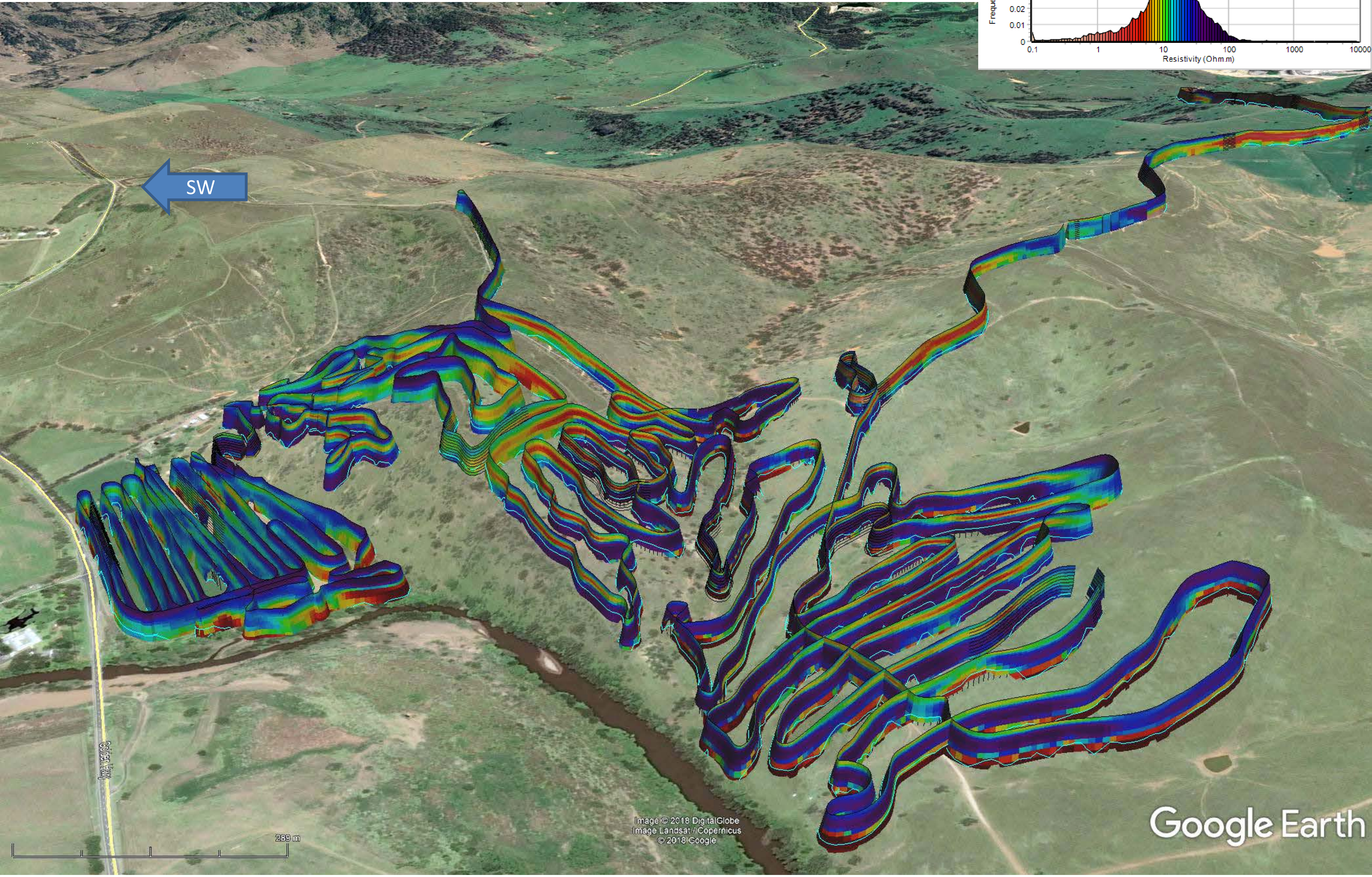
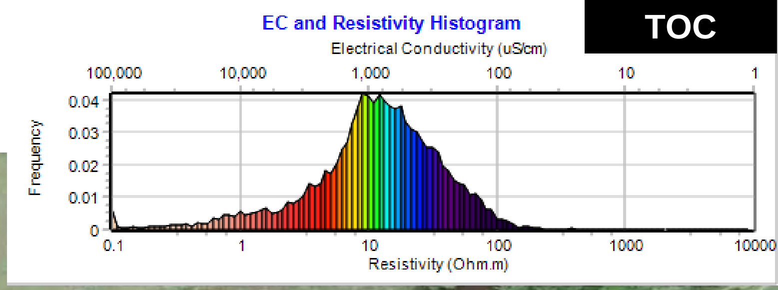


Hunter River Site - Modelled Resistivity projected 40m up



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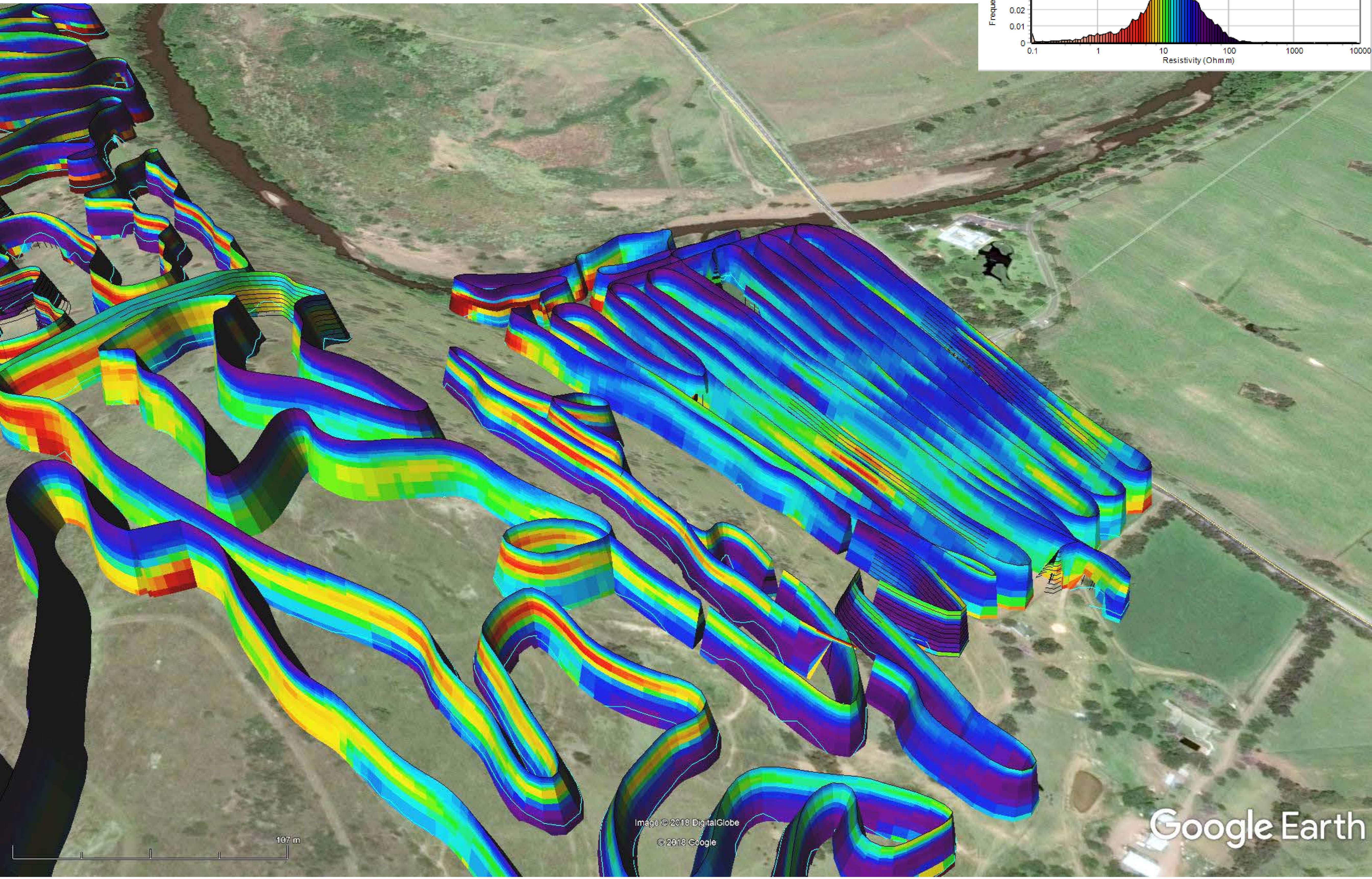
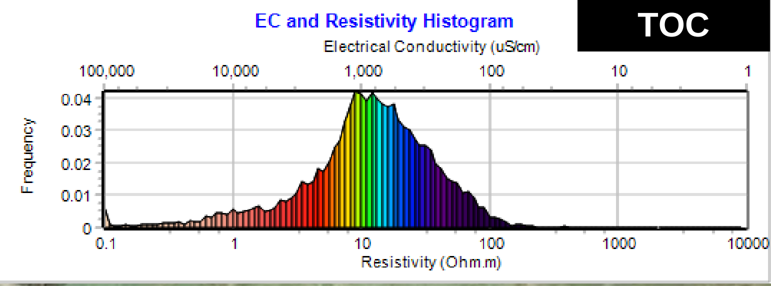
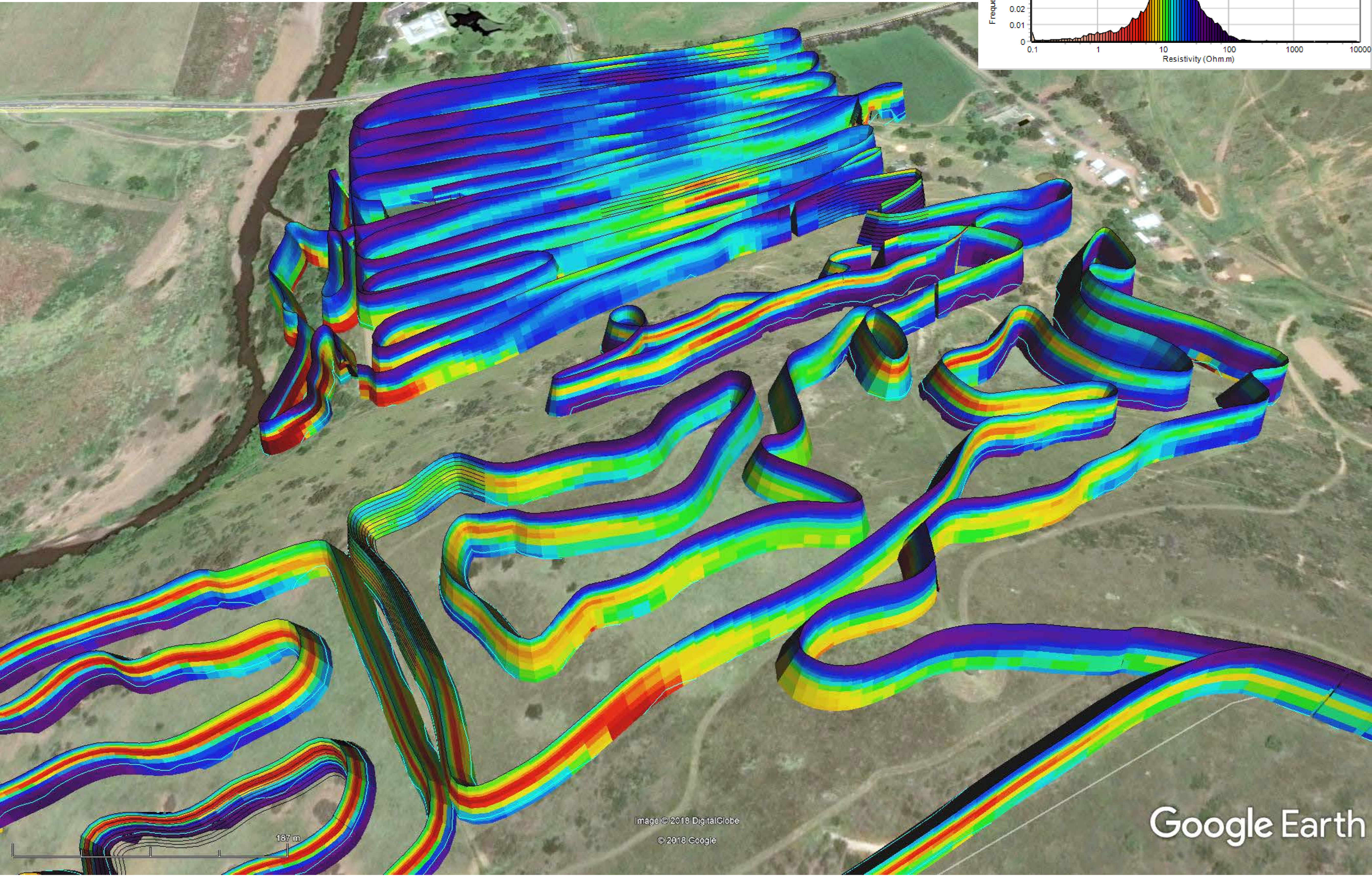


Hunter River Site - Modelled Resistivity projected 40m up

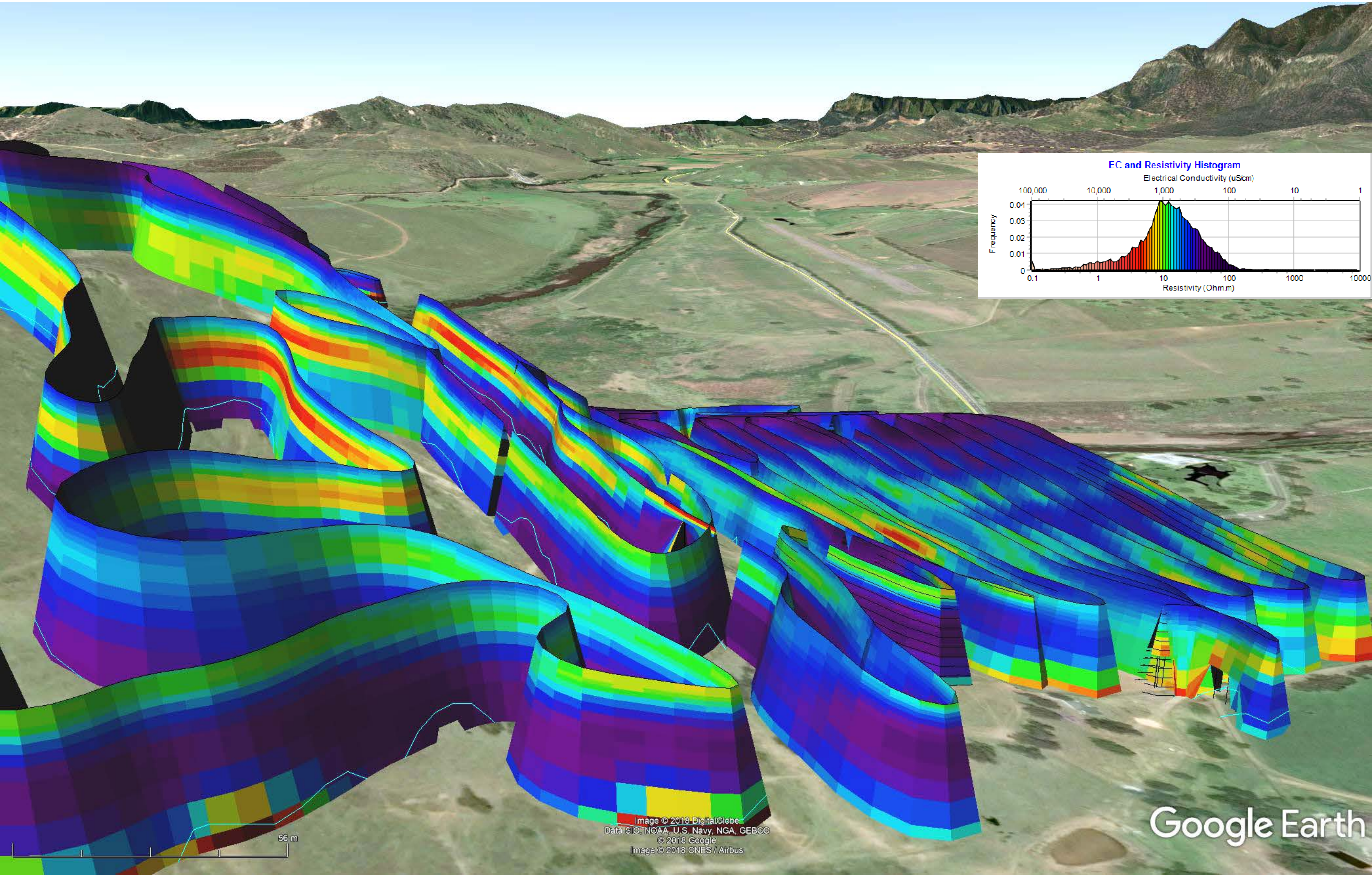
TOC





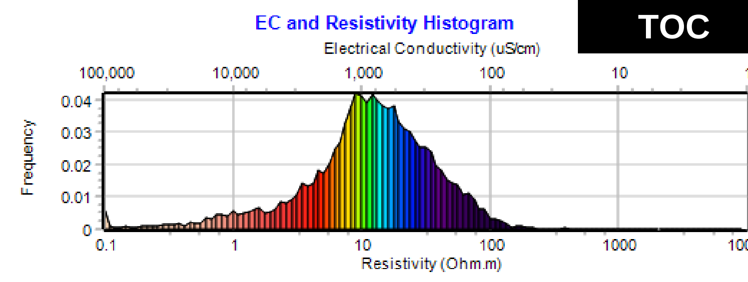
Hunter River Site - Modelled Resistivity projected 40m up

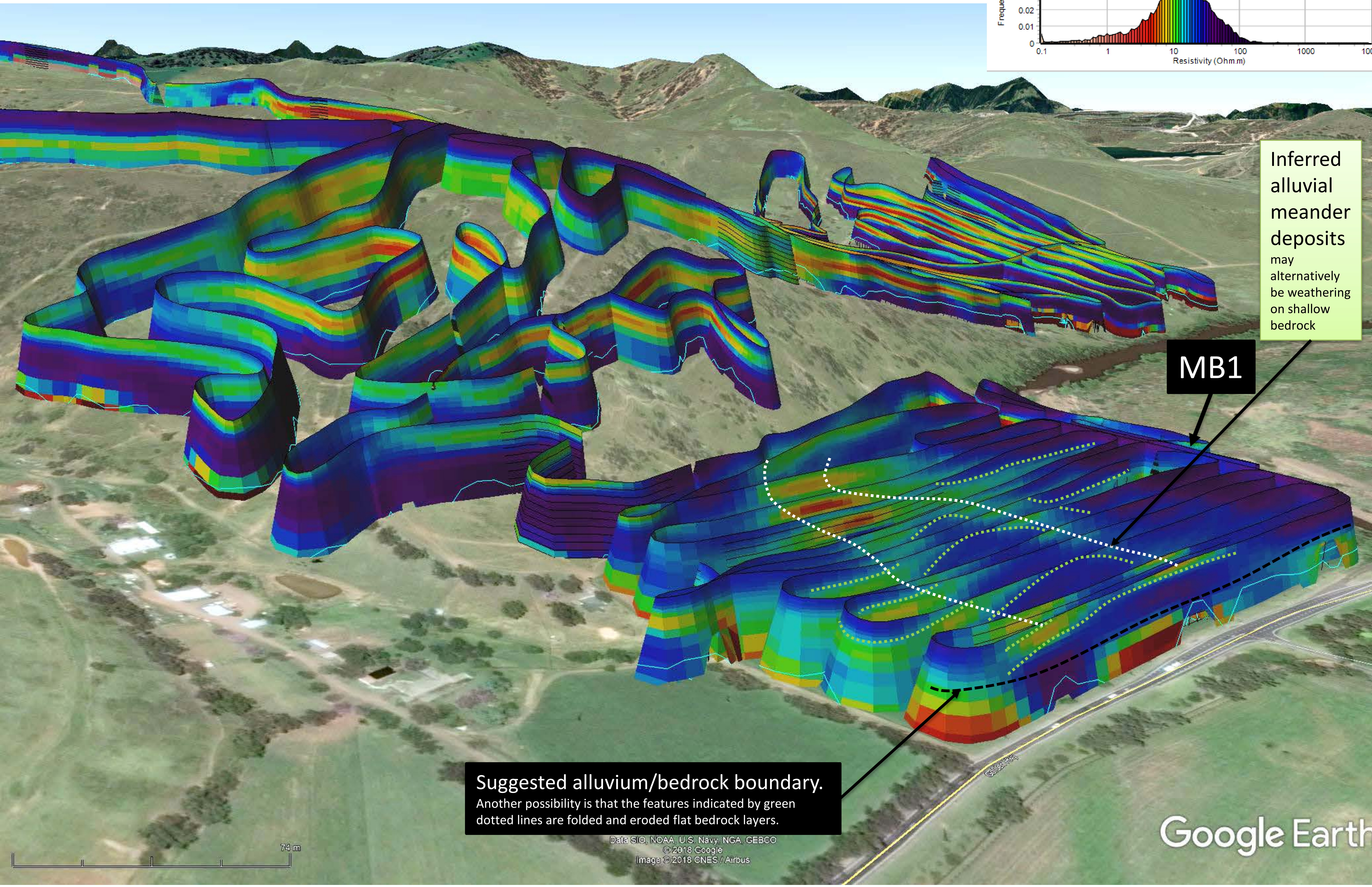
TOC



Hunter River Site - Modelled Resistivity projected 40m up

TOC





Modelled Resistivity projected 40m up

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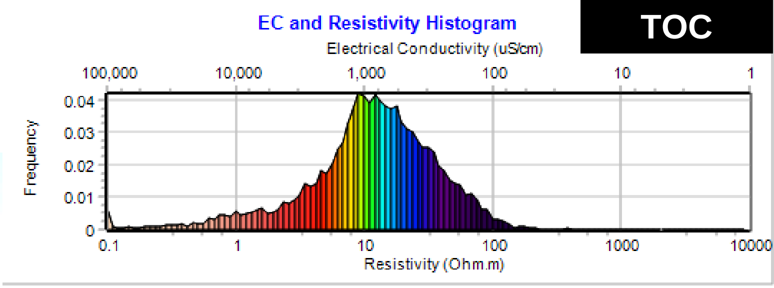
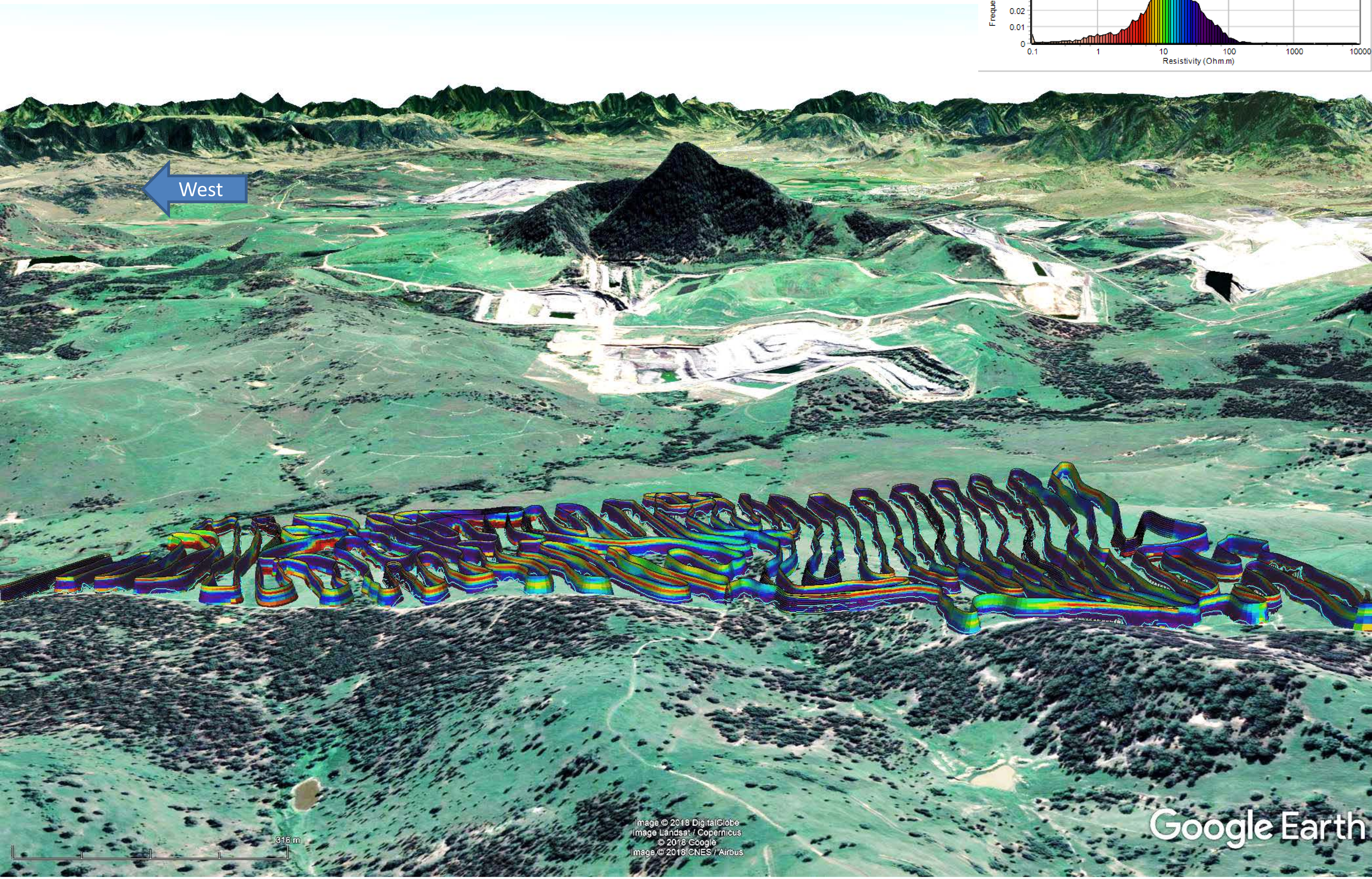
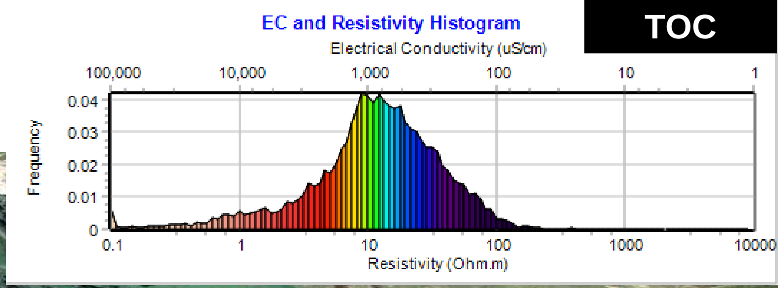




Modelled Resistivity projected 40m up



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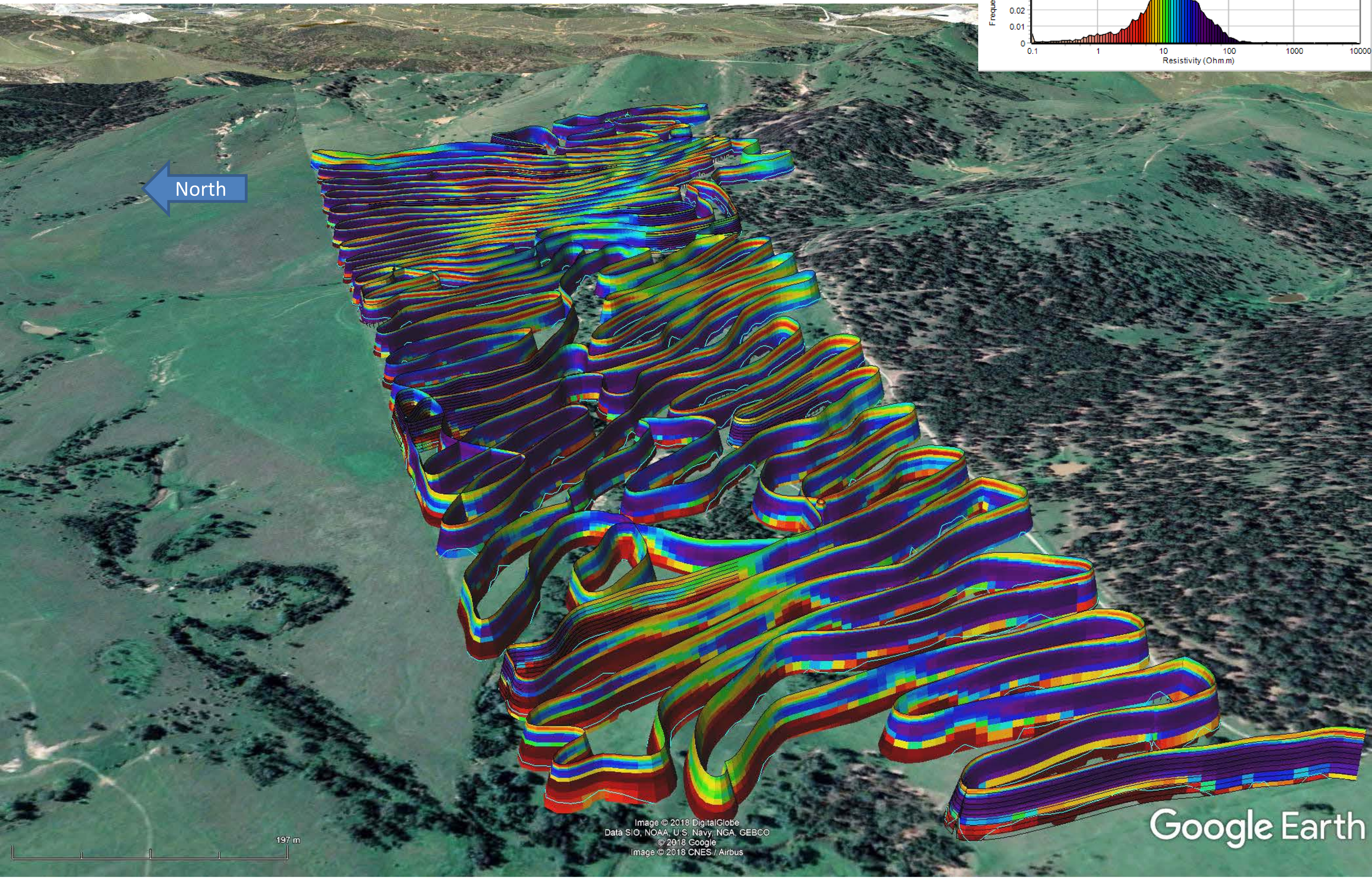

Modelled Resistivity projected 40m up

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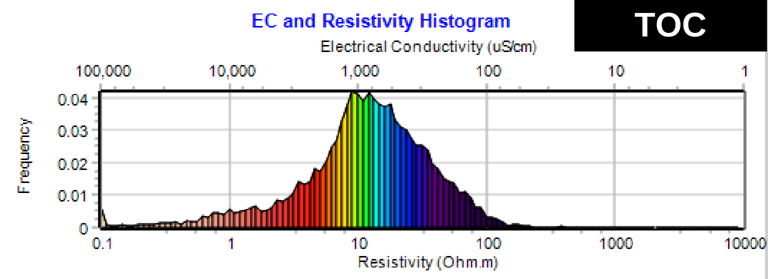

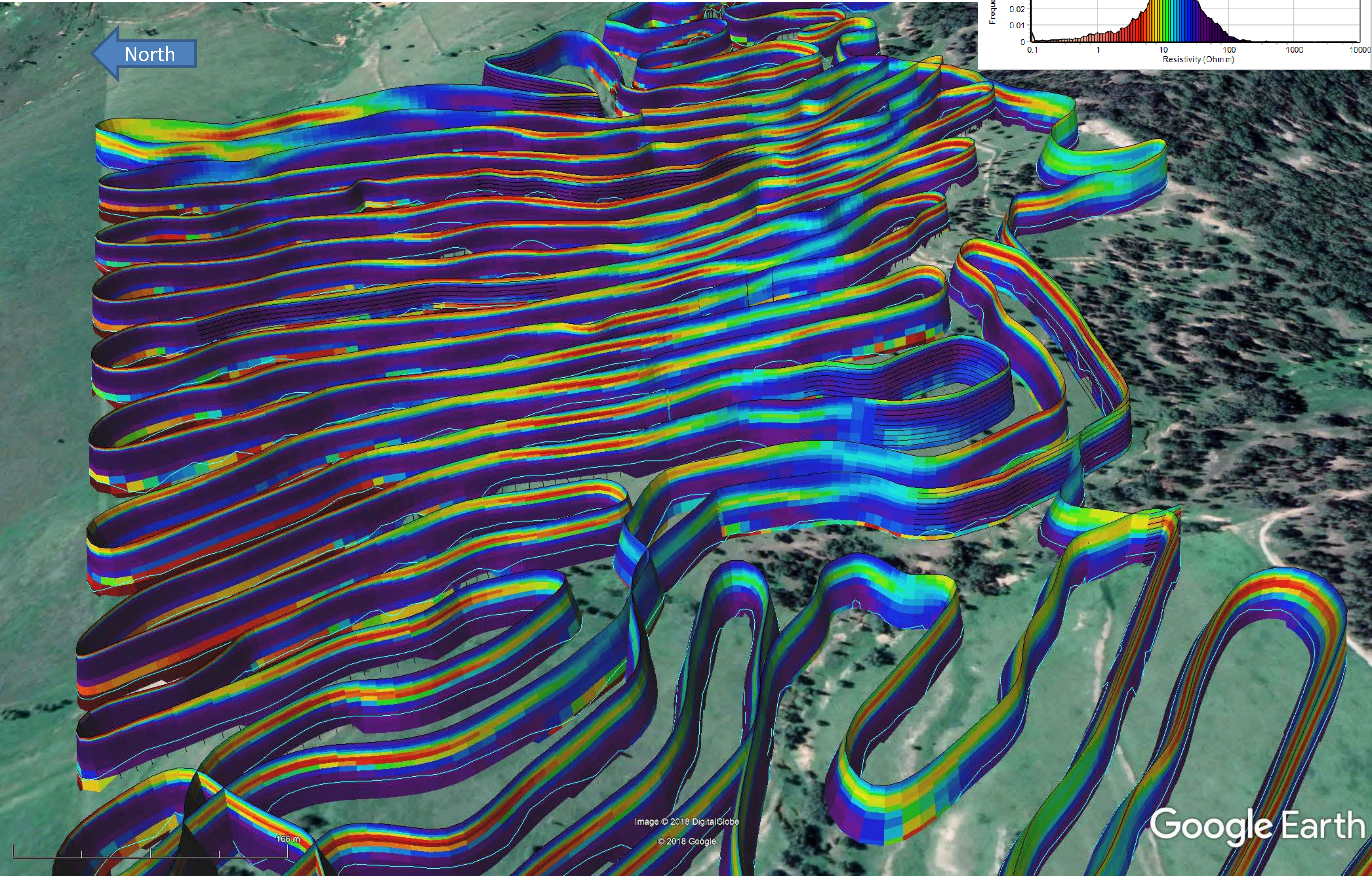

Modelled Resistivity projected 40m up

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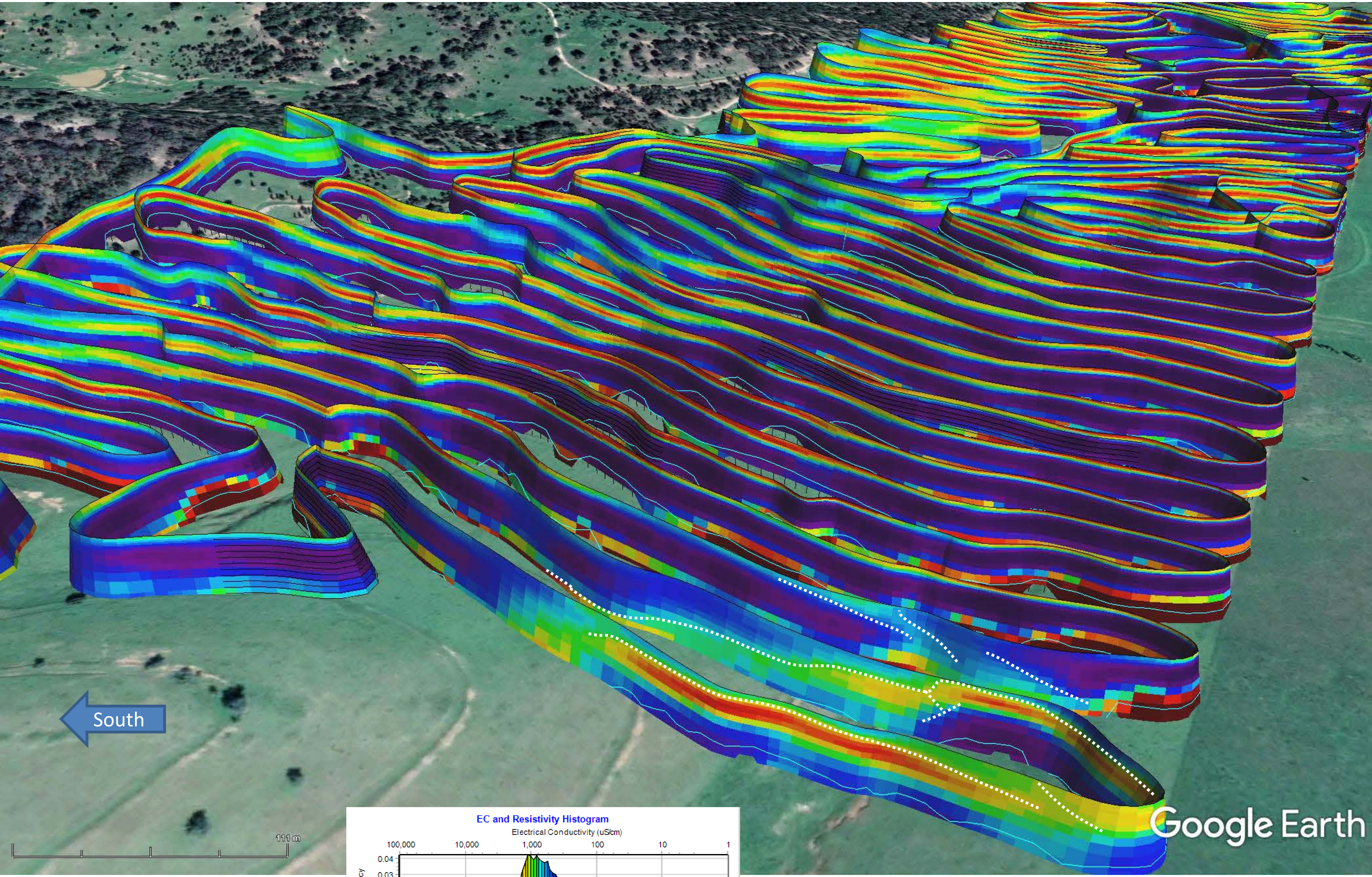

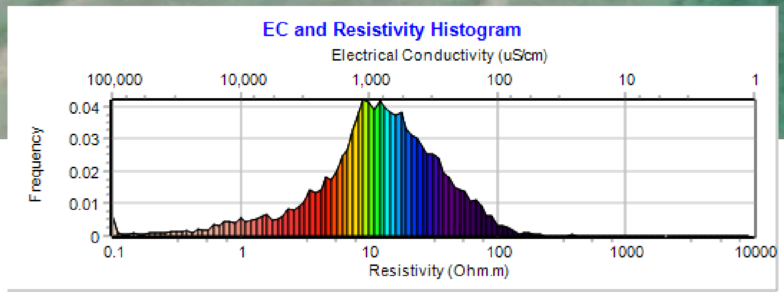

Modelled Resistivity projected 40m up

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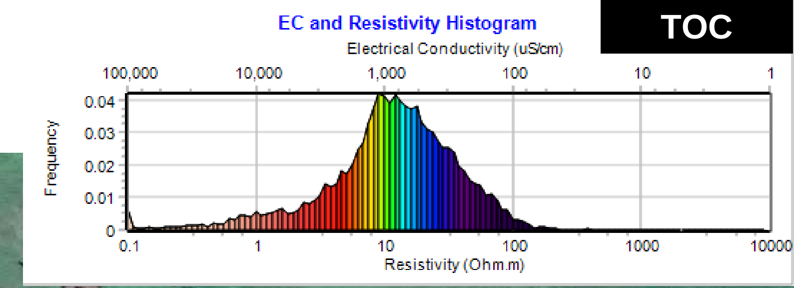
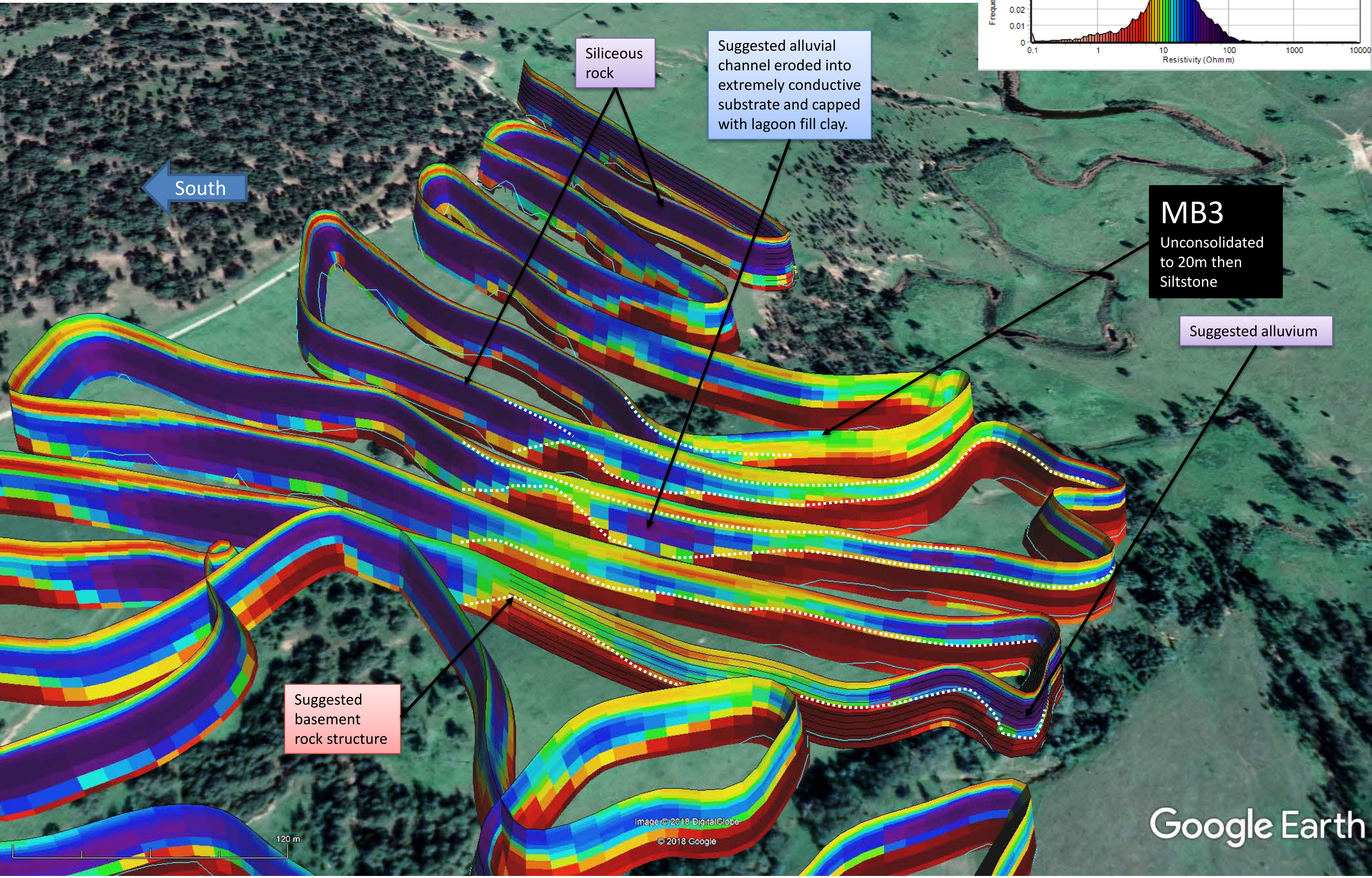
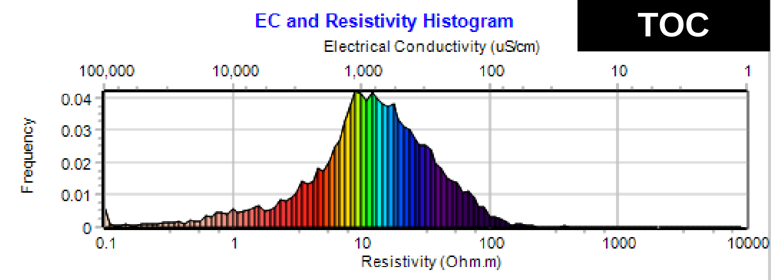




Modelled Resistivity projected 40m up



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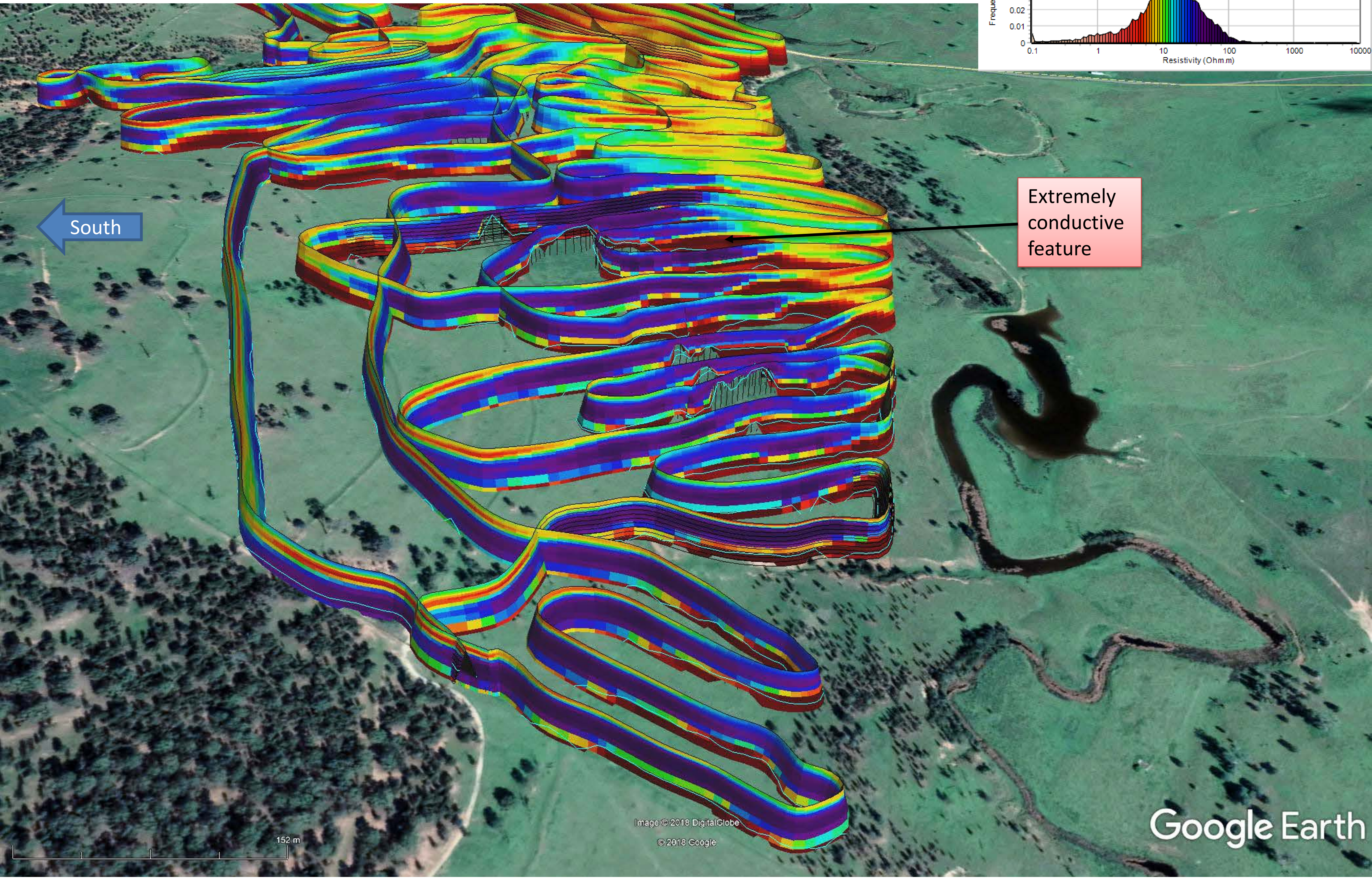

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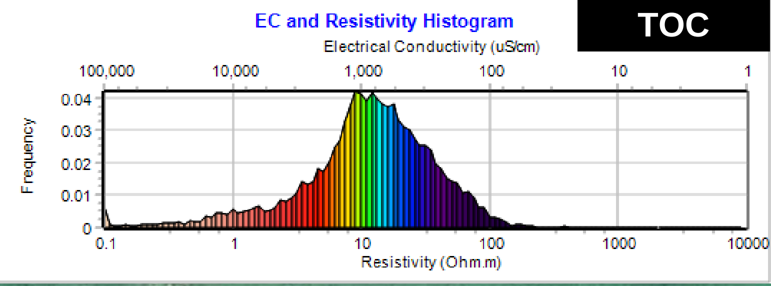

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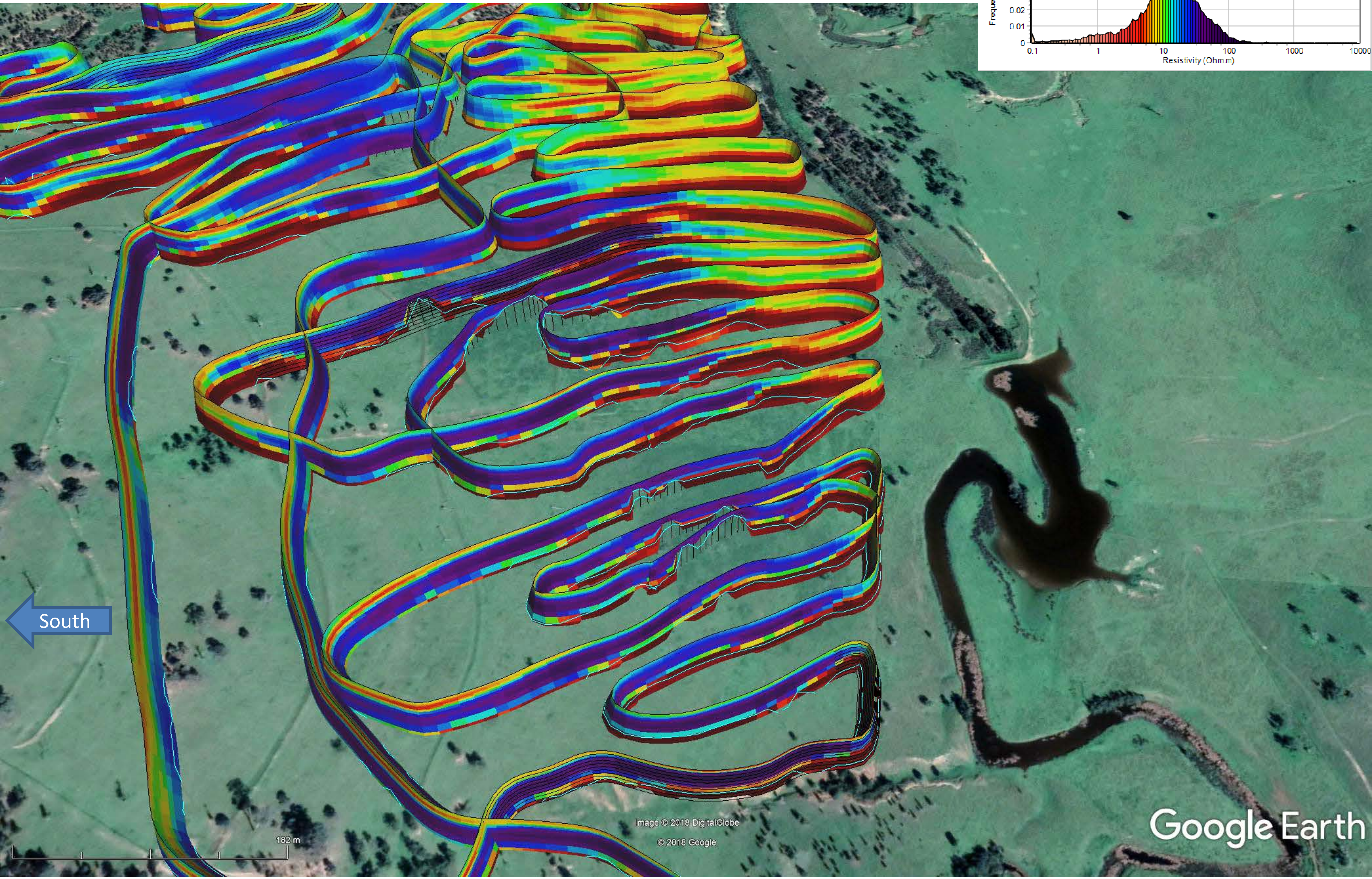
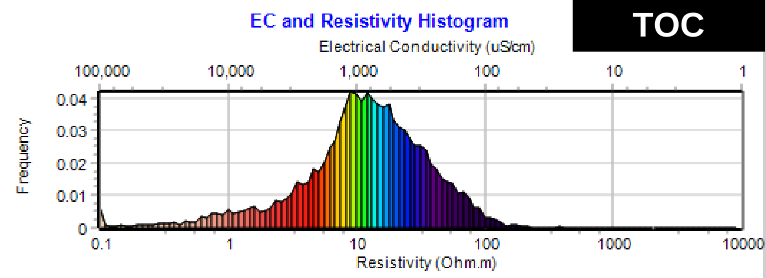


Modelled Resistivity projected 40m up



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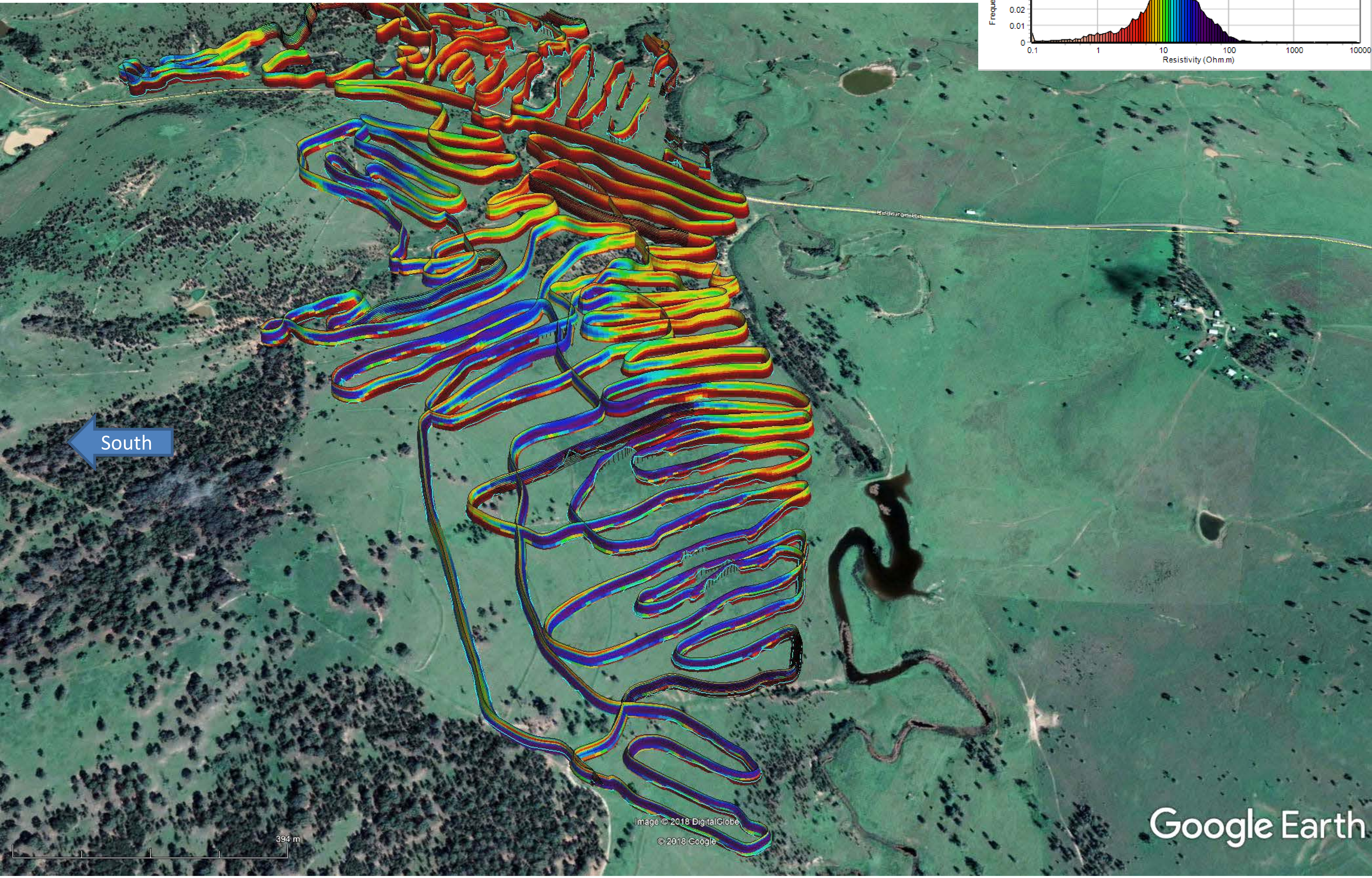

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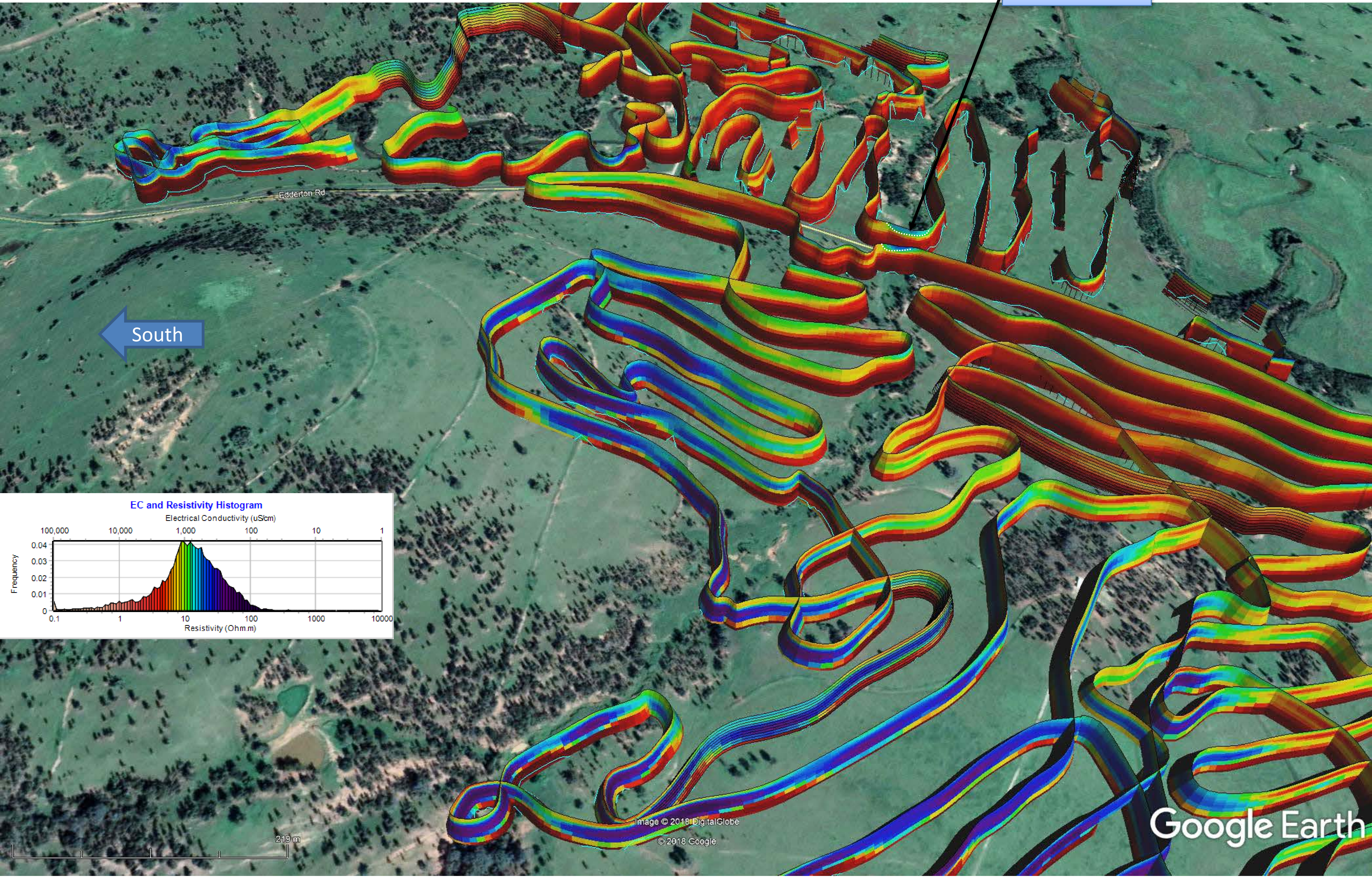
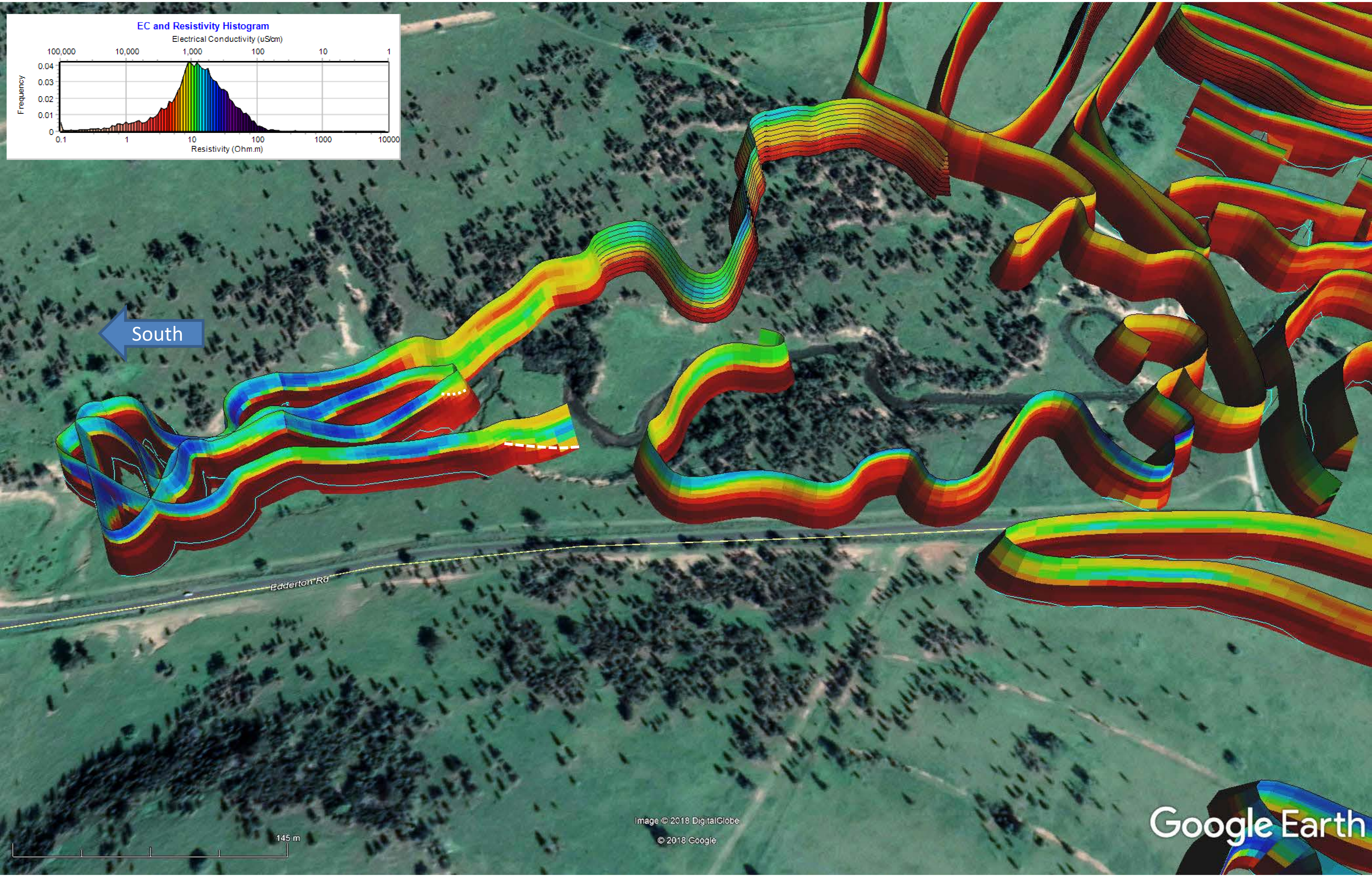


Modelled Resistivity projected 40m up



Modelled Resistivity projected 40m up

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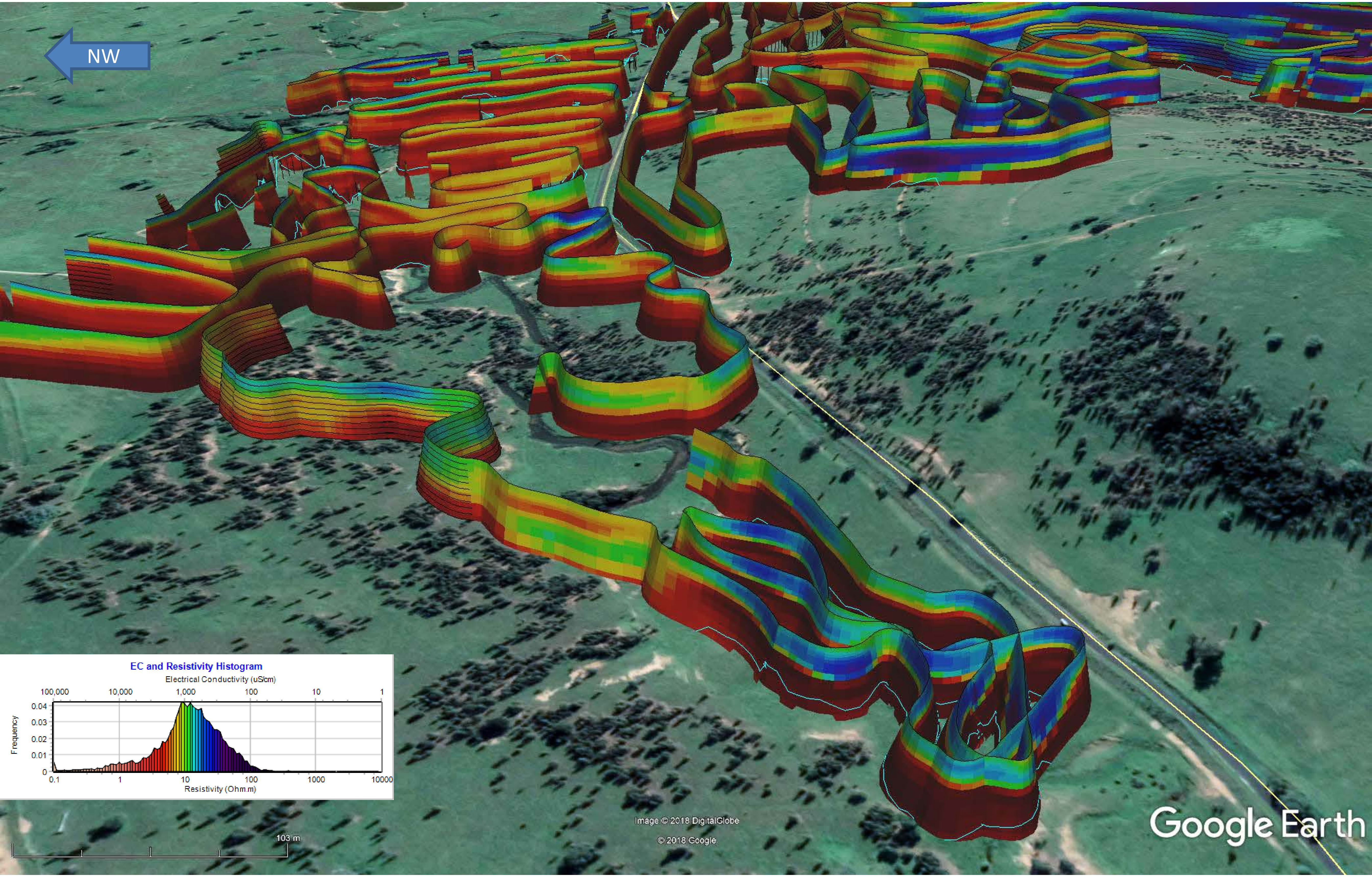

Modelled Resistivity projected 40m up

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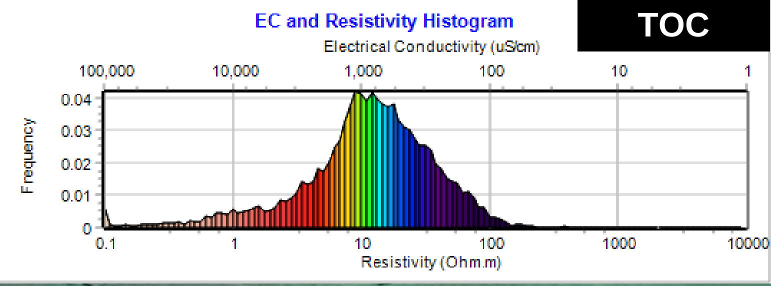
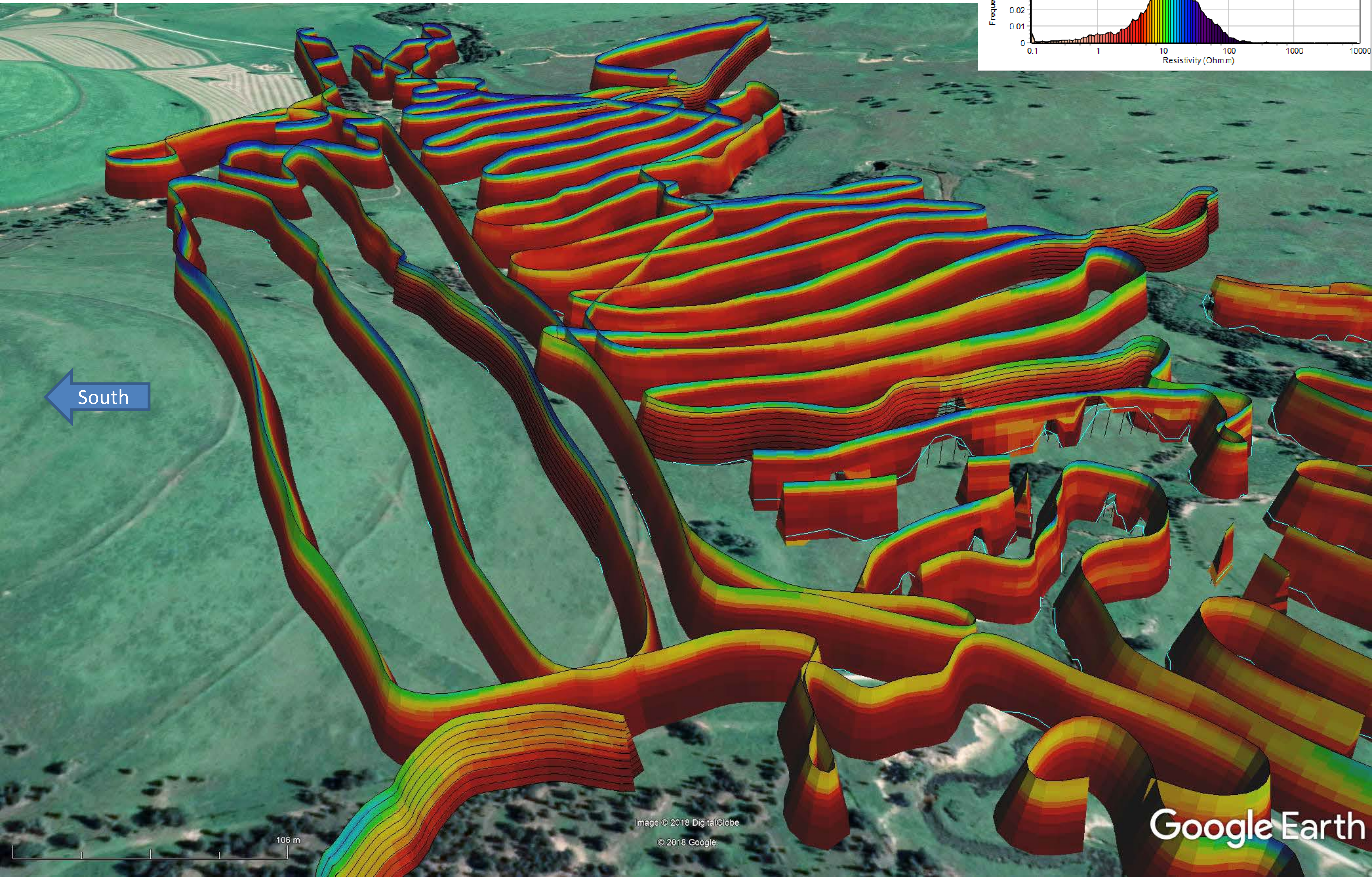
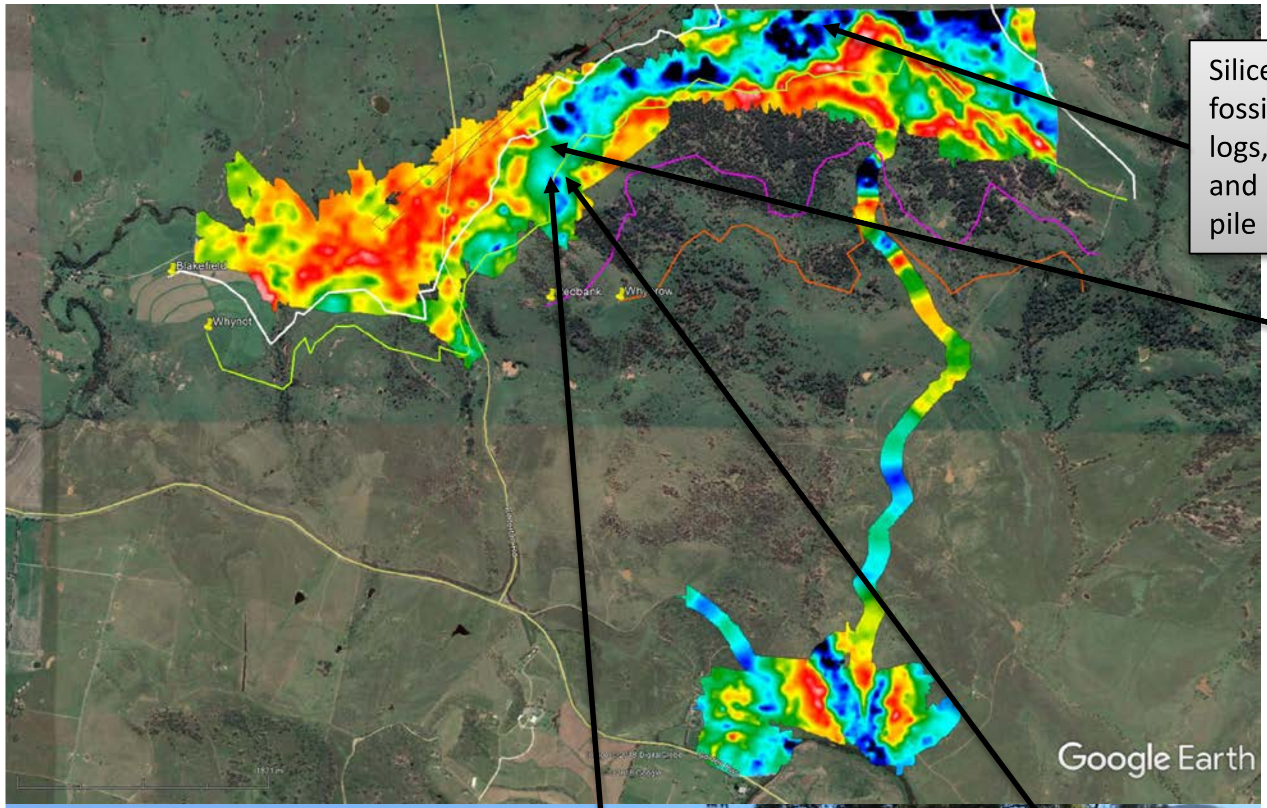




Float rock on the resistive layer subcrop

Positions approximate



Siliceous fossilized logs, twigs and leaf pile

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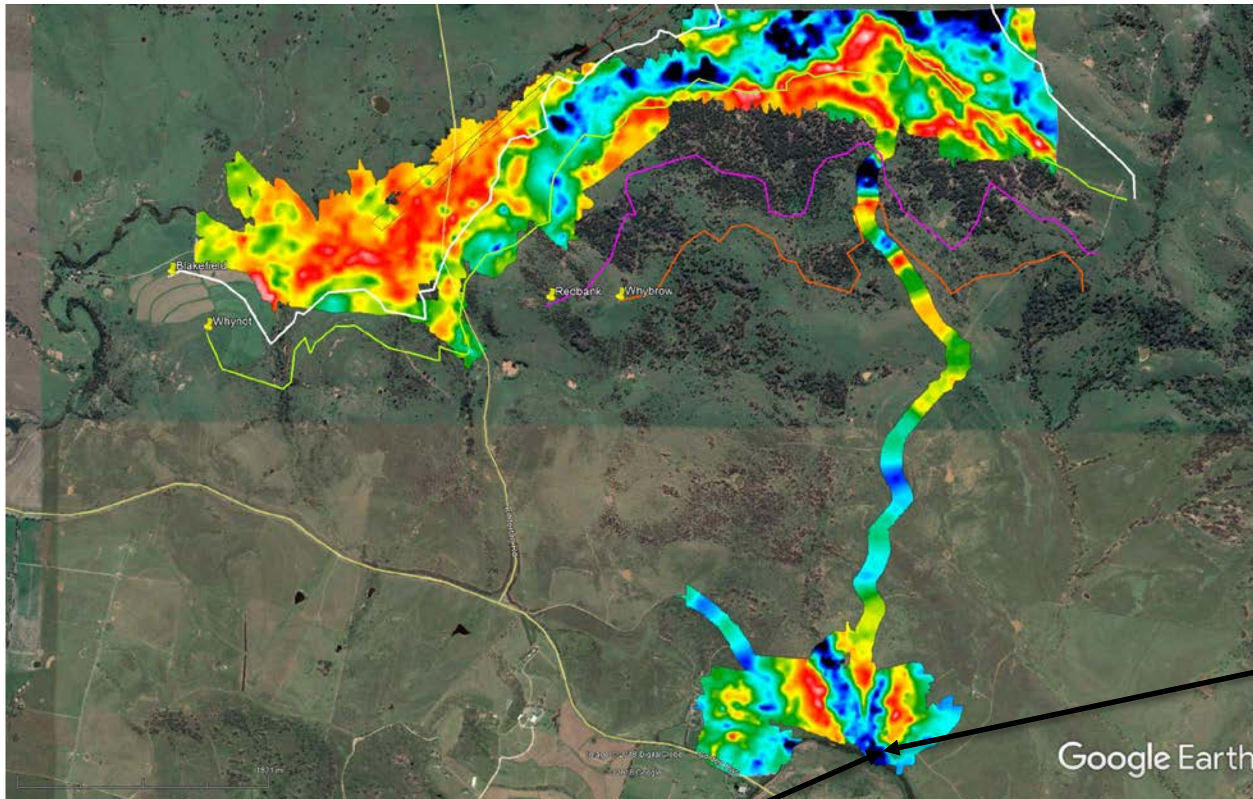
The size of this waterworn boulder brings one to imagine the velocity of water that must have been needed to transport it within suspension (not bedload) within its host sediment.

Igneous sill or dyke by the Hunter River



Appendices

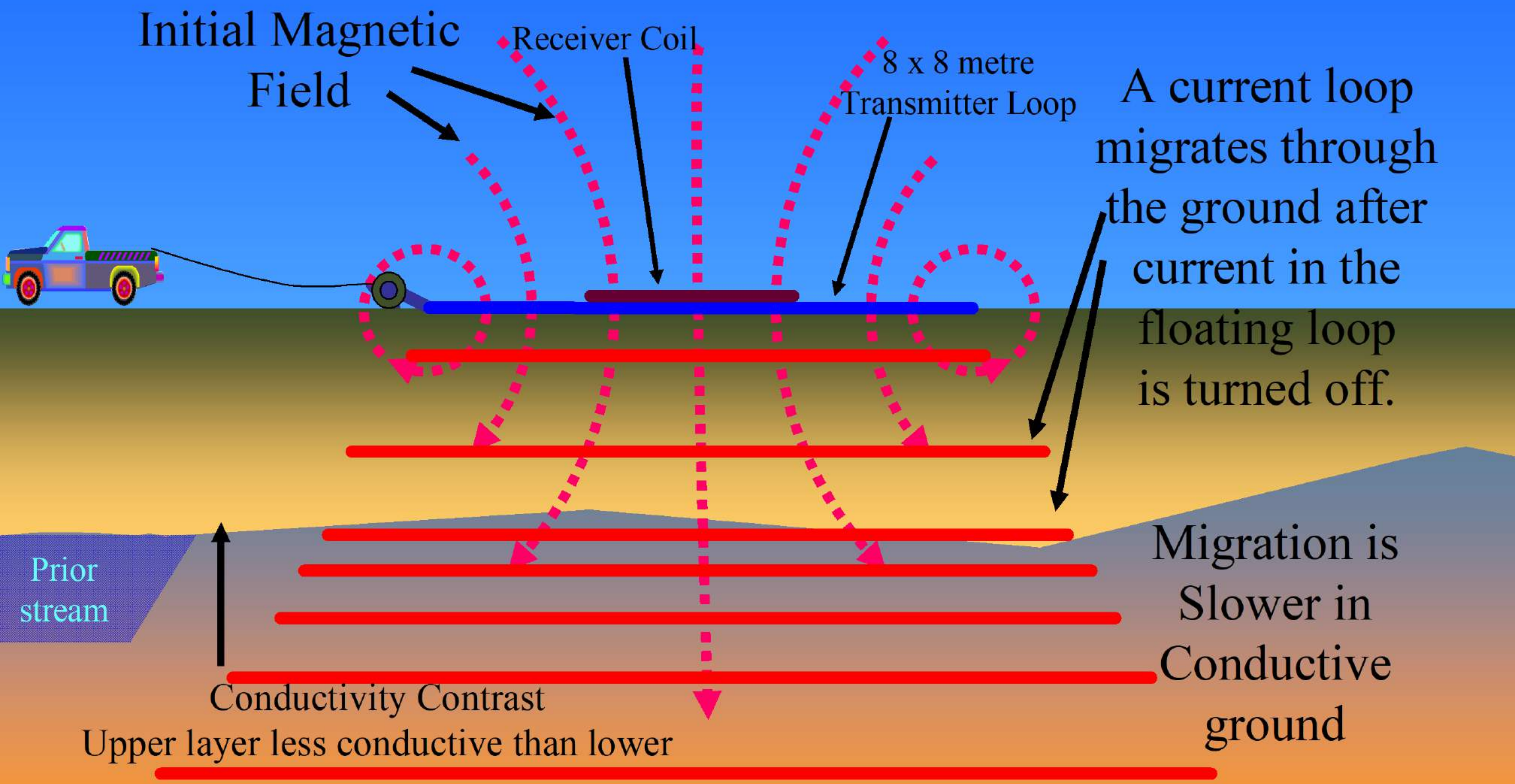
- Production Report
- Identifying depths on ribbon images
- Towed Transient Electromagnetic schematic
- TEM platform configuration schematics
- TerraTEM specifications

Production Report

Date	Charge	Details
24/04/2018	Mobilisation	Travel Dubbo to Muswellbrook via other job.
	Production	7.00am - Induction done in minutes. Go to site from office and commence survey. Edderton Rd West
	Production	Edderton Rd East then travel over highland to Hunter River Site
	Production, Demobilization	Hunter River Site survey, pack up and demobilize in late afternoon / evening.

Total TEM production distance to date excluding gaps >60m =
129.3km Total or $118.30/km

Towed Transient Electromagnetic System



TOC

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.

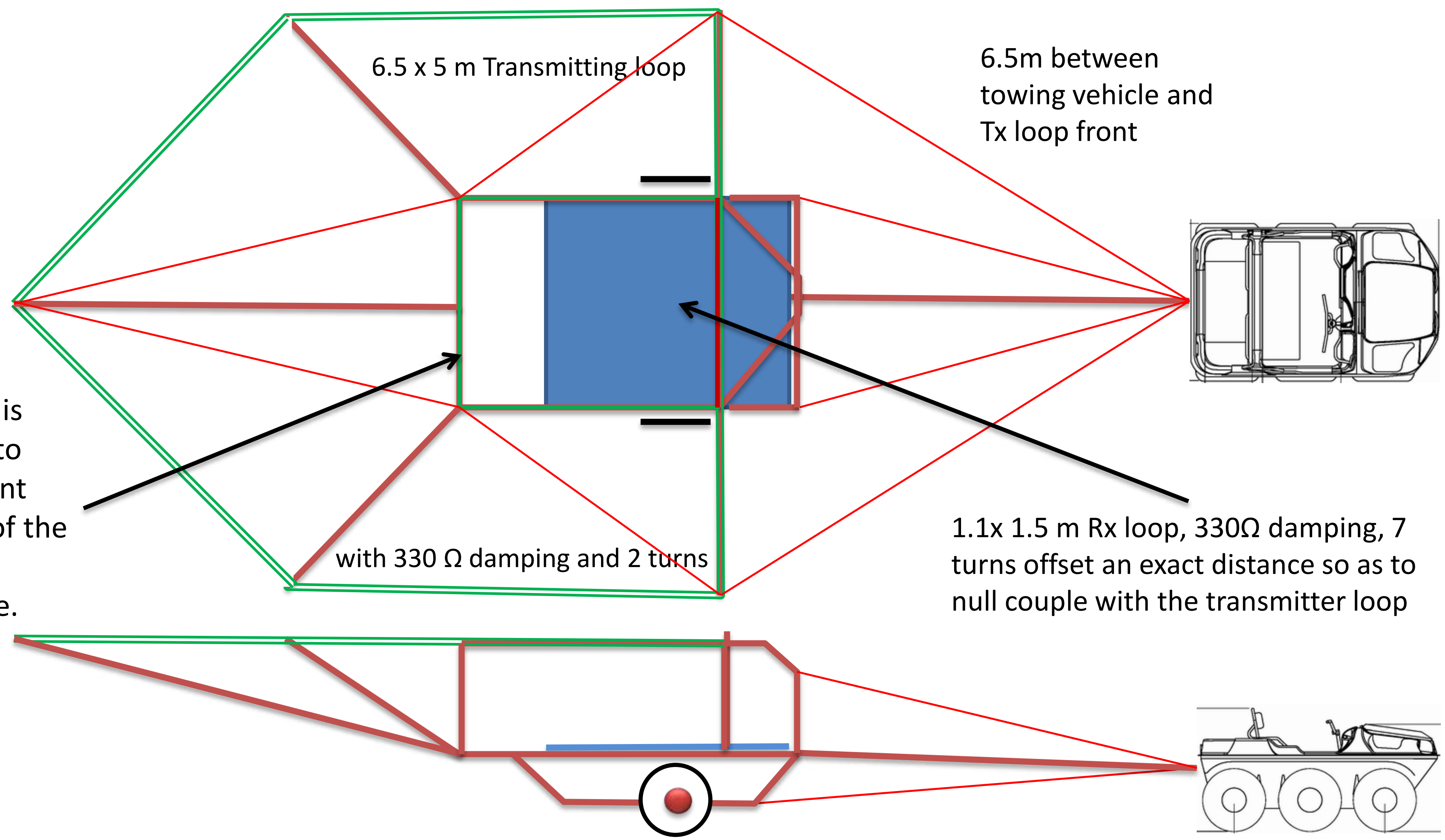
Transient EM equipment configuration

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. Resample data to time-smooth and create AarhusInv inversion input files.
15. Run AarhusInv 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 AarhusInv 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 GeoInstruments

terraTEM

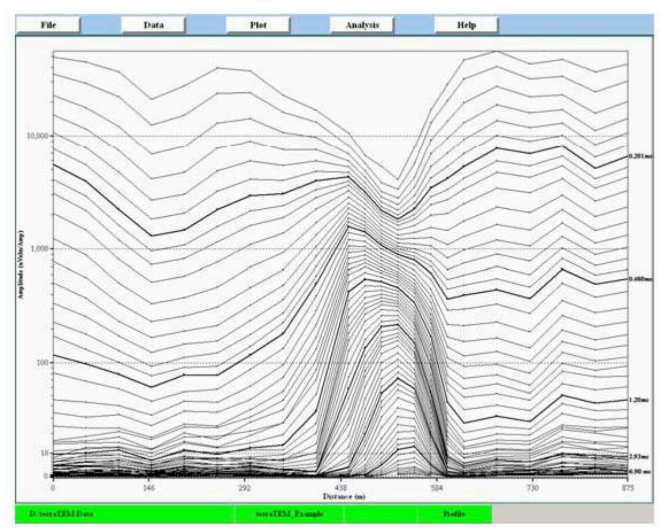
Time-Domain EM Surveying System

terraTEM Features

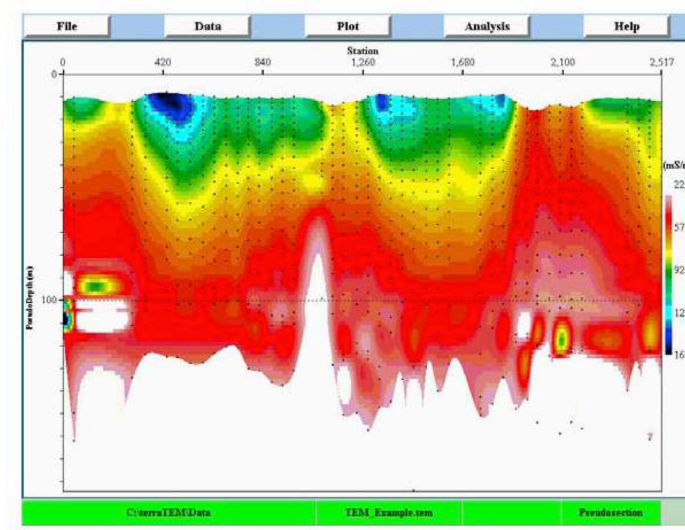
- Transmitter and receiver in one unit
- Single or 3 channel receiver with 10 amp. transmitter
- High speed sampling at 500 kHz for superior near surface resolution
- Easy to use touch screen with auto set-up and smart menus
- Large 15" LCD display for data visualisation
- Fast and easy data transfer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

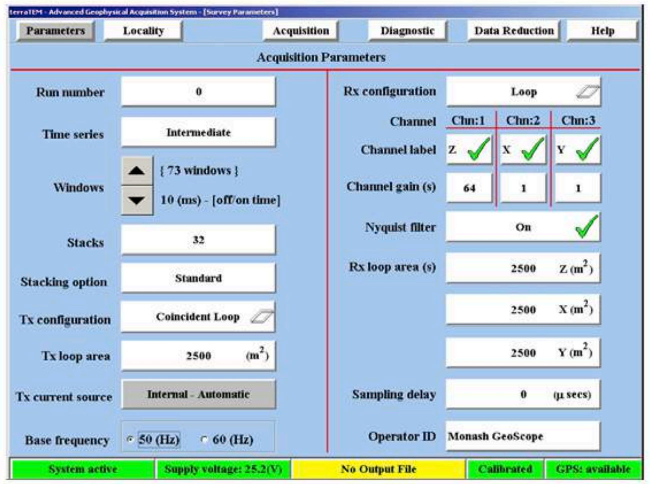
The **terraTEM** is designed, developed and manufactured by **Monash GeoScope**

Monash GeoScope

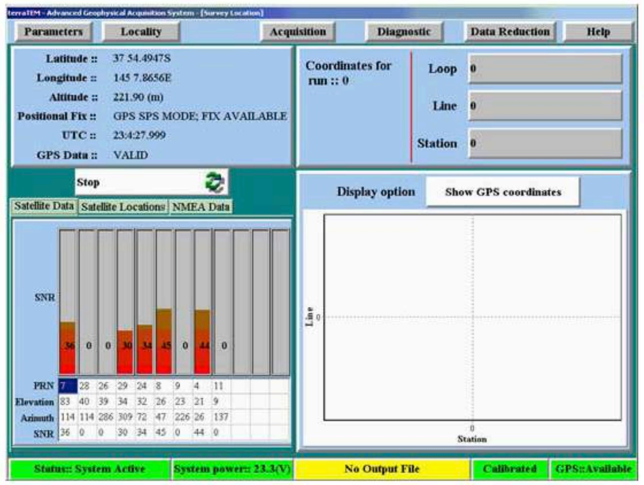
Applications

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:

terraTEM
Technical Specifications

Transmitter

Output	15 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
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:

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

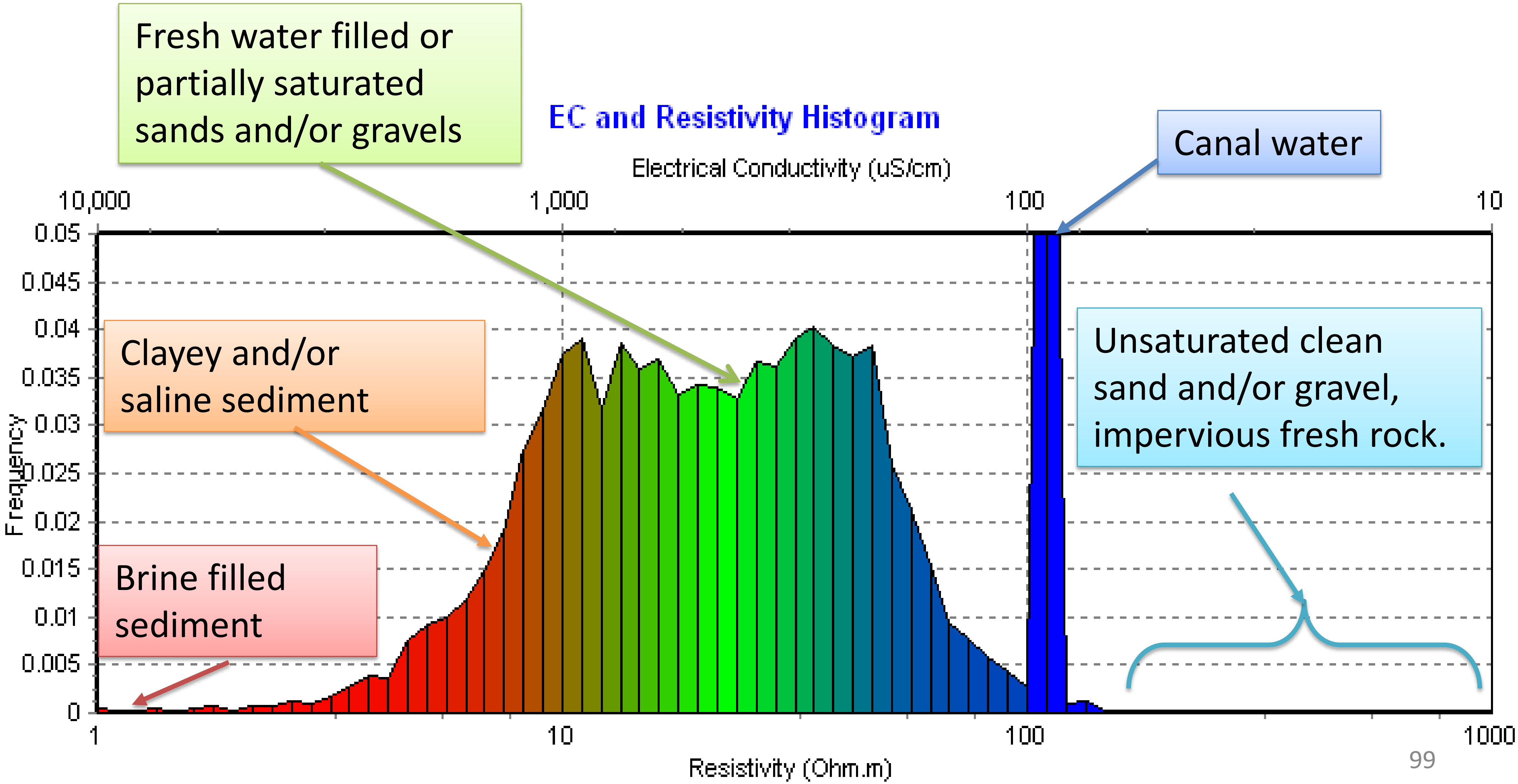
Accompanying data files in dBase IV format can be loaded in and out of MS Excel. The format has been chosen because it is easy to load into ESRI ArcView products. The final data is labelled *Ohmm.dbf and is of course in units of Ohm.m, the reciprocal of Siemens per metre. Each resistivity column is accompanied 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.

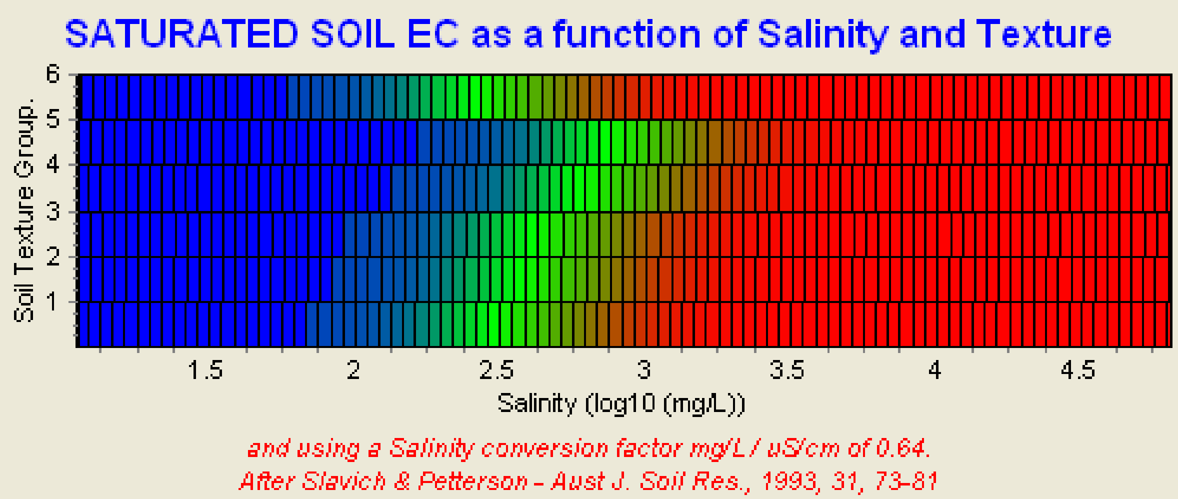


Understanding the 3D graphics

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

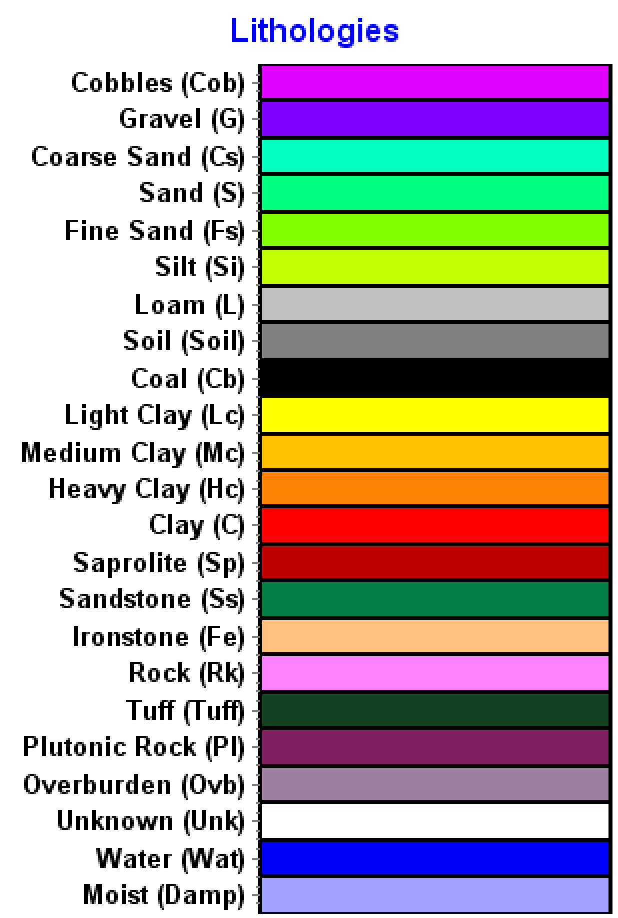
In the images, bore logs are displayed graphically using lithology keys such as the one given here.

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.).



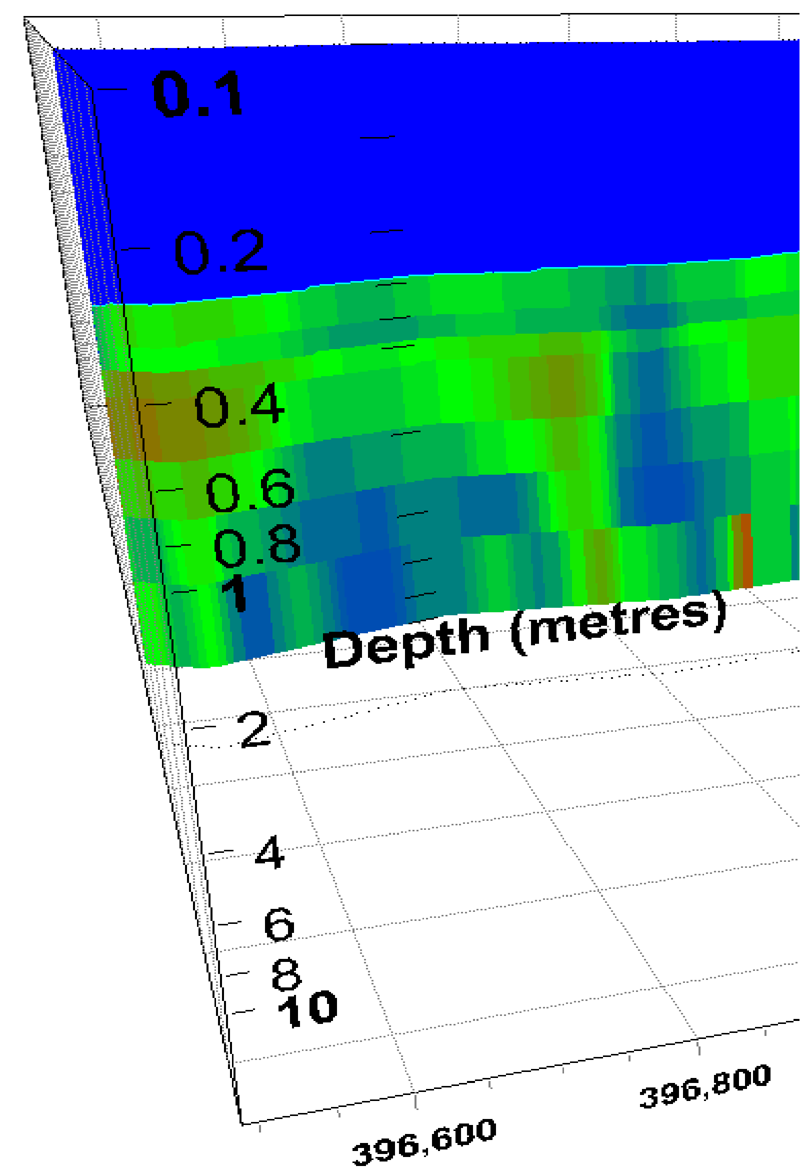
TOC

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.



ATTACHMENT C

ENRS ALLUVIUM REPORT

ALLUVIAL DRILLING REPORT

MAXWELL PROJECT

MUSWELLBROOK LOCAL GOVERNMENT AREA, NSW

Prepared For: **Malabar Coal Limited**

Project Number: **ENRS1046**

Date: **December 2018**

ENVIRONMENT & NATURAL RESOURCE SOLUTIONS
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Author and Document Control

Written/Submitted by:	Reviewed / Approved by:
Taite Beeston *Geologist & Environmental Scientist*	**Rohan Last** *Hydrogeologist & Environmental Scientist*

Record of Distribution

Copies	Report No. & File Name	Status	Date	Prepared for:
1 x PDF	ENRS1046r3_Maxwell_Alluvial Drilling Report	Rev.1	1st Nov. 2018	Malabar Coal Limited
1 x PDF	ENRS1046r3_Maxwell_Alluvial Drilling Report	Rev.2	9th Nov. 2018	Malabar Coal Limited
1 x PDF	ENRS1046r3_Maxwell_Alluvial Drilling Report	Rev.3	4th Dec. 2018	Malabar Coal Limited

EXECUTIVE SUMMARY

Environment & Natural Resource Solutions (ENRS Pty Ltd) were commissioned as independent hydrogeological consultants in September 2018 by *Malabar Coal Limited* (the client) to supervise test drilling and construction of monitoring bores to investigate the extent and nature of unconsolidated alluvial and colluvial deposits adjacent to the Maxwell Project situated within the Muswellbrook local government area, NSW. ENRS understand the project is required to support groundwater assessments (including numerical modelling) of the potential impacts on shallow unconsolidated aquifers associated with the extraction of coal from the Wittingham Coal Measures.

This report summarises the results of borehole drilling, monitoring bore construction, and field observations during one (1) site mobilisation between the 24th and 25th of September 2018.

The objectives of the project were to:

- Conduct test drilling to investigate the depth and boundary of alluvial deposits, if any at eleven (11) pre-selected sites (adjusted in the field if required) across three (3) transects N1-N4, W1-W4, S1-S3 in the vicinity of Saddlers Creek and the Hunter River;
- Correlate drilling observations with previous Transient Electromagnetic (TEM) geophysics survey; and
- Construct groundwater monitoring bores to facilitate groundwater monitoring.

The scope of work for this groundwater investigation comprised the following tasks:

- ENRS hydrogeologist to supervise test drilling by the client's appointed drilling contractor and log drill cuttings/chips. Where drilling methods permit, record the depth, yield and water quality of any aquifer intercepts;
- Review drilling observations and prepare monitoring bore construction design. Position slotted casing coincident with alluvial aquifers, if present. Supervise construction by drilling contractor and record final installation details;
- Develop monitoring bores manually to remove any remnant sediment; and
- Compile investigation results and prepare drilling investigation report.

Based on the observations made during the scope of works, the following conclusions and recommendations are provided:

- Drilling at the Northern Transect near Saddlers Creek intersected groundwater in borehole N1 at the base of clayey gravels at depth of 7 metres below ground level (mbgl). No groundwater was observed in boreholes N2, N3 and N4. Shallow gravel was also recorded in borehole N2 between a depth of 3-4 m which is above the groundwater table and therefore not expected to host groundwater. The drilling results indicate the boundary of the saturated alluvium is positioned mid-way between N1 and N2 which is consistent with the TEM Geophysical Survey;

- Drilling at the Western Transect near Saddlers Creek intersected groundwater in borehole W1 associated with gravel to a depth of 8 m. No groundwater was observed in boreholes W2, W3 and W4. Shallow unsaturated alluvium characterised as clay bound fine gravel and clayey sand was recorded to a depth of 4 m in W2 and to 5 m in W3. These shallow clay-bound sediments are noted to be positioned above the groundwater table and hence not expected to host groundwater. Borehole W4 intersected weathered sandstone with no alluvium. The drilling results indicate the boundary of the saturated alluvium is positioned mid-way between W1 and W2 which is consistent with the TEM Geophysical Survey;
- Drilling at the Southern Transect near the Hunter River intersected alluvial deposits with gravels to a depth of 10 m in boreholes S2 and S3. Borehole S1 was drilled approximately 5 m north of S2 at the base of a steep hill. Borehole S1 intersected residual clay and weathered sandstone with no alluvial deposits. The drilling results indicate the boundary of the alluvium is immediately north of borehole S2 which is consistent with the Site topography and the TEM Geophysical Survey;
- Monitoring bores were constructed at each drill transect by a licensed water bore driller with water entry zones positioned to target the base of alluvium;
- The investigation programme has met the project objectives supporting the alluvial boundaries delineated in the TEM survey report; and
- This report must be read in conjunction with the Statement of Limitations in Section 11.0.

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FIGURES

Tables

APPENDICES

1.0 INTRODUCTION

Environment & Natural Resource Solutions (ENRS Pty Ltd) were commissioned as independent hydrogeological consultants in September 2018 by *Malabar Coal Limited* (the client) to supervise test drilling and construction of monitoring bores to investigate the extent and nature of unconsolidated alluvial and colluvial deposits adjacent to the Maxwell Project situated within the Muswellbrook local government area, NSW. ENRS understand the project is required to support groundwater assessments (including numerical modelling) of the potential impacts on shallow unconsolidated aquifers associated with the extraction of coal from the Wittingham Coal Measures.

This report summarises the results of borehole drilling, monitoring bore construction, and field observations during one (1) site mobilisation between the 24th and 25th of September 2018.

1.1 OBJECTIVES

The objectives of the project were to:

- Conduct test drilling to investigate the depth and boundary of alluvial deposits, if any at eleven (11) pre-selected sites (adjusted in the field if required) across three (3) transects N1-N4, W1-W4, S1-S3 in the vicinity of Saddlers Creek and the Hunter River;
- Correlate drilling observations with previous Transient Electromagnetic (TEM) geophysics survey; and
- Construct groundwater monitoring bores to facilitate groundwater monitoring.

1.2 SCOPE OF WORK

The scope of work for this groundwater investigation comprised the following tasks:

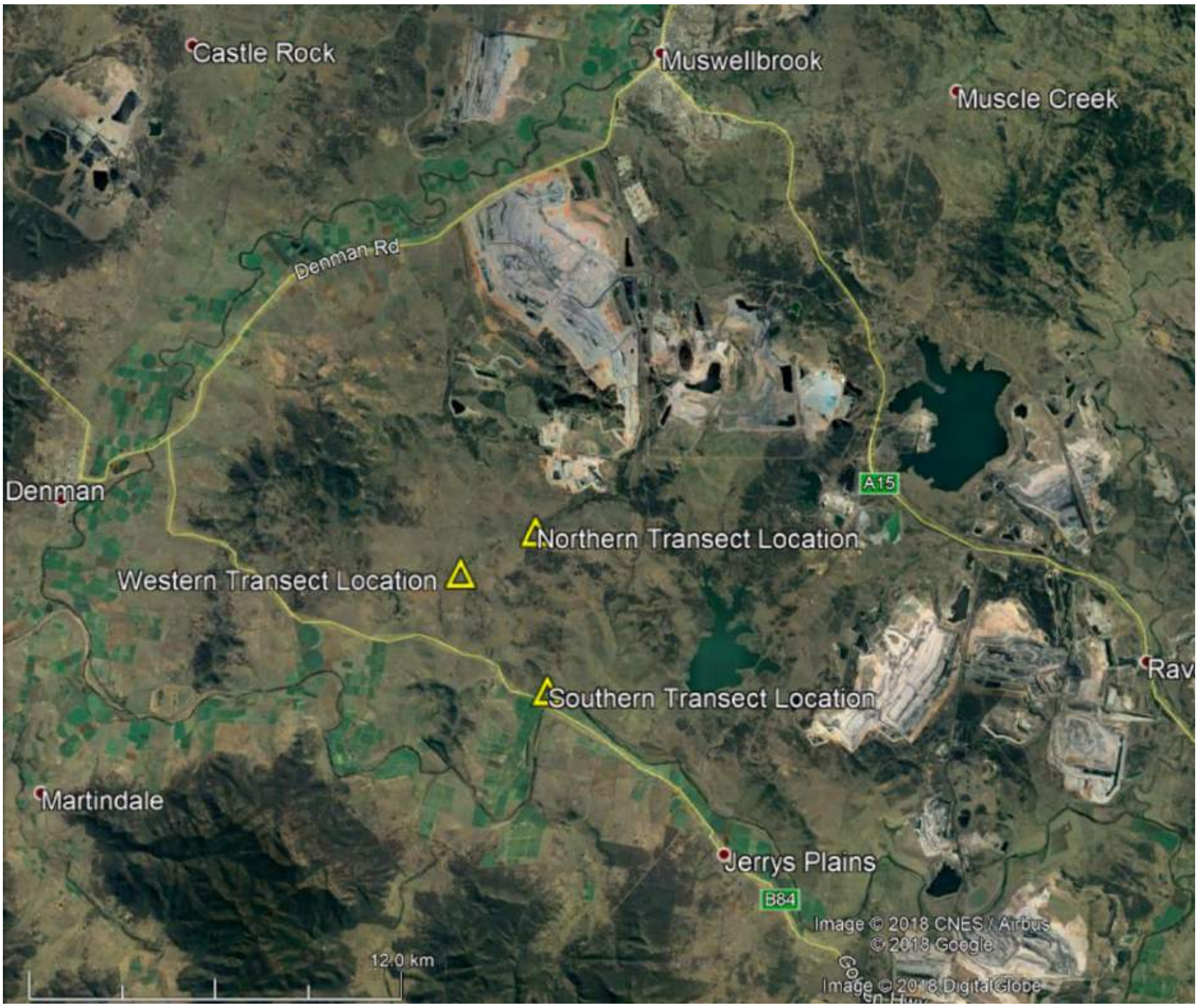
- ENRS hydrogeologist to supervise test drilling by the client's appointed drilling contractor and log drill cuttings/chips. Where drilling methods permit, record the depth, yield and water quality of any aquifer intercepts;
- Review drilling observations and prepare monitoring bore construction design. Position slotted casing coincident with alluvial aquifers, if present. Supervise construction by drilling contractor and record final installation details;
- Develop monitoring bores manually to remove any remnant sediment; and
- Compile investigation results and prepare drilling investigation report.

2.0 SITE DESCRIPTION

2.1 SITE LOCATION

The drilling investigation areas were in the vicinity of the Hunter River and Saddlers Creek, as Shown in **Figure 1**. Borehole locations were selected to ground truth previous geophysics surveys and the published geology.

Figure 1 Site Location Map



Source: Google Earth 2018

2.2 GEOLOGY

Review of the Jerry Plains 1:25,000 series coalfield sheet (9033-11-S) indicated that all three (3) transect areas were on the boundary between the Jerry Plains Subgroup (Pswj) of the Singleton Supergroup and Quaternary aged sediments (Qha). Pwsj is described as interbedded sandstone and siltstone beds, coal seams and tuffaceous claystone. Qha is characterised as silty sand, sand and stream sediments. Drill locations were selected to identify the extents of the alluvial deposits. Drill locations and geology maps are provided in **Figures 2-4** below.

Figure 2 Site Geology (Jerry Plains 1:25K) – Northern Transect Drill Locations

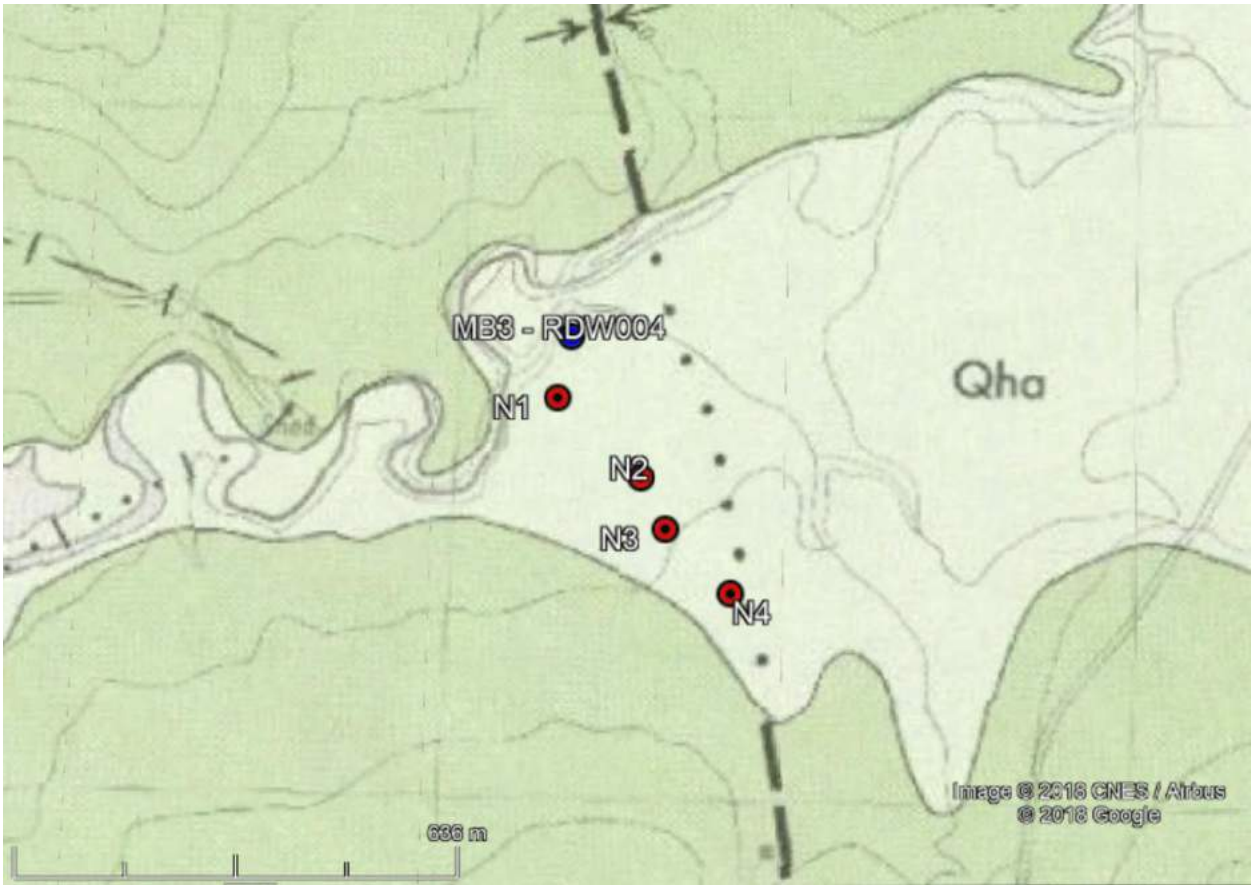


Figure 3 Site Geology (Jerry Plains 1:25K) – Western Transect Drill Locations

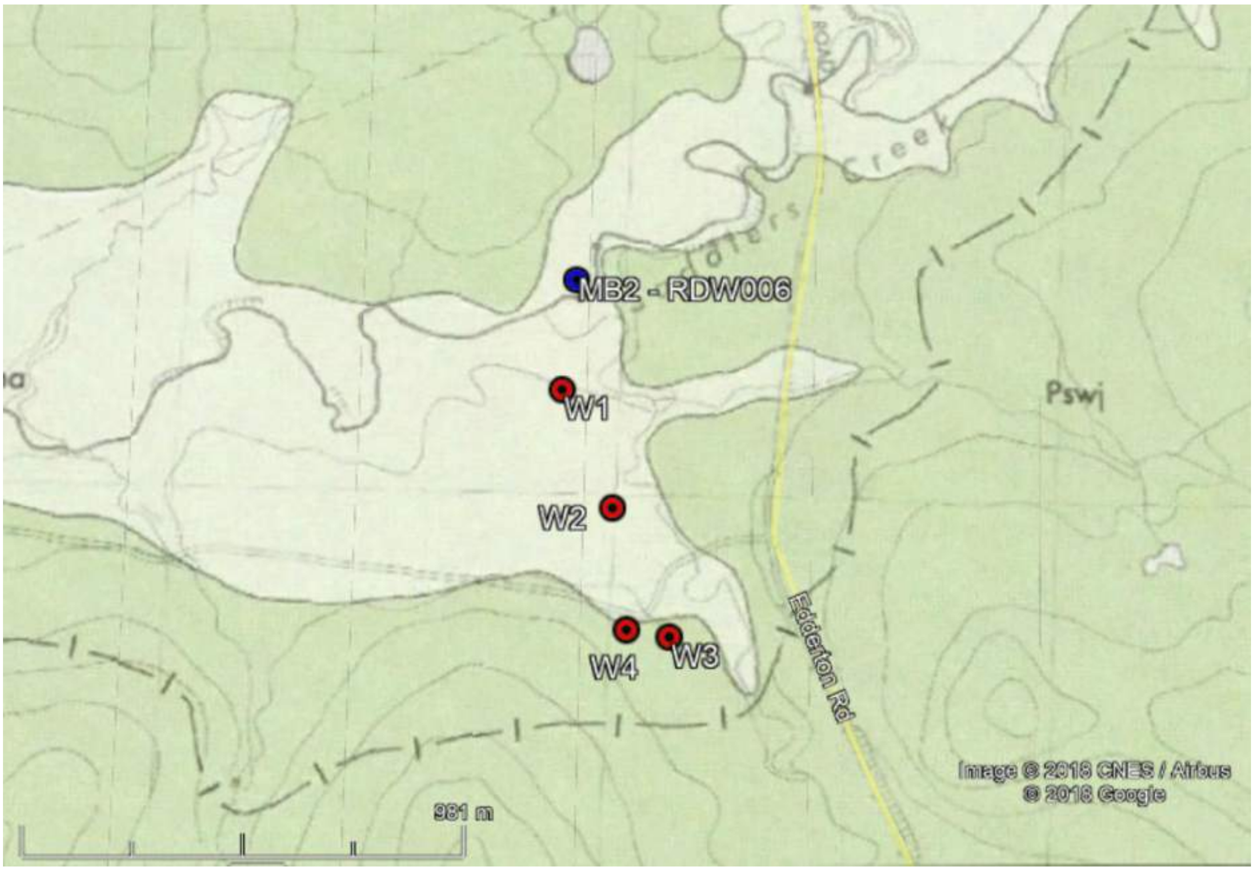


Figure 4 Site Geology (Jerry Plains 1:25K) – Southern Transect Drill Locations

2.3 TEM GEOPHYSICS

A vehicle towed TEM survey (AgTEM4) was conducted across the area in May 2018 by Groundwater Imaging Pty Ltd (GWI). **Figure 5** depicts the extent of the survey area. The survey results were interpreted and documented by Dr David Allen. The survey report provides an assessment of the location and thickness of alluvial deposits and hence potential distribution of unconfined groundwater resources. The reader is referred to the standalone survey report for further discussion of the survey results.

Figure 5 TEM Survey Extent and Drilling Transect Locations

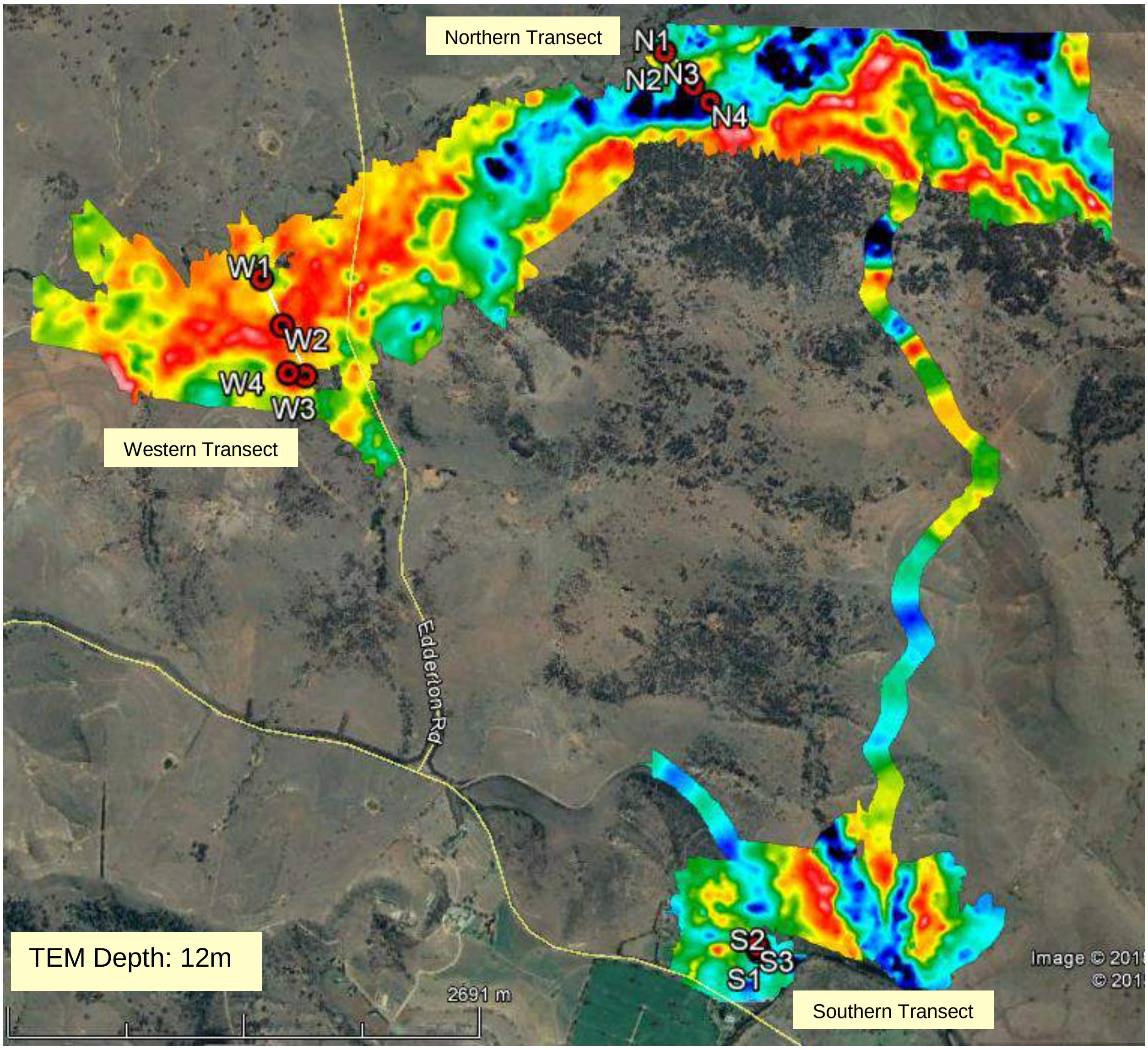


Figure 6 TEM Survey 7m Depth (Northern Drilling Transect)

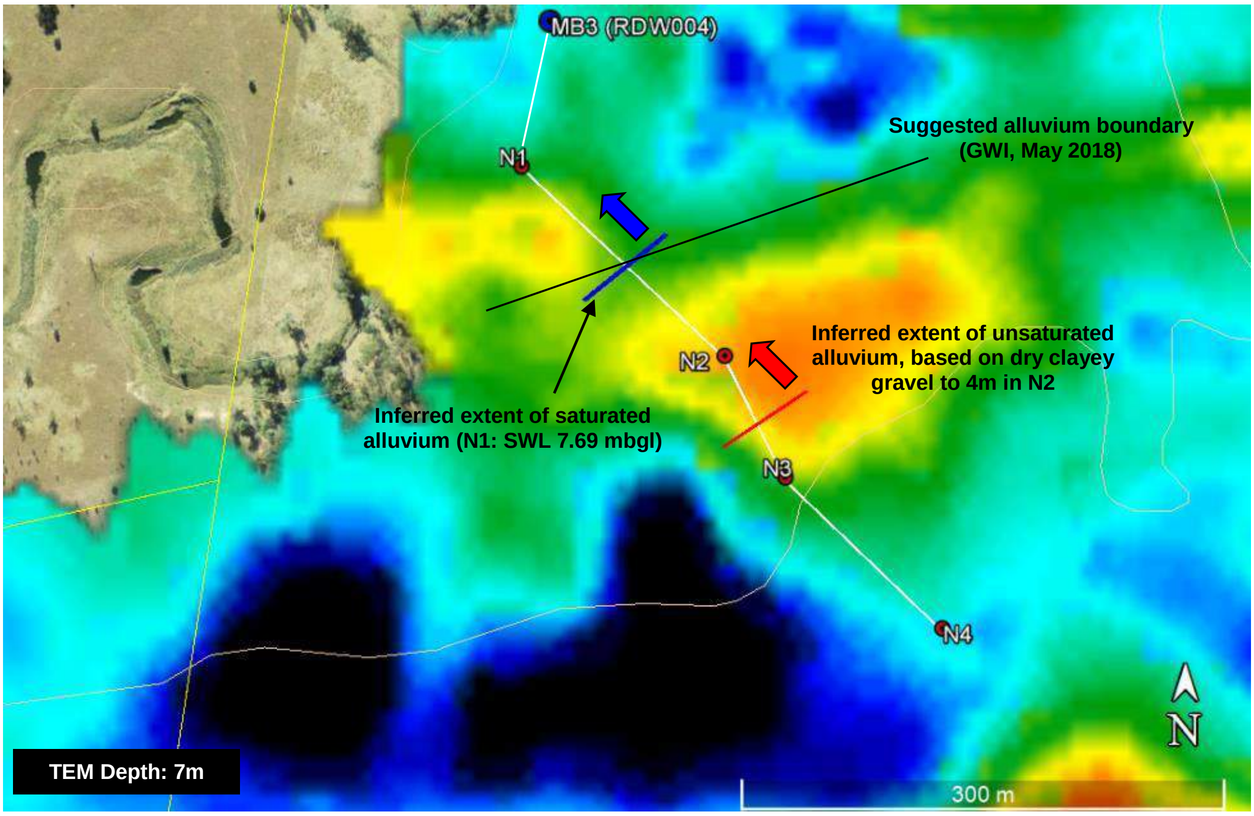


Figure 7 TEM Survey 4m Depth (Northern Drilling Transect)

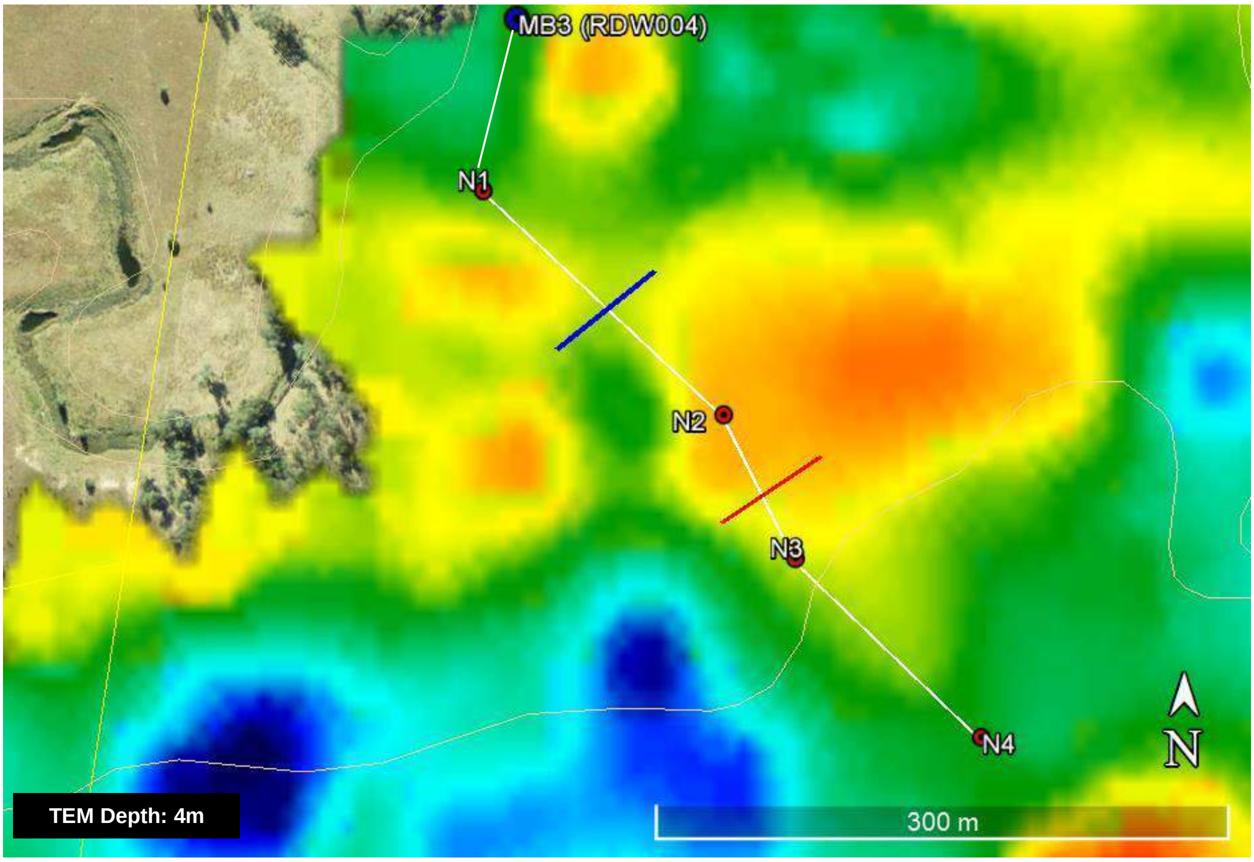


Figure 8 TEM Survey 7m Depth (Western Drilling Transect)

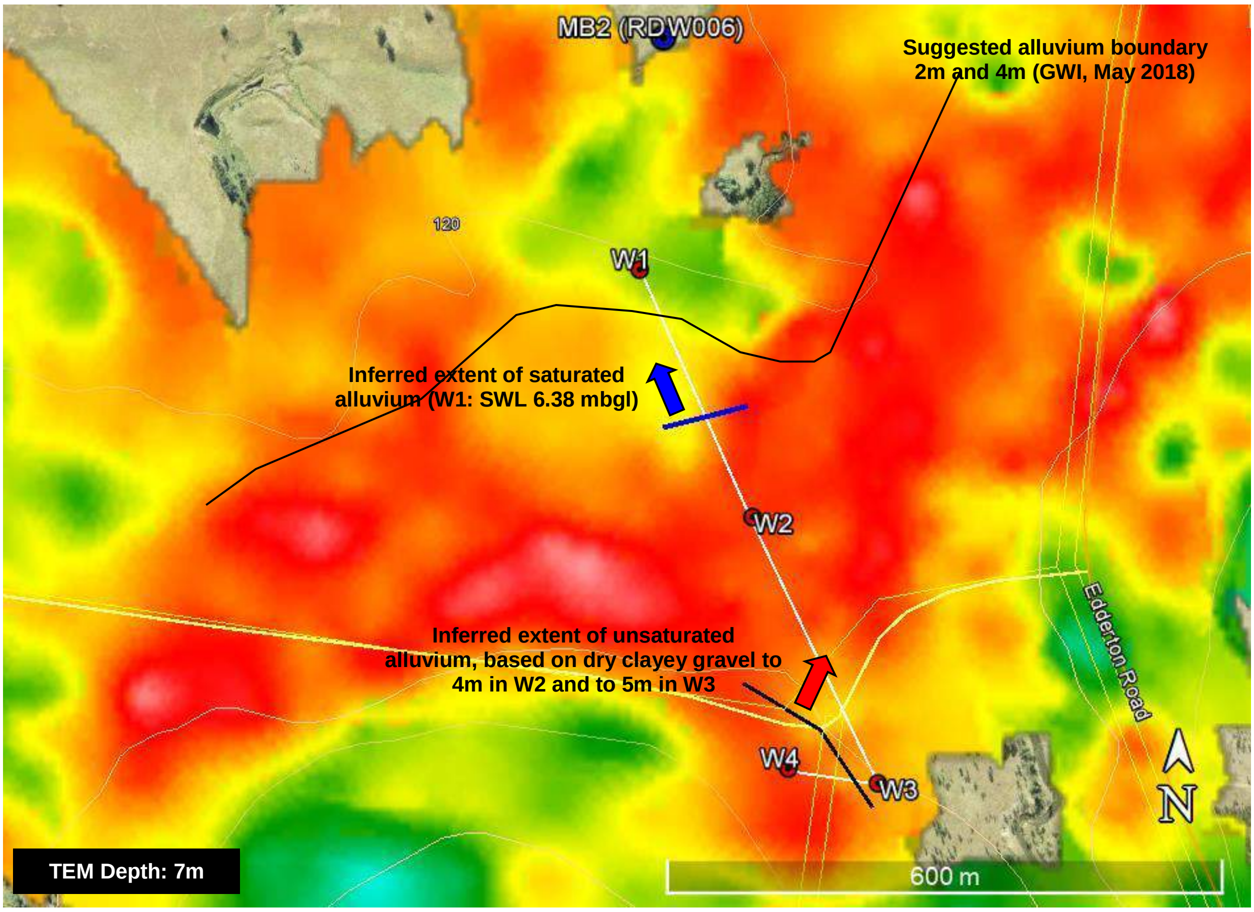


Figure 9 TEM Survey 4m Depth (Western Drilling Transect)

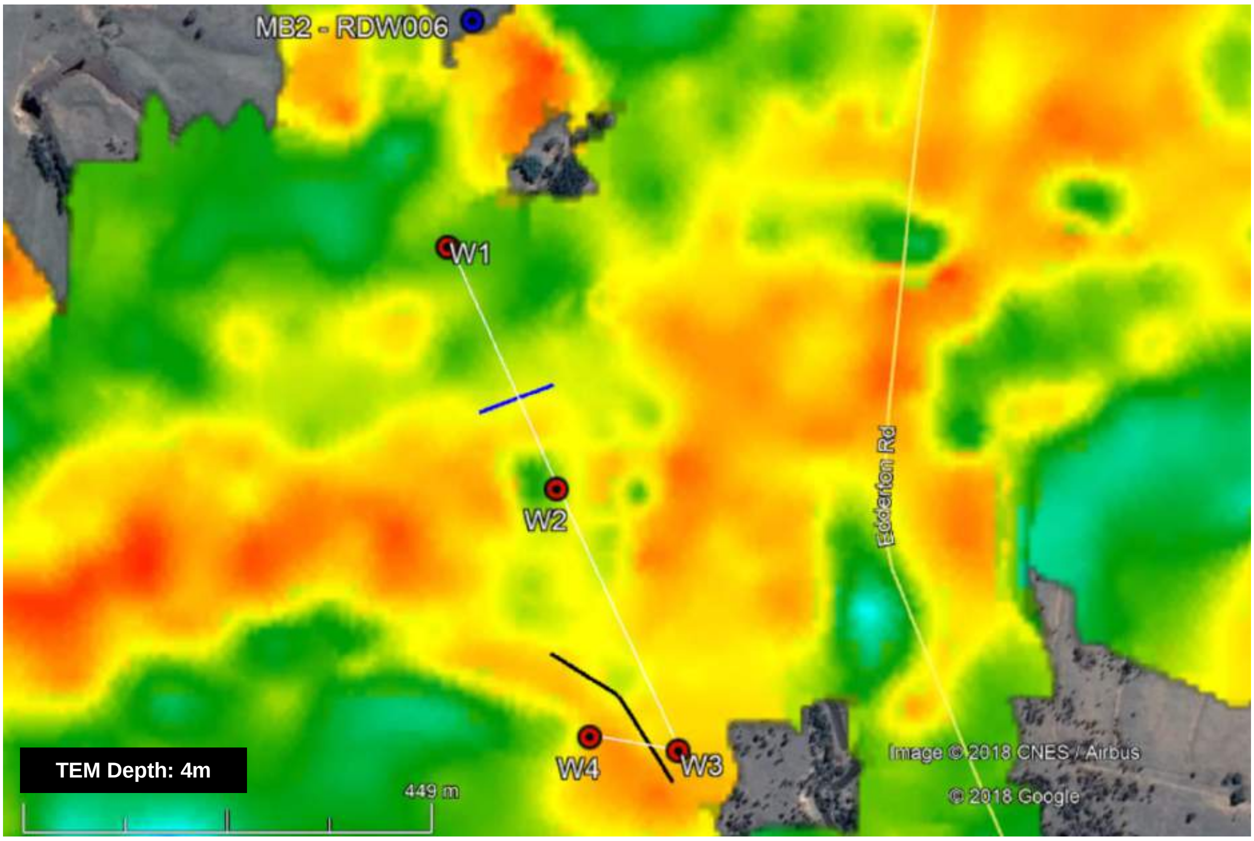
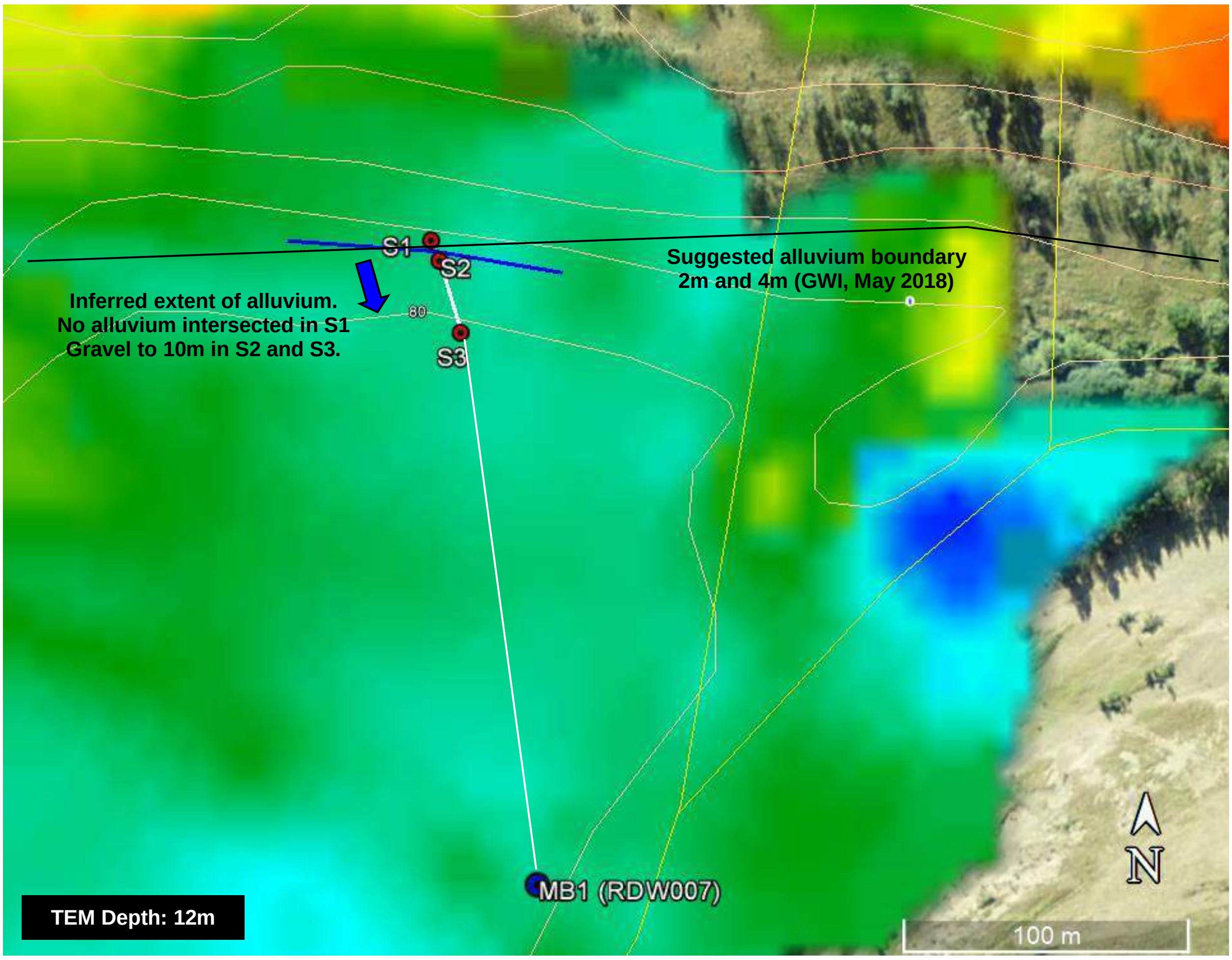


Figure 10 TEM Survey 12m Depth (Southern Drilling Transect)



3.0 PROJECT RESOURCES

3.1 PROJECT MANAGEMENT

The project was managed by Resource Strategies Pty Ltd in consultation with the client. Site inductions, drilling supervision, establishment and rehabilitation requirements were managed by the client.

3.2 DRILLING CONTRACTOR

The drilling contractor for the project was commissioned under separate contract by the client. Drilling and borehole construction was conducted by ***Hagstrom Drilling Pty Ltd*** with groundwater bore works supervised by a licensed water bore driller in accordance with Department of Industry - Water requirements.

3.3 GROUNDWATER CONSULTANT

Drilling and borehole construction was overseen by ENRS professionals under direction from Hydrogeologist, Rohan Last. Rohan possesses more than fifteen years industry experience and holds a post graduate qualification in hydrogeology.

4.0 BORE LICENSING

ENRS understand Drillers Form A construction logs are to be prepared by the driller and lodged by the client.

5.0 DRILLING METHODOLOGY

Test drilling was conducted using a multipurpose rig. Boreholes were installed using solid flight augers, which were raised and inspected at one (1) metre intervals for visual inspection to obtain accurate and representative samples of cuttings from each stratigraphic layer. The following points summarise the investigation methodology:

1. Drill test hole to identify depth of target formations: (i) Alluvium, if any; and (ii) depth to Permian sequence;
2. Collect samples of drill cuttings at 1 metre (m) intervals or any significant change in stratigraphy. Compile chip trays for project records and document drill log in the field on designated field sheets. Photograph drill cuttings and daily site works;
3. Where alluvium is identified, at selected sites construct a shallow monitoring bore with slotted casing at the base of the alluvial deposits and install a bentonite sanitary seal near the surface. Complete bores with surface concrete pads and lockable standpipes;
4. Develop completed bores after grout has set by removing between 3-5 Well volumes. Bores were developed by manual bailing which is considered adequate as no drilling muds were used during construction which require mechanical or pressurised air lifting;
5. Gauge the depth of the bore and standing water level after development;
6. Record field measurements for salinity (EC) and pH from the newly installed groundwater monitoring bores; and
7. Survey final bore heads (top of internal PVC casing and ground level immediately adjacent to the bore) to metres Australian Height Datum (completed by client). Survey certificate shall be appended to this report.

6.0 MONITORING BORE CONSTRUCTION

Monitoring bores were constructed under supervision of a licensed water bore driller with design provided by ENRS Hydrogeologist, Rohan Last, in accordance with the *Minimum Construction Requirements for Water Bores in Australia* (Third Edition).

The position of water entry zones was selected based on drilling observations and interpretation of samples. The target aquifer for screening was the base of any alluvium and unconsolidated materials.

Records of the borehole construction are documented in the borehole log reports (**Appendix A**) with a photo log provided in **Appendix B**. The bores were constructed with class 18 PVC pressure pipe with machine slotted casing installed at the base of the bores. The borehole annulus was filled with 5 mm graded gravel to above the screened zone. Bentonite seals were installed above the screened zone and near the surface. Bores were grouted at the surface with a lockable steel monument stand.

7.0 GROUND SURVEY

Bore locations were recorded in the field by a registered surveyor, with locations attached to this report. Bore heads should be surveyed for elevations reported for the top of PVC casing inside the steel monuments and ground level.

8.0 HYDROGEOLOGY

The following sections outline the key observations and findings from the alluvium and groundwater investigation program.

8.1 DRILLING RESULTS

8.1.1 Northern Transect

Test drilling at the Northern Transect in the vicinity of Saddlers Creek intersected clay overlying alluvial sand and gravel in boreholes N1 and N2. Groundwater was intersected at a depth of 8 m in borehole N1 at the base of clayey gravel, rounded up to 10 mm in diameter. Borehole N1 was converted to a monitoring well with a final Standing Water Level (SWL) of 7.69 metres below ground level (mbgl) (refer to **Appendix A** for the well construction log). Shallow gravel deposits in N2 were observed to a depth of 4.0 metres overlying clay with no groundwater encountered. Boreholes N3 and N4 did not intersect any groundwater, alluvial gravels or sand.

Based on the drilling observations the extent of saturated alluvium is inferred to be midway between N1 and N2 as depicted in **Figure 6** and **Figure 7**, whilst the shallow unsaturated alluvium is expected to extend midway between N2 and N3, which is consistent with the site topography and geophysical survey (GWI, May 2018).

A summary of the borehole stratigraphy is provided in **Table 1** below:

Table 1 Summary of Northern Transect Drilling Results

N1	N2	N3	N4
0-5 Clay	0-1 Clay	0-2 Clay	0-2 Clay
5-6 Sand	1-3 Sandy Clay	2-3 Sandy Clay	2-4 Clay with Minor Sand
6-7 Clayey Gravel	3-4 Gravel (<5mm)	3-4 Clay with Sand	4-6 Clay
7-9 Clay	4-10 Sandy Clay	4-4.2 Weathered Sandstone	6.0 Weathered Sandstone
9-10 Weathered Sandstone	10-11.5 Weathered Sandstone	-	-

8.1.2 Western Transect

Test drilling at the Western Transect in the vicinity of Saddlers Creek intersected clay overlying alluvial gravel in boreholes W1, W2 and W3. Groundwater was intersected at a depth of 8 m in borehole W1 in large rounded gravel up to 100 mm in diameter. Borehole W1 was converted to a monitoring Well with a final Standing Water Level (SWL) of 6.38 mbgl (refer to **Appendix A** for the well construction log).

Shallow gravel deposits in W2 and W3 were noted by be clay bound and semi-rounded less than 10mm in diameter to a maximum depth of 4m in W2. No groundwater was intersected in boreholes W2, W3 or W4. Borehole W4 intersected residual clays at the surface overlying weathered sandstone.

Based on the drilling observations, the extent of saturated alluvium is inferred to be midway between W1 and W2 as depicted in **Figure 8** and **Figure 9**, whilst the margin of the shallow unsaturated alluvium does not extend west to W4, which is consistent with the site topography and geophysical survey (GWI, May 2018).

A summary of the borehole stratigraphy is provided in the **Table 2** below:

Table 2 Summary of Western Transect Drilling Results

W1	W2	W3	W4
0-4 Clay	0-1 Clay	0-1 Clay	0-1 Clay
4-5 Gravel (<2mm)	1-2 Sandy Clay	1-2 Clay with Sand and Gravel	1-4 Weathered Sandstone
5-6 Gravel (<20mm)	2-4 Clayey Gravel (<10mm)	2-3 Clayey Gravel (<5mm)	-
6-7 Gravel (<50mm)	4-5 Weathered Sandstone	3-4 Clayey Sand	-
7-8 Gravel (<100mm)	-	4-5 Clay with Gravel (<5mm)	-
8-9 Clay	-	5-8 Sandy Clay	-
9-9.5 Weathered Sandstone	-	-	-

8.1.3 Southern Transect

Test drilling at the Southern Transect in the vicinity of the Hunter River intersected silt overlying alluvial gravel in boreholes S2 and S3 which were positioned on the river flat south of a steep incline. Borehole S1 was drilled at the base of slope approximately 5 m north of S2 and intersected weathered sandstone with no alluvial deposits. The extent of alluvium is inferred to be immediately north of borehole S2 and south of S1, as depicted in **Figure 10**. The inferred alluvial boundary is consistent with the site topography and geophysical survey (GWI, May 2018).

Borehole S3 was planned for conversion to a monitoring well. However, the well could not be installed to an adequate depth due to borehole stability and drilling refusal on boulders. The constructed well was gauged to be dry at a total depth of 6.85 mbgl.

Review of existing monitoring borelog for MB1-Alluvial (RDW007), located on the river bank south of the transect Site, reports the SWL was 7.8 mbgl on the 24th August 2011.

A summary of the borehole stratigraphy is provided in the **Table 3** below:

Table 3 Summary of Southern Transect Drilling Results

S1	S2	S3
0-3 Silt	0-6 Silt	0-4 Silt
3-5 Sandy Silt	6-7 Gravel <2mm	4-6 Silt with Gravel <2mm
5-7 Weathered Sandstone	7-10 Gravel <10mm	6-7 Sand
-	10-12 Weathered Sandstone	7-7.5 Sandy Gravel (>10mm)
-	-	7.5-10 Gravel (>100mm)
-	-	10 Refusal in Gravel and Boulders

8.2 DEPTH TO WATER

Where groundwater was intersected in test bores, selected bores were converted to monitoring wells. The monitoring wells are constructed in alluvial deposits. Groundwater depths were recorded approximately 24 hours after installation and development. The depth to water was recorded the 25/09/2018 in the newly constructed wells and two (2) existing monitoring bores in proximity to the transect sites. The water level measurements are summarised in **Table 4** below.

Table 4 Depth to groundwater in Monitoring Bores

Monitoring Well/Bore ID	Depth to Groundwater (mbTOC)	Casing Stick Up (magl)	Depth to Water (mbgl)
N1 (MW1)	-8.43	+0.74	-7.69
W1 (MW2)	-7.04	+0.66	-6.38
S3 (MW3)	Dry at 7.6	+0.75	Dry at 6.85
MB1-Alluvial (RDW007)	-6.74	~+1.0	~5.74
MB3-Alluvial (RDW004)	-9.79	~+1.0	~8.79

8.3 WATER QUALITY

Field measurements of salinity (EC) and pH were recorded using a calibrated multiparameter water quality meter. Results are provided in **Table 5** below.

Table 5 Field Measurements Salinity (EC) & pH

Monitoring Well/Bore ID	Salinity as EC (µS/cm)	pH
N1 (MW1)	5720	7.03
W1 (MW2)	5450	7.34
S1 (MW3)	Dry	
MB1 (adjacent southern transect area)	3460	7.04
MB3 (adjacent northern transect area)	4240	7.33

9.0 CONCLUSIONS & RECOMMENDATIONS

Based on the observations made during the scope of works, the following conclusions and recommendations are provided:

- Drilling at the Northern Transect near Saddlers Creek intersected groundwater in borehole N1 at the base of clayey gravels at depth of 7 metres below ground level (mbgl). No groundwater was observed in boreholes N2, N3 and N4. Shallow gravel was also recorded in borehole N2 between a depth of 3-4 m which is above the groundwater table and therefore not expected to host groundwater. The drilling results indicate the boundary of the saturated alluvium is positioned mid-way between N1 and N2 which is consistent with the TEM Geophysical Survey;
- Drilling at the Western Transect near Saddlers Creek intersected groundwater in borehole W1 associated with gravel to a depth of 8 m. No groundwater was observed in boreholes W2, W3 and W4. Shallow unsaturated alluvium characterised as clay bound fine gravel and clayey sand was recorded to a depth of 4 m in W2 and to 5 m in W3. These shallow clay-bound sediments are noted to be positioned above the groundwater table and hence not expected to host groundwater. Borehole W4 intersected weathered sandstone with no alluvium. The drilling results indicate the boundary of the saturated alluvium is positioned mid-way between W1 and W2 which is consistent with the TEM Geophysical Survey;
- Drilling at the Southern Transect near the Hunter River intersected alluvial deposits with gravels to a depth of 10 m in boreholes S2 and S3. Borehole S1 was drilled approximately 5 m north of S2 at the base of a steep hill. Borehole S1 intersected residual clay and weathered sandstone with no alluvial deposits. The drilling results indicate the boundary of the alluvium is immediately north of borehole S2 which is consistent with the Site topography and the TEM Geophysical Survey;
- Monitoring bores were constructed at each drill transect by a licensed water bore driller with water entry zones positioned to target the base of alluvium;
- The investigation programme has met the project objectives supporting the alluvial boundaries delineated in the TEM survey report; and
- This report must be read in conjunction with the Statement of Limitations in **Section 11.0**.

10.0REFERENCES

Australian Government National Water Commission (2012). Minimum Construction Requirements for Water Bores in Australia (Third Edition).

Murray-Darling Basin Commission (1997). Murray-Darling Basin Groundwater Quality Sampling Guidelines, Technical Report No. 3, MDBC Groundwater Working Group, Commonwealth of Australia.

Sniffin M.J. and Summerhayes G.J., 1987, Jerry Plains 1:25,000 Coalfield Sheet (9033-11-S) Geology Map. Geological Survey of New South Wales, Sydney

Standards Australia (1998a). AS/NZS 5667.1:1998 Water quality sampling guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples

Standards Australia (1998b). AS/NZS 5667.11:1998 Water Quality Sampling Guidance on Sampling of Groundwaters, Standards Australia, New South Wales.

11.0 LIMITATIONS

This report and the associated services performed by ENRS are in accordance with the scope of services set out in the contract between ENRS and the Client. The scope of services was defined by the requests of the Client, by the time and budgetary constraints imposed by the Client, and by the availability of access to Site.

ENRS derived the data in this report primarily from visual inspections, and, limited sample collection and analysis made on the dates indicated. In preparing this report, ENRS has relied upon, and presumed accurate, certain information provided by government authorities, the Client and others identified herein. The report has been prepared on the basis that while ENRS believes all the information in it is deemed reliable and accurate at the time of preparing the report, it does not warrant its accuracy or completeness and to the full extent allowed by law excludes liability in contract, tort or otherwise, for any loss or damage sustained by the Client arising from or in connection with the supply or use of the whole or any part of the information in the report through any cause whatsoever.

Limitations also apply to analytical methods used in the identification of substances (or parameters). These limitations may be due to non-homogenous material being sampled (i.e. the sample to be analysed may not be representative), low concentrations, the presence of 'masking' agents and the restrictions of the approved analytical technique. As such, non-statistically significant sampling results can only be interpreted as 'indicative' and not used for quantitative assessments.

The data, findings, observations, conclusions and recommendations in the report are based solely upon the state of Site at the time of the investigation. The passage of time, manifestation of latent conditions or impacts of future events (e.g. changes in legislation, scientific knowledge, land uses, etc) may render the report inaccurate. In those circumstances, ENRS shall not be liable for any loss or damage that may be occasioned directly or indirectly through the use of, or reliance on, the contents of the report.

This report has been prepared on behalf of and for the exclusive use of the Client, and is subject to and issued in connection with the provisions of the agreement between ENRS and the Client. ENRS accepts no liability or responsibility whatsoever and expressly disclaims any responsibility for or in respect of any use of or reliance upon this report by any third party or parties.

It is the responsibility of the Client to accept if the Client so chooses any recommendations contained within and implement them in an appropriate, suitable and timely manner.

APPENDICES

Appendix A

Borehole Logs

ENVIRONMENT & NATURAL RESOURCE SOLUTIONS
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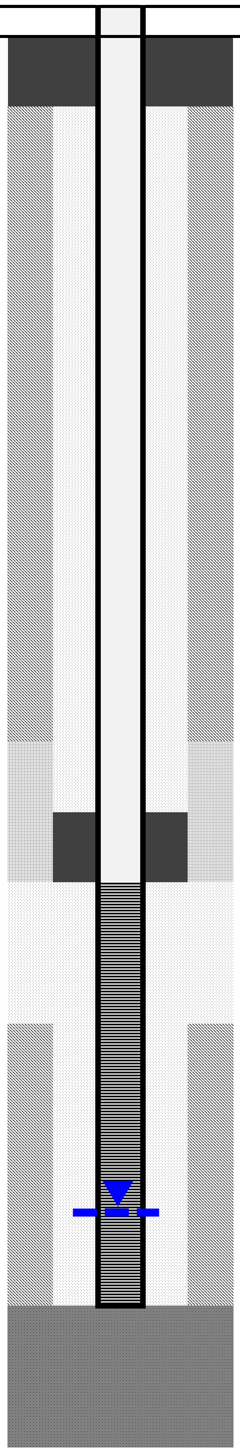
ENVIRONMENTAL BOREHOLE CONSTRUCTION LOG

BOREHOLE ID: N1 (MW1)

PROJECT No:	ENRS1046 Maxwell	**DATE DRILLED:**	24/09/2018
LOCATION:	Saddlers Creek	**LOGGED BY:**	TB
CLIENT:	Malabar Coal	**DRILLED BY:**	Hagstrom
SURFACE RL:	136.53	**DRILL METHOD:**	Solid Flight Auger
EASTING (GDA94):	(56) 297253.693	**HOLE DIAMETER:**	120mm
NORTHING:	6412760.005	**FINAL DEPTH:**	10m

Depth (m)	Groundwater Well Construction	Photographic Record of Drill Cuttings	Graphic Log	Description (Soil/Rock TYPE, particle size, colour, particle shape, minor constituents)
				Ground Surface
0.0	+0.74m Well Stick up and Monument 0-0.3m Cement 0.0-6.0m 50mm PVC Casing			0-3.0m CLAY, light brown
0.5				
1.0				
1.5				
2.0				
2.5				
3.0				3.0-4.0m CLAY, with silt
3.5				
4.0				4.0-5.0m CLAY, dark brown with silt
4.5				
5.0				5.0-6.0m SAND, with minor silt
5.5	5.5-5.8 Bentonite sanitary seal 5.8-9.0m Gravel Pack graded 6.0-9.0m Slotted 50mm PVC Screen			
6.0				6.0-7.0m clayey GRAVEL, rounded <10mm
6.5				
7.0				7.0-8.0m CLAY, with minor silt
7.5				
8.0				8.0-9.0m CLAY, sandy, brown
8.5	**SWL 8.43mbTOC 25/09/2018**			
9.0	9.0m Push on end cap			9.0-10.0m SANDSTONE, brown, weathered, mositure cut
9.5				
10.0				10.0m Target Depth Reached - Refusal



Moisture: (D) Dry (M) Moist (W) Wet
Consistency: (VS) Very Soft (S) Soft (F) Firm(St) Stiff (VSt) Very Stiff (H) Hard (Fb) Friable
Density Index: (VL) Very Loose (L) (MD) Medium Dense (VD) Very Dense

TOC

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ENVIRONMENTAL BOREHOLE CONSTRUCTION LOG

BOREHOLE ID: N2

PROJECT No:	ENRS1046 Maxwell	**DATE DRILLED:**	24/09/2018
LOCATION:	Saddlers Creek	**LOGGED BY:**	TB
CLIENT:	Malabar Coal	**DRILLED BY:**	Hagstrom
SURFACE RL:	139.063	**DRILL METHOD:**	Solid Flight Auger
EASTING (GDA94):	(56) 297381.375	**HOLE DIAMETER:**	120mm
NORTHING:	6412646.099	**FINAL DEPTH:**	11.5m

Depth (m)	Groundwater Well Construction	Photographic Record of Drill Cuttings	Graphic Log	Description (Soil/Rock TYPE, particle size, colour, particle shape, minor constituents)
				Ground Surface
0.0				0-1.0m CLAY, light brown
0.5				
1.0	NOT CONSTRUCTED			1.0-3.0m sandy CLAY, orangey brown
1.5				
2.0				
2.5				
3.0				3.0-4.0m GRAVEL, rounded <5mm, dry
3.5				
4.0				4.0-10.0m CLAY, brown, with some sand
4.5				
5.0				
5.5				
6.0				
6.5				
7.0				
7.5				
8.0				
8.5				
9.0				
9.5				
10.0				10.0-11.5m SANDSTONE, brown, weathered
10.5				
11.0				
11.5				11.5m Target Depth Reached - Refusal

Moisture: (D) Dry (M) Moist (W) Wet
Consistency: (VS) Very Soft (S) Soft (F) Firm(St) Stiff (VSt) Very Stiff (H) Hard (Fb) Friable
Density Index: (VL) Very Loose (L) (MD) Medium Dense (VD) Very Dense

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ENVIRONMENTAL BOREHOLE CONSTRUCTION LOG

BOREHOLE ID: N3

PROJECT No:	ENRS1046 Maxwell	**DATE DRILLED:**	24/09/2018
LOCATION:	Saddlers Creek	**LOGGED BY:**	TB
CLIENT:	Malabar Coal	**DRILLED BY:**	Hagstrom
SURFACE RL:	140.473	**DRILL METHOD:**	Solid Flight Auger
EASTING (GDA94):	(56) 297420.121	**HOLE DIAMETER:**	120mm
NORTHING:	6412572.102	**FINAL DEPTH:**	4.2m

Depth (m)	Groundwater Well Construction	Photographic Record of Drill Cuttings	Graphic Log	Description (Soil/Rock TYPE, particle size, colour, particle shape, minor constituents)
				Ground Surface
0.0				0-2.0m CLAY, light brown
0.5				
1.0	NOT CONSTRUCTED			
1.5				
2.0				2.0-3.0m sandy CLAY, brown
2.5				
3.0				3.0-4.0m CLAY, dark brown, with some sand
3.5				
4.0				4.0-4.2m SANDSTONE, Weathered
				4.2m Target Depth Reached - Refusal
4.5				
5.0				
5.5				
6.0				
6.5				
7.0				
7.5				
8.0				
8.5				
9.0				
9.5				
10.0				

Moisture: (D) Dry (M) Moist (W) Wet
Consistency: (VS) Very Soft (S) Soft (F) Firm(St) Stiff (VSt) Very Stiff (H) Hard (Fb) Friable
Density Index: (VL) Very Loose (L) (MD) Medium Dense (VD) Very Dense

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ENVIRONMENTAL BOREHOLE CONSTRUCTION LOG

BOREHOLE ID: N4

PROJECT No:	ENRS1046 Maxwell	**DATE DRILLED:**	24/09/2018
LOCATION:	Saddlers Creek	**LOGGED BY:**	TB
CLIENT:	Malabar Coal	**DRILLED BY:**	Hagstrom
SURFACE RL:	143.153	**DRILL METHOD:**	Solid Flight Auger
EASTING (GDA94):	(56) 297519.397	**HOLE DIAMETER:**	120mm
NORTHING:	6412481.767	**FINAL DEPTH:**	6.0m

Depth (m)	Groundwater Well Construction	Photographic Record of Drill Cuttings	Graphic Log	Description (Soil/Rock TYPE, particle size, colour, particle shape, minor constituents)
				Ground Surface
0.0				0-2.0m CLAY, light brown
0.5				
1.0	NOT CONSTRUCTED			
1.5				
2.0				2.0-3.0m CLAY, light brown-orange with minor sand
2.5				
3.0				3.0-4.0m CLAY, brown with minor sand
3.5				
4.0				4.0-6.0m CLAY, brown
4.5				
5.0				
5.5				
6.0				6.0m SANDSTONE, weathered Target Depth Reached
6.5				
7.0				
7.5				
8.0				
8.5				
9.0				
9.5				
10.0				
10.5				
11.0				
11.5				

Moisture: (D) Dry (M) Moist (W) Wet
Consistency: (VS) Very Soft (S) Soft (F) Firm(St) Stiff (VSt) Very Stiff (H) Hard (Fb) Friable
Density Index: (VL) Very Loose (L) (MD) Medium Dense (VD) Very Dense

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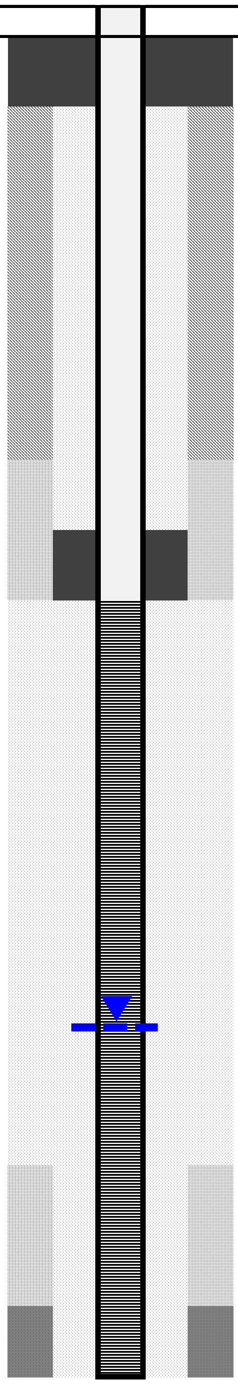
ENVIRONMENTAL BOREHOLE CONSTRUCTION LOG

BOREHOLE ID: W1 (MW2)

PROJECT No:	ENRS1046 Maxwell	**DATE DRILLED:**	25/09/2018
LOCATION:	Bowfield	**LOGGED BY:**	TB
CLIENT:	Malabar Coal	**DRILLED BY:**	Hagstrom
SURFACE RL:	119.36	**DRILL METHOD:**	Solid Flight Auger
EASTING (GDA94):	(56) 294977.248	**HOLE DIAMETER:**	120mm
NORTHING:	6411419.137	**FINAL DEPTH:**	9.5m



Depth (m)	Groundwater Well Construction	Photographic Record of Drill Cuttings	Graphic Log	Description (Soil/Rock TYPE, particle size, colour, particle shape, minor constituents)
				Ground Surface
0.0	+0.66 Well Stick up and Monument			0-3.0m CLAY, light brown
	0-0.3m Cement			
0.5	0.0-4.0m 50mm PVC Casing			
1.0				
1.5				
2.0				
2.5				
3.0				3.0-4.0m CLAY, light brown with minor sand
3.5				
4.0	3.5-3.8m Bentonite sanitary seal			4.0-5.0m GRAVEL, rounded <2mm, sandy
	3.8-9.5m Gravel pack graded			
4.5	4.0-9.5m Slotted 50mm PVC Screen			
5.0				5.0-6.0m GRAVEL, rounded <20mm, sandy
5.5				
6.0				6.0-7.0m GRAVEL, rounded <50mm
6.5				
7.0	**SWL 7.04mbTOC 25/09/2018**			7.0-8.0m GRAVEL, rounded <100mm
7.5				
8.0				8.0-9.0m CLAY, sandy
8.5				
9.0				9.0-9.5m SANDSTONE, weathered
9.5	9.5m Push on end cap			9.5m Target Depth Reached - Refusal
10.0				

Moisture: (D) Dry (M) Moist (W) Wet
Consistency: (VS) Very Soft (S) Soft (F) Firm(St) Stiff (VSt) Very Stiff (H) Hard (Fb) Friable
Density Index: (VL) Very Loose (L) (MD) Medium Dense (VD) Very Dense

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ENVIRONMENTAL BOREHOLE CONSTRUCTION LOG

BOREHOLE ID: W2

PROJECT No:	ENRS1046 Maxwell	**DATE DRILLED:**	25/09/2018
LOCATION:	Bowfield	**LOGGED BY:**	TB
CLIENT:	Malabar Coal	**DRILLED BY:**	Hagstrom
SURFACE RL:	123.485	**DRILL METHOD:**	Solid Flight Auger
EASTING (GDA94):	(56) 295104.114	**HOLE DIAMETER:**	120mm
NORTHING:	6411156.894	**FINAL DEPTH:**	5.0m

Depth (m)	Groundwater Well Construction	Photographic Record of Drill Cuttings	Graphic Log	Description (Soil/Rock TYPE, particle size, colour, particle shape, minor constituents)
				Ground Surface
0.0				0-1.0m CLAY, light brown
0.5				
1.0	NOT CONSTRUCTED			1.0-2.0m sandy CLAY, light brown
1.5				
2.0				2.0-3.0m clayey GRAVEL, dry, semi-rounded <5mm, with sand
2.5				
3.0				3.0-4.0m clayey GRAVEL, dry, semi-rounded <10mm, with sand
3.5				
4.0				4.0-5.0m clayey SANDSTONE, brown, highly weathered
4.5				
5.0				5.0m Target Depth Reached
5.5				
6.0				
6.5				
7.0				
7.5				
8.0				
8.5				
9.0				
9.5				
10.0				
10.5				
11.0				
11.5				

Moisture: (D) Dry (M) Moist (W) Wet
Consistency: (VS) Very Soft (S) Soft (F) Firm(St) Stiff (VSt) Very Stiff (H) Hard (Fb) Friable
Density Index: (VL) Very Loose (L) (MD) Medium Dense (VD) Very Dense

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ENVIRONMENTAL BOREHOLE CONSTRUCTION LOG

BOREHOLE ID: W3

PROJECT No:	ENRS1046 Maxwell	**DATE DRILLED:**	25/09/2018
LOCATION:	Bowfield	**LOGGED BY:**	TB
CLIENT:	Malabar Coal	**DRILLED BY:**	Hagstrom
SURFACE RL:	127.583	**DRILL METHOD:**	Solid Flight Auger
EASTING (GDA94):	(56) 295245.976	**HOLE DIAMETER:**	120mm
NORTHING:	6410873.812	**FINAL DEPTH:**	8.0m

Depth (m)	Groundwater Well Construction	Photographic Record of Drill Cuttings	Graphic Log	Description (Soil/Rock TYPE, particle size, colour, particle shape, minor constituents)
				Ground Surface
0.0				0-1.0m CLAY, light brown
0.5				
1.0	NOT CONSTRUCTED			1.0-2.0m CLAY, brown with rounded gravel <5mm, and sand
1.5				
2.0				2.0-3.0m clayey GRAVEL, rounded <5mm, dry with sand
2.5				
3.0				3.0-4.0m clayey SAND, dry, brown
3.5				
4.0				4.0-5.0m CLAY, brown with gravel, semi-rounded <5mm
4.5				
5.0				5.0-8.0 sandy CLAY, brown
5.5				
6.0				
6.5				
7.0				
7.5				
8.0				8.0m Target Depth Reached
8.5				
9.0				
9.5				
10.0				
10.5				
11.0				
11.5				

Moisture: (D) Dry (M) Moist (W) Wet
Consistency: (VS) Very Soft (S) Soft (F) Firm(St) Stiff (VSt) Very Stiff (H) Hard (Fb) Friable
Density Index: (VL) Very Loose (L) (MD) Medium Dense (VD) Very Dense

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ENVIRONMENTAL BOREHOLE CONSTRUCTION LOG

BOREHOLE ID: W4

PROJECT No:	ENRS1046 Maxwell	**DATE DRILLED:**	25/09/2018
LOCATION:	Bowfield	**LOGGED BY:**	TB
CLIENT:	Malabar Coal	**DRILLED BY:**	Hagstrom
SURFACE RL:	130.78	**DRILL METHOD:**	Solid Flight Auger
EASTING (GDA94):	(56) 295148.039	**HOLE DIAMETER:**	120mm
NORTHING:	6410887.097	**FINAL DEPTH:**	4.0m

Depth (m)	Groundwater Well Construction	Photographic Record of Drill Cuttings	Graphic Log	Description (Soil/Rock TYPE, particle size, colour, particle shape, minor constituents)
				Ground Surface
0.0				0-1.0m CLAY, red/brown
0.5				
1.0	NOT CONSTRUCTED			1.0-4.0m SANDSTONE, light brown, weathered
1.5				
2.0				
2.5				
3.0				
3.5				
4.0				4.0m Target Depth Reached - Refusal
4.5				
5.0				
5.5				
6.0				
6.5				
7.0				
7.5				
8.0				
8.5				
9.0				
9.5				
10.0				
10.5				
11.0				
11.5				

Moisture: (D) Dry (M) Moist (W) Wet
Consistency: (VS) Very Soft (S) Soft (F) Firm(St) Stiff (VSt) Very Stiff (H) Hard (Fb) Friable
Density Index: (VL) Very Loose (L) (MD) Medium Dense (VD) Very Dense

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ENVIRONMENTAL BOREHOLE CONSTRUCTION LOG

BOREHOLE ID: S1

PROJECT No:	ENRS1046 Maxwell	**DATE DRILLED:**	25/09/2018
LOCATION:	Llanillo - Hunter River	**LOGGED BY:**	TB
CLIENT:	Malabar Coal	**DRILLED BY:**	Hagstrom
SURFACE RL:	81.864	**DRILL METHOD:**	Solid Flight Auger
EASTING (GDA94):	(56) 297892.881	**HOLE DIAMETER:**	120mm
NORTHING:	6407682.464	**FINAL DEPTH:**	7.0m

Depth (m)	Groundwater Well Construction	Photographic Record of Drill Cuttings	Graphic Log	Description (Soil/Rock TYPE, particle size, colour, particle shape, minor constituents)
				Ground Surface
0.0				0-3.0m SILT, brown
0.5				
1.0	NOT CONSTRUCTED			
1.5				
2.0				
2.5				
3.0				3.0-5.0m sandy SILT, dark brown
3.5				
4.0				
4.5				
5.0				5.0-7.0m SANDSTONE, weathered, light brown
5.5				
6.0				
6.5				
7.0				7.0m Target Depth Reached - Refusal
7.5				
8.0				
8.5				
9.0				
9.5				
10.0				
10.5				
11.0				
11.5				

Moisture: (D) Dry (M) Moist (W) Wet
Consistency: (VS) Very Soft (S) Soft (F) Firm(St) Stiff (VSt) Very Stiff (H) Hard (Fb) Friable
Density Index: (VL) Very Loose (L) (MD) Medium Dense (VD) Very Dense

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ENVIRONMENTAL BOREHOLE CONSTRUCTION LOG

BOREHOLE ID: S2

PROJECT No:	ENRS1046 Maxwell	**DATE DRILLED:**	25/09/2018
LOCATION:	Llanillo - Hunter River	**LOGGED BY:**	TB
CLIENT:	Malabar Coal	**DRILLED BY:**	Hagstrom
SURFACE RL:	81.321	**DRILL METHOD:**	Solid Flight Auger
EASTING (GDA94):	(56) 297896.860	**HOLE DIAMETER:**	120mm
NORTHING:	6407674.564	**FINAL DEPTH:**	12.0m

Depth (m)	Groundwater Well Construction	Photographic Record of Drill Cuttings	Graphic Log	Description (Soil/Rock TYPE, particle size, colour, particle shape, minor constituents)
				Ground Surface
0.0				0-3.0m SILT, brown
0.5				
1.0	NOT CONSTRUCTED			
1.5				
2.0				
2.5				
3.0				3.0-6.0m SILT, dark brown
3.5				
4.0				
4.5				
5.0				
5.5				
6.0				6.0-7.0m sandy GRAVEL, rounded <2mm, dark brown with silt
6.5				
7.0				7.0-10.0m GRAVEL, rounded <10mm with some clay and sand
7.5				
8.0				
8.5				
9.0				
9.5				
10.0				10.0-12.0m SANDSTONE, weathered, grey/brown
10.5				
11.0				
11.5				
12.0				12.0m Target Depth Reached - Refusal

Moisture: (D) Dry (M) Moist (W) Wet
Consistency: (VS) Very Soft (S) Soft (F) Firm(St) Stiff (VSt) Very Stiff (H) Hard (Fb) Friable
Density Index: (VL) Very Loose (L) (MD) Medium Dense (VD) Very Dense

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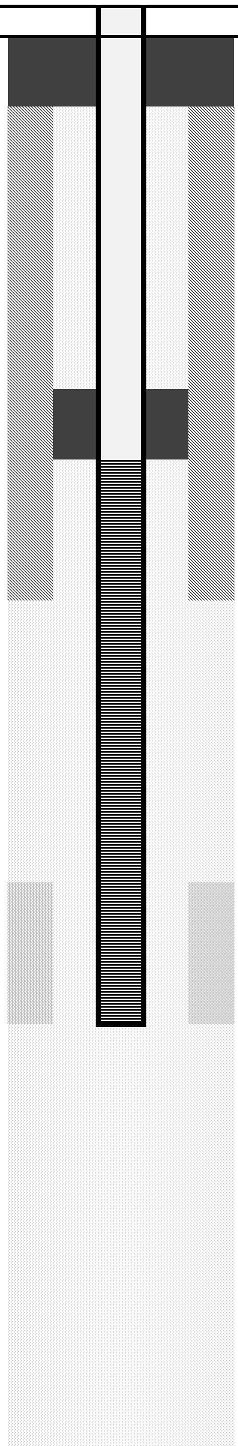
ENVIRONMENTAL BOREHOLE CONSTRUCTION LOG

BOREHOLE ID: S3 (MW3)

PROJECT No:	ENRS1046 Maxwell	**DATE DRILLED:**	25/09/2018
LOCATION:	Llanillo - Hunter River	**LOGGED BY:**	TB
CLIENT:	Malabar Coal	**DRILLED BY:**	Hagstrom
SURFACE RL:	81.641	**DRILL METHOD:**	Solid Flight Auger
EASTING (GDA94):	(56) 297903.823	**HOLE DIAMETER:**	120mm
NORTHING:	6407651.743	**FINAL DEPTH:**	10.0m

Depth (m)	Groundwater Well Construction	Photographic Record of Drill Cuttings	Graphic Log	Description (Soil/Rock TYPE, particle size, colour, particle shape, minor constituents)
				Ground Surface
0.0	+0.75 Well Stick up and Monument			0-4.0m SILT, dark brown
	0-0.3m Cement			
0.5	0.0-2.85m 50mm PVC Casing			
1.0				
1.5				
2.0				
2.5	2.45-2.75m Bentonite sanitary seal			
	2.75-6.85m Gravel pack graded			
3.0	2.85-6.85m Slotted 50mm PVC Screen			
3.5				
4.0				4.0-6.0m sandy SILT, brown with gravel rounded <2mm,
4.5				
5.0				
5.5				
6.0				6.0-7.0m SAND, coarse, brown with minor gravel <2mm
6.5	Dry after construction			
7.0	6.85m Push on end cap			7.0m-7.5m sandy GRAVEL, rounded >10mm
7.5	borehole collapse - unable to install Well below 6.85m			7.5-10.0m GRAVEL, rounded >100mm
8.0				
8.5				
9.0				
9.5				
10.0				10.0m Target Depth Reached - Refusal in gravel



Moisture: (D) Dry (M) Moist (W) Wet
Consistency: (VS) Very Soft (S) Soft (F) Firm(St) Stiff (VSt) Very Stiff (H) Hard (Fb) Friable
Density Index: (VL) Very Loose (L) (MD) Medium Dense (VD) Very Dense

Appendix B

Photographic Record of Drill Cuttings

Northern Drilling Transect – cuttings photo log

N1: 1-10 metres

N2: 1-11.5 metres

N3: 1-4.2 metres

N4: 1-6 metres

Western Drilling Transect – cuttings photo log

W1 1-9 metres

W2 1-5 metres

W3 1-8 metres

W4 1-4 metres

TOC

Southern Drilling Transect – cuttings photo log

S1: 1-7 metres

S2: 1-12 metres

S3: 1-10 metres

Appendix C

Photographic Record of Site Conditions

Photograph 1: Looking from N3 towards N1

Photograph 2: N1 Groundwater Monitoring Well installation

Photograph 3: W2 Drill location looking north

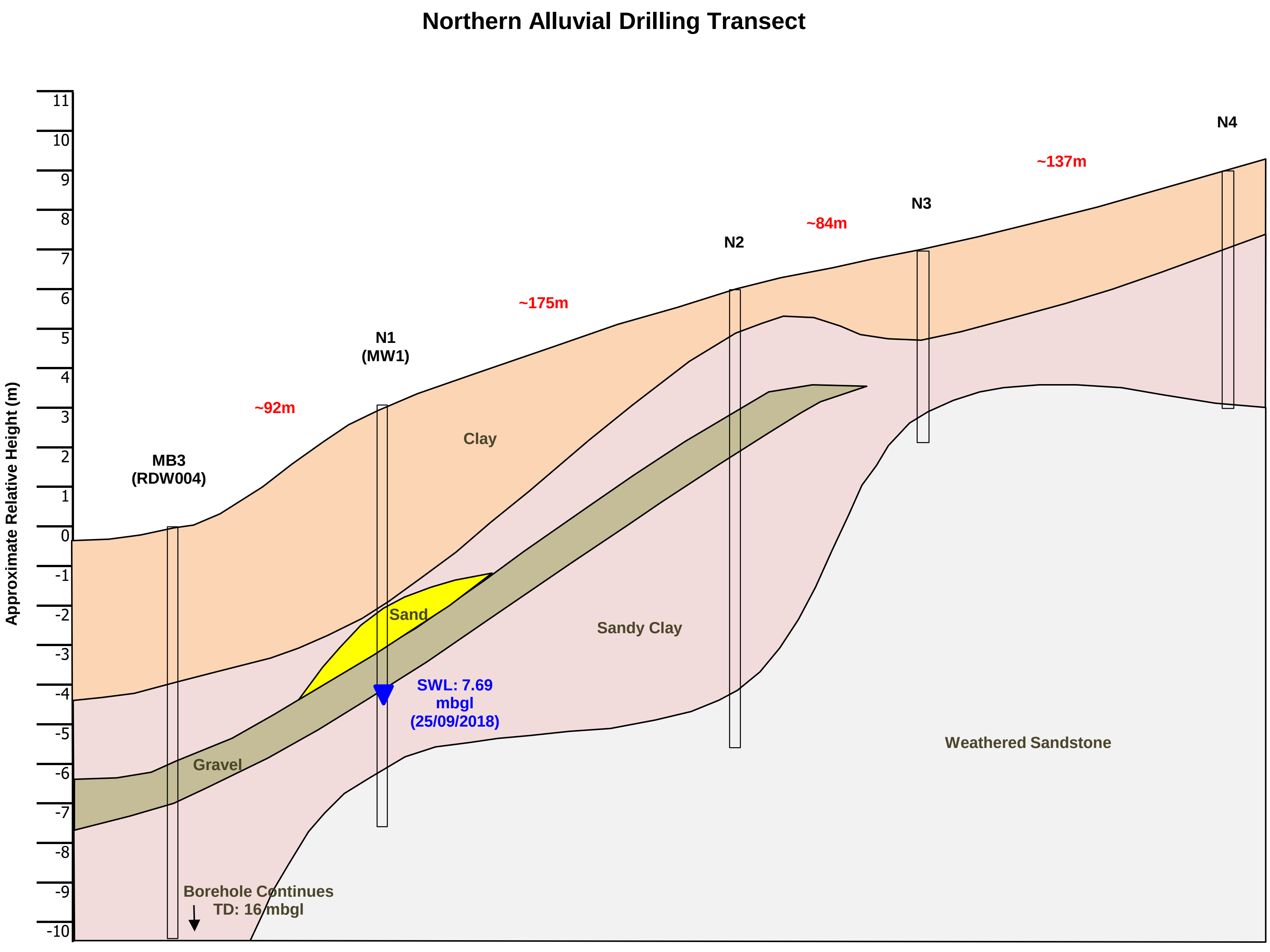
Photograph 4: W1 Groundwater Monitoring Well installation

Photograph 5: S3 drilling

Photograph 6: Southern drilling site S1-2

Appendix D

Drill Transects



Scale:	scale bar	Status:	Rev 1	Client:	Malabar Coal	Title:	Drilling Transect
Revision:	A	Drawn:	TB	Project:	ENRS1046 Maxwell	Date:	7/11/2018
Checked:	RL	Approved:	RL	Location:	Saddlers Creek	Figure:	11

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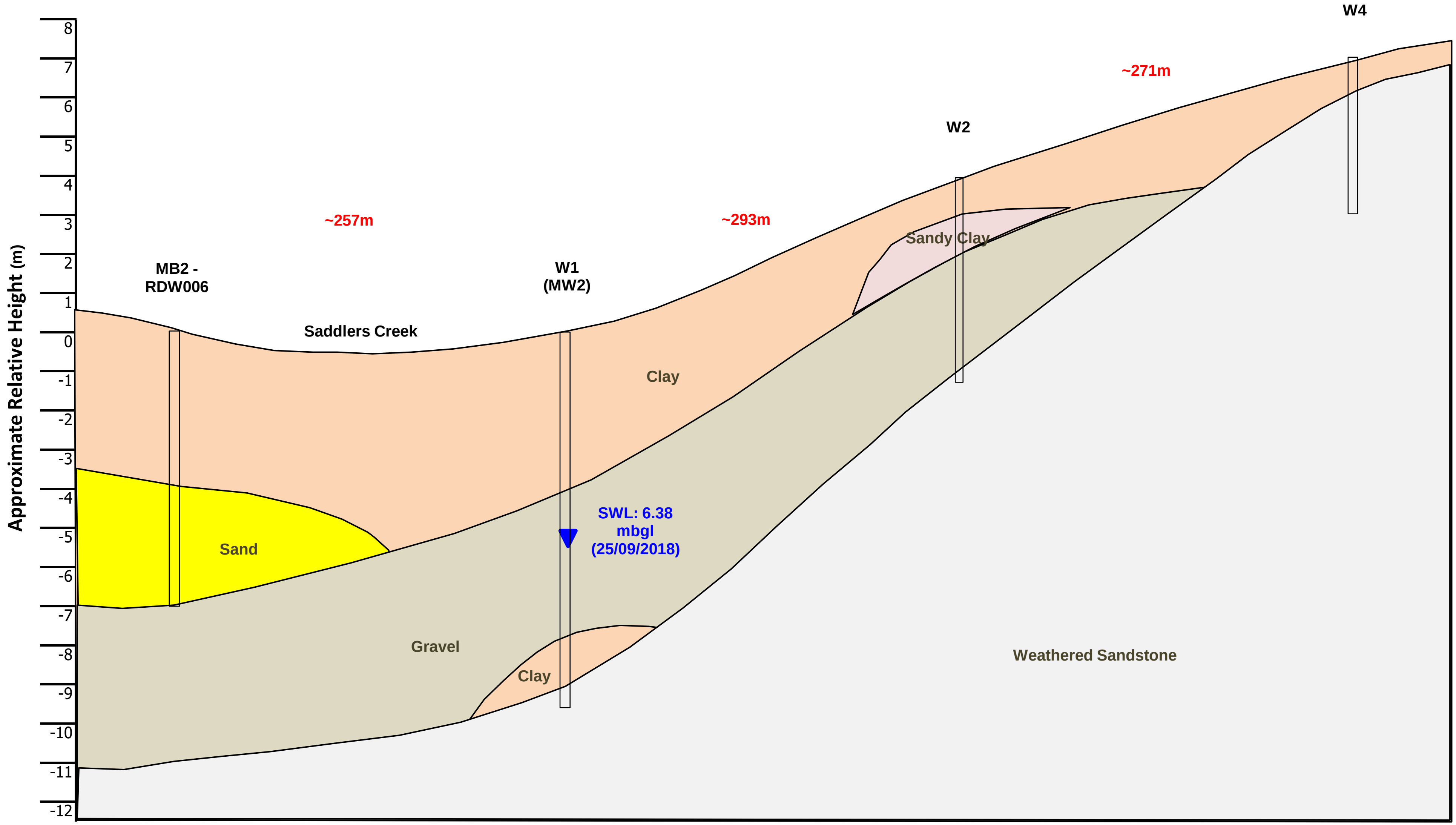
Western Alluvial Drilling Transect



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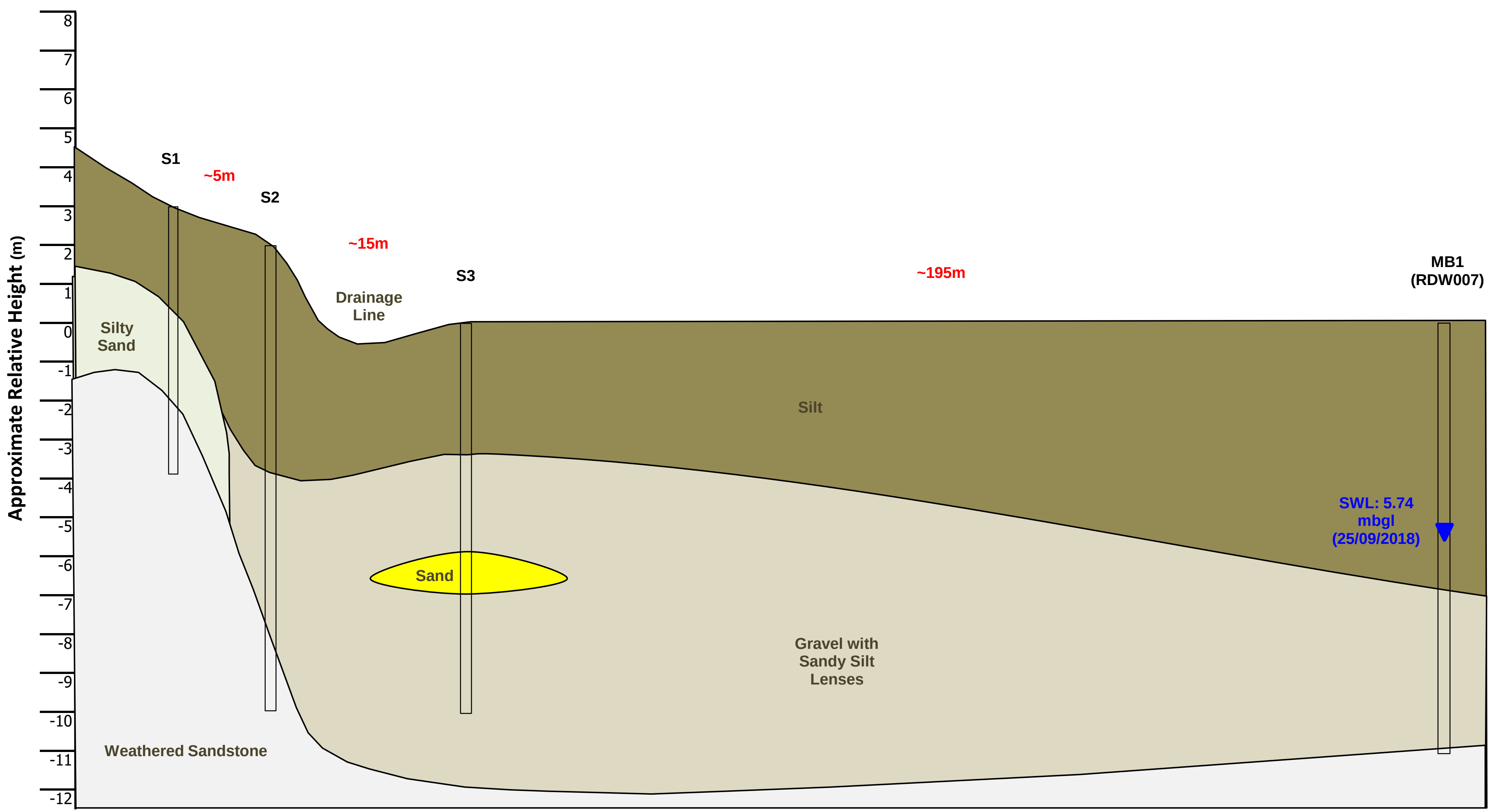
108 Jerry Bailey Road, Shoalhaven Heads, NSW, 2535	Revision:	**A**	Drawn:	**TB**	Project:	**ENRS1046 Maxwell**	Date:	**7/11/2018**
T/F 02 90374708 M. 0401518443 projects@enrs.com.au	Checked:	**RL**	Approved:	**RL**	Location:	**Saddlers Creek**	Figure:	**12**



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Scale:	scale bar	Status:	Rev 1	Client:	Malabar Coal	Title:	Drilling Transect
Revision:	A	Drawn:	TB	Project:	ENRS1046 Maxwell	Date:	7/11/2018
Checked:	RL	Approved:	RL	Location:	Saddlers Creek	Figure:	13